The Northern Plains and Rocky Mountains Consortium:

Researching the Green Economy

FINAL SUMMARY REPORT
April 19, 2011

MONTANA MANUFACTURING EXTENSION CENTER
An affiliate of the NIST Manufacturing Extension Partnership

greenjobs
The Northern Plains & Rocky Mountain Consortium: researching the green economy
Iowa, Montana, Nebraska, South Dakota, Utah, & Wyoming

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The Northern Plains and Rocky Mountain Consortium: Researching the Green Economy

Final Summary Report

Executive Summary

The Montana Manufacturing Extension Center (MMEC) at Montana State University was contracted by the Northern Plains and Rocky Mountain Consortium (Consortium) to provide assistance to its "Researching the Green Economy" project. The Consortium states include Montana, South Dakota, Wyoming, Nebraska, Iowa, and Utah. Consortium members include state Departments of Labor, Manufacturing Extension Partnerships (MEPs) and other stakeholders interested in working together to improve labor market information collection and research in the six states to enhance the labor exchange system for careers within the green economy. A variety of "green" energy technology sectors were evaluated to determine what new and emerging technologies have potential for commercial viability within the next five to ten years and what impacts they would have on the green job market. The technology sectors evaluated included:

- wind energy;
- commercial-scale carbon capture/sequestration;
- biofuels and bio-lubricants (include methane capture);
- biomass;
- smart grid and transmission;
- solar;
- geothermal;
- other "green" technologies that may be deployed; and other "traditional" technologies that may offset the use of fossil fuels.

The Consortium initiated this project to determine the workforce ramifications of the growing green economy. The Consortium recognized the need for timely, accurate and detailed information about the number of workers needed and the skill and educational requirements to ensure employer, worker and community competitiveness. The Consortium agreed that objective labor market data about green fuels and energy technologies would help them efficiently and effectively respond to the needs of workers and employers.

The Consortium selected MMEC to help identify the green energy fuels and technologies that are likely to be deployed in Consortium states in the next 5-10 years. MMEC was selected because of its network of engineering and manufacturing expertise in the region and knowledge of and access to research centers in the Consortium states.

MMEC initiated the research project by developing a list of 90 potential subject matter experts (SMEs) from universities, industry, trade associations and state and federal agencies. MMEC contacted the appropriate universities, state and federal agencies, research centers and industry associations in the consortium states to identify potential SMEs and also sought input from consortium representatives. MMEC staff discussed the green technology project with each potential SME and pared down the list to 26 entities according to several factors, including: interest and availability in participation within the project timeframe, knowledge of emerging technologies, and budget. Eight entities were ultimately selected to submit reports to MMEC on 19 emerging green energy technologies. The remaining 18 entities either failed to respond or declined to participate because of budget or time restrictions.

MMEC created a scope of work (SOW) for each potential SME to use to evaluate the selected green energy fuels and technologies. The SOW included a template of specific questions designed to solicit uniform responses that could be quantified, compared and easily transferred into report form. SOW questions included requests for detailed descriptions of the fuels and technologies, analyses of their development progress and issues to be considered in their production and deployment. The SOW also included questions about a variety of factors necessary for fuel and technology deployment, including natural resource harvesting; manufacturing; construction; marketing; and maintenance.

The SOW asked for detailed information about the potential impacts of each fuel and technology on jobs in the consortium states. SMEs were asked to describe impacts for natural resource harvesting; manufacturing; construction; marketing; and maintenance. SMEs were also asked to provide analysis about the education and job skills training required to develop, deploy, transport and maintain each fuel or technology.

The final component of the SOW was a series of questions intended to evaluate the potential economic, social, environmental, transportation, political and financial obstacles to deployment of the technologies.

Montana State University in Bozeman, MT was directed by MMEC staff to issue contracts to the SMEs chosen to contribute to the project. The contracting process was initiated in July 2010 with six of eight SMEs under contract by July 15, 2010. The first draft SME report was received on July 22, 2010. The remaining draft reports, except two, were received by mid-September while the final two were received the first week of October.

MMEC reviewed the draft reports and prepared a mid-summary report and presentation on the project for the Consortium meeting in Rapid City, SD on October 13, 2010. Consortium representatives provided feedback on the technologies and draft reports to MMEC staff and also requested brief synopses of the reports in layman's terms for review. MMEC staff provided synopses of the reports to consortium representatives on November 3, 2010.

The technologies selected for review include the following:

Technology Sector	**Energy Technology**
wind energy	horizontal axis wind turbines
carbon capture and sequestration	CO_2 capture and geological sequestration
biofuels and biolubricants	algae/cyanobacterial production of 2nd and 3rd generation biofuels
	biochemical conversion to 2nd and 3rd generation biofuels
	biodiesel
	bio-oils from lignocellulose
	cellulosic ethanol
	pyrolysis
biomass	cofiring
	methane capture/biogas
	solid fuel combustion
	gasification
	pellet fuels
smart grid and transmission	primary assets and functions
solar	nanostructured solar cells (photovoltaics)
geothermal	advanced adiabatic compressed air energy storage
	smart thermosiphon arrays
other	hybrid-nuclear energy
	in-stream hydrokinetic energy

This final report will be delivered to consortium members and other interested entities in the Consortium states. A presentation on the findings of the report will also be delivered to the Consortium at a conference in Des Moines, IA in April 2011.

The data presented in this document require periodic updating to remain current. The technologies evaluated for the report evolve rapidly, significantly impacting job projections.

MMEC does not assert a definition of "green jobs." For the purposes of this report, MMEC researched the emerging technologies in the sectors outlined in the first paragraph of this Executive Summary as instructed by the Consortium. MMEC exercised broad latitude in including emerging technologies that have potential for commercialization within the Consortium states and leaves the issue of specifically defining "green jobs" up to policy makers.

A summary of potential job impacts from the reviewed technologies is presented in the table below:

Technology Sector	**Construction/Harvesting/Manufacturing Jobs**	**Operations and Maintenance Jobs**	**Total Jobs**
Wind Energy	5503	222	5725
CCS			46529
Biofuels	1105	176	1296
Biomass	267	66	333
Smart Grid			500
Solar			770
Geothermal	442	10	452
Hybrid-Nuclear			2500
TOTAL			**58105**

Table of Contents

Definition of Terms and Acronyms

AEO	Annual Energy Outlook
ASTM	American Society for Testing and Materials
Btu	British thermal unit - amount of energy needed to heat 1 lb. of water from 39 to 40 degrees F. Used to describe heat value of fuels.
CCS	Carbon Capture and Sequestration
CH_2	methane
CHP	combined heat and power
CO2e	carbon dioxide equivalency--a quantity that describes the amount of CO2 emissions that would have global warming potential over a quantified period of time.
Conduction Band	Electrons within the conduction band are mobile charge carriers in solids, responsible for conduction of electric currents in metals and other good electrical conductors.
Diluent	Filler, dilutent or thinner
DOD	US Department of Defense
DOE	US Department of Energy
Electrolytes	Any substance containing free ions that make the substances electrically conductive.
ECBM	Enhanced Coal Bed Methane recovery - techniques for increasing the amount of coalbed methane recovered from coal seams.
EIA	US Energy Information Administration
EOR	Enhanced Oil Recovery - techniques for increasing the amount of crude oil extracted from an oil field. It is achieved through gas, chemical, microbial or thermal injection.
EPA	US Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse Gases - water vapor, CO2, methane, nitrous oxide, ozone
GMO	genetically modified organism
GW	gigawatt (1 billion watts or 1,000 megawatts)
HAWT	Horizontal Axis Wind Turbine
Hemicellulose	Heteropolymer present in cell walls

Jatropha	A genus of approximately 175 plants, shrubs and trees suitable for biodiesel production
JEDI Reports	Jobs and Economic Development Impact Reports - National Renewable Energy Laboratory economic development impact reports
Kilowatt	1,000 watts (average home consumes about 8,900 kw in a year)
LED	light emitting diode lamp
Lignin	a complex chemical compound derived from wood
MBTU	1,000 Btu
Micronized Coal	Coal ground to micron-sized particles.
MMBTU	1 million Btu
MMTCO2e	million metric tons of CO2 equivalent
MW	megawatt (1 million watts - amount of electricity needed to supply 1,000 homes)
MWh	Megawatt hour – one MW of electricity used contiuously for one hour
NSF	National Science Foundation
N_2O	nitrous oxide
NYSERDA	New York State Energy Research and Development Authority
Pyrolysis	thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen
RPS	Renewable Portfolio Standard
Saccharification	Process of breaking a complex carbohydrate into simple sugar
SCADA	Supervisory Control and Data Acquisition System
Torrefaction	Mild form of pyrolysis at temperatures typically ranging between 200-320 °C
USDA	United States Department of Agriculture
Valance Band	The highest range of electron energies in which electrons are normally present at absolute zero temperature. Valence electrons are bound to individual atoms, as opposed to conduction electrons (found in conductors and semiconductors), which can move freely within the atomic lattice of the material.
VAWT	Vertical Axis Wind Turbine

Introduction

MMEC contracted with eight subject matter experts (SMEs) to write reports on new and emerging green technologies. MMEC has summarized and compiled their findings in this report. Each green sector evaluated in this report is based solely on the data, and opinions of the SMEs contracted by MMEC or other documented sources. Biographical information on each SME is presented at the beginning of each chapter. The raw unedited SME reports and initial contact lists made by MMEC are available in a separate raw data report.

According to the U.S. Energy Information Administration (EIA), the economic downturn in the United States had a significant effect on electricity markets in 2009 and 2010. The EIA reported that electricity demand fell 4.1 percent, representing the largest drop in 60 years. Along with decreased demand for electricity, generation also declined—leading to significant reductions in emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x,) and sulfur dioxide (SO_2)—the largest declines on record.

Fuel costs also declined in 2009 and 2010. The price of delivering natural gas to electric power plants fell to almost half the level of 2008. Fuel cost declines were largely caused by increased supply due to the availability of shale gas, higher production, increased storage levels, pipeline expansion and mild winter temperatures[1].

Coal, natural gas and nuclear generation remain the largest sources of electricity generation, accounting for almost 90 percent of net generation. Natural gas has experienced significant growth recently while coal declined about 12 percent since 2008. Coal's decline can be attributed to higher coal prices, lower natural gas prices, surplus natural gas capacity and environmental compliance costs. Coal-fired electricity generation plants have been required to achieve higher levels of control over SO_2, mercury (H_g), NO_x, and particulate matter. Expected federal limits on CO_2 will likely continue this trend.

Hydroelectric power generation remains an important component of the nation's generation portfolio, particularly in the West. Hydroelectric generation increased nationally over seven percent from 2008 to 2009, though western hydroelectric generation fell during the same period because of prolonged drought.

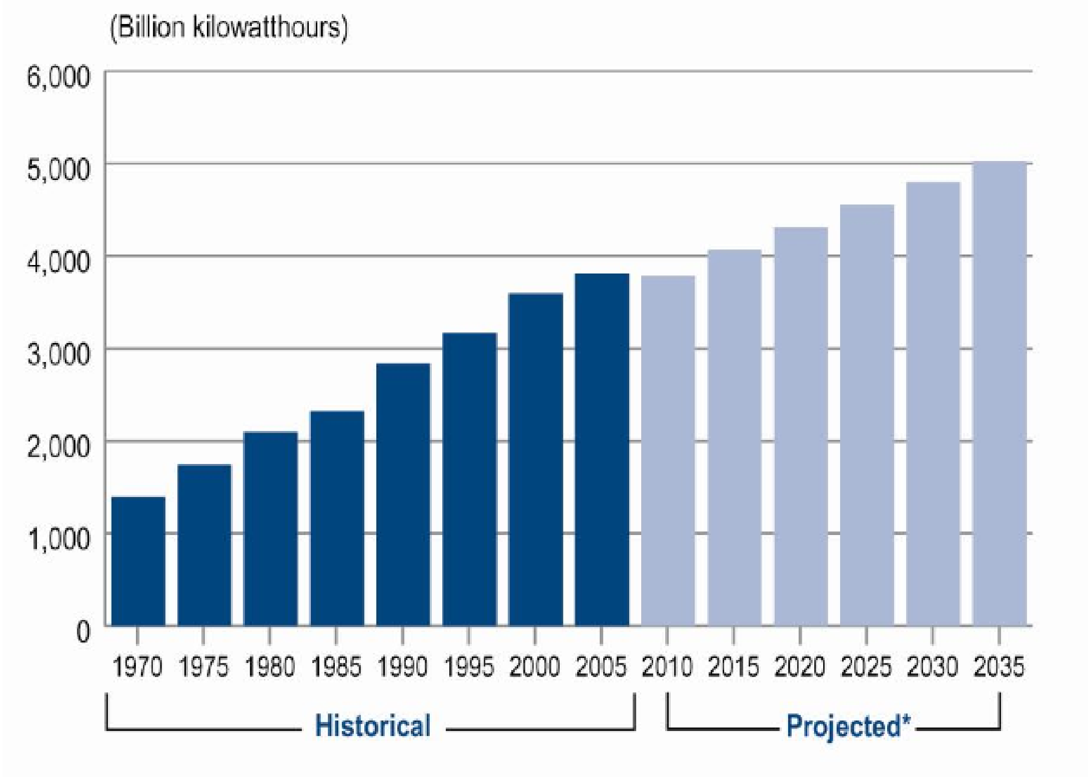
While overall electricity generation declined, along with natural gas prices, renewable sources of electricity generation continued to increase. Non-hydro renewable generation increased 14 percent in 2009 after an almost 20 percent increase in 2008. Wind power was the fastest growing renewable sector, accounting for a 33.5 percent increase over 2008 levels. At least some of this increase must be credited to federal incentives and state renewable portfolio standard requirements. In 2009-2010, wind generators were eligible for federal production and investment tax credits, cash grants and loan guarantees.

Renewable sources of electricity generation make up about 10.6 percent of total U.S. generation. The largest sources of renewable electricity generation in the U.S. remain hydro (6.9 percent), wind (1.9 percent) and wood/wood-derived fuels (0.9 percent)[2].

Despite the recent declines in electricity demand and electricity generation, demand for electricity is expected to increase 30 percent in the next 25 years[3].

[1] U.S. Energy Information Administration, Electric Power Annual, January 4, 2011.
[2] Ibid.

[3] Ibid.



*Electricity demand projections based on expected growth between 2008 and 2035.

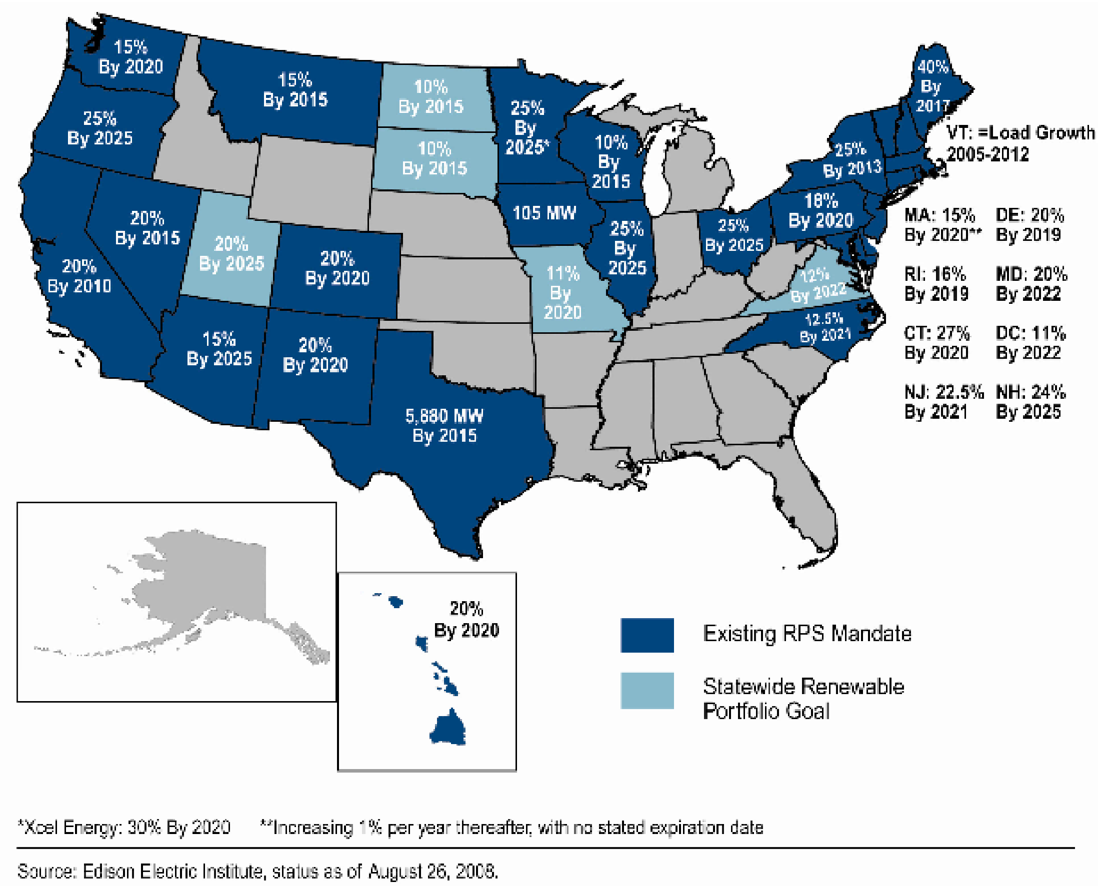
Source: U.S. Department of Energy, Energy Information Administration, Annual Energy Review and Annual Energy Outlook 2010, April 2010, Table A8-Electricity Supply, Disposition, Prices, and Emissions (Reference Case).

According to the EIA, about 231 gigawatts (GW) of generation capacity will need to be built by 2030 to meet the expected increase in demand for electricity by 2035. Most of this increase will likely be coal-based (about 44 percent) while natural gas combustion will make up about 23 percent and renewable sources comprise 16 percent. Other sources of generation will include natural gas combined-cycle plants and nuclear energy.

Renewable energy capacity continues to grow at a rapid rate. In 2007, the EIA predicted renewable energy would add only 9 GW of capacity to the nation's electricity supply. However, the agency's new projections forecast 38 GW of renewables to come online by 2030. Much of this increase is credited to the enactment of renewable portfolio standards (RPS) in a growing number of states. An RPS is a requirement that an electricity supply entity produce a fraction of their generation from renewable sources of energy such as wind, solar, biomass or geothermal. An RPS also requires that electricity transmission and distribution companies acquire a certain percentage of their energy from the same mix of renewable sources. Some states also allow hydroelectricity or a portion of its generation to count towards an entity's RPS compliance.

The following graphic demonstrates the various states that have adopted renewable portfolio standards and their respective compliance dates and percentages.

States with Renewable Portfolio Standards



Among Consortium states, Montana, South Dakota and Utah have adopted RPS, with Utah's standard being the most aggressive (requiring 20 percent compliance by 2025). Iowa adopted a mandate for the construction of 105 megawatts (MW) of renewable energy in the state rather than a percentage-based RPS.

Expanding the nation's portfolio of renewable energy generation will require accomplishment of several key factors. (1) The electricity grid will need to be enhanced with additional transmission infrastructure to transport electricity generated most often in rural areas to population centers. (2) Renewable sources of electricity will need to be improved to increase their reliability and systems will need to be developed to minimize their intermittent ability to generate power. (3) Financial incentives and state and federal statutes will need to be sustained and continued to encourage investment in renewable projects[4].

If the EIA forecasts for the future growth of renewable electricity generation are accurate, there will certainly be an associated impact on jobs. Each renewable project requires jobs for construction and operation and maintenance while others also include impacts on natural resource harvesting, transportation and other factors. This report analyzes the expected impacts on jobs associated with development of renewable electricity generation and other green energy technologies in the Consortium.

[4] Edison Electric Institute, 2011. www.eei.org

The following chapters discuss each of the technologies evaluated and provide analysis of their expected impact on jobs in the Consortium states.

Chapter 1. Wind Energy

SME Information

Robb Larson, P.E., Assistant Professor, Department of Mechanical and Industrial Engineering

Director, Montana Wind Applications Center

Montana State University, Bozeman, MT

Professor Larson holds a BSME and MSME in Mechanical Engineering and has worked in the engineering field since 1982. He teaches mechanical design, instrumentation, and alternative energy applications. He has served since 2008 as Director of the Montana Wind Applications Center, one of 11 U.S. State National Renewable Energy Laboratory-designated centers of expertise in wind energy issues.

1.1 Background

Wind energy is available on both small and large scales, each contributing to the electrical grid. Single, small 100-watt or 10-kilowatt (kW) wind turbines can be found on farms or residences while larger wind farms employ turbines capable of generating between 700 kW to 1.8 MW of power. Wind farm turbines are typically 160 to 300 feet in length and are tied directly into utility transmission systems.

Wind energy is perhaps the key component for the nation as it looks for alternatives to traditional sources of electricity generation such as coal, hydroelectric power, nuclear and natural gas. Wind eliminates the problems presented by traditional sources such as mining, drilling, damming waterways, and storing wastes. However, two factors limit wind projects: intermittency and distance. Unlike baseload sources of electricity generation such as nuclear, coal-fired or hydroelectric power plants, wind energy is not able to supply electricity at a constant rate. Wind cannot match the dispatchability of baseload generation, meaning its facilities cannot always be started when operators need their electricity. Dispatchability requires that electricity be available any time, day or night and regardless of weather conditions. Wind power is limited because it cannot be started unless the wind is blowing. Moreover, it cannot match the reliability of traditional sources of generation. Even if the wind is blowing, it rarely blows at a constant speed, making generation difficult to control.

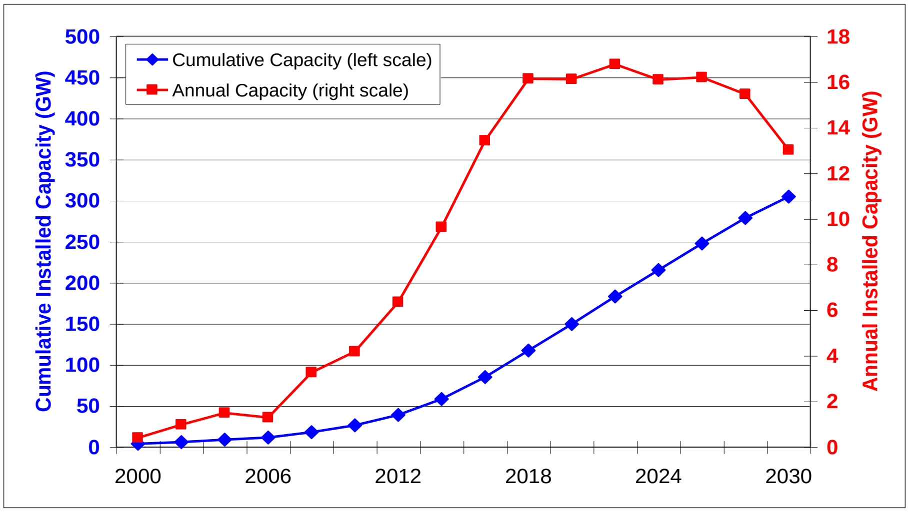
Fluctuations in wind require that wind generation be backed up by baseload sources of electricity to avoid interruptions in energy supply. Wind facilities are also typically located in sparsely populated areas, far from the populated areas they serve. These remote locations require siting and construction of extra transmission lines and their distance from population centers results in reduced efficiency and line loss.

Wind power remains an important part of the electrical grid system, however, because the system doesn’t require that every one of its components offer 100 percent reliability, but rather that they fit in with hundreds of other intermittent and baseload sources of generation to create a large, reliable system.

Wind generation in the Consortium states represents an important part of helping the nation meet its goals to increase overall electricity availability yet reduce emissions from traditional sources of energy. The U.S. Department of Energy supports and promotes the “20 x 30 Initiative,” a plan to meet 20 percent of the U.S. electric power needs from wind energy by the year 2030.

The approximate annual installed wind energy electrical generation capacities required to meet this goal are shown below.

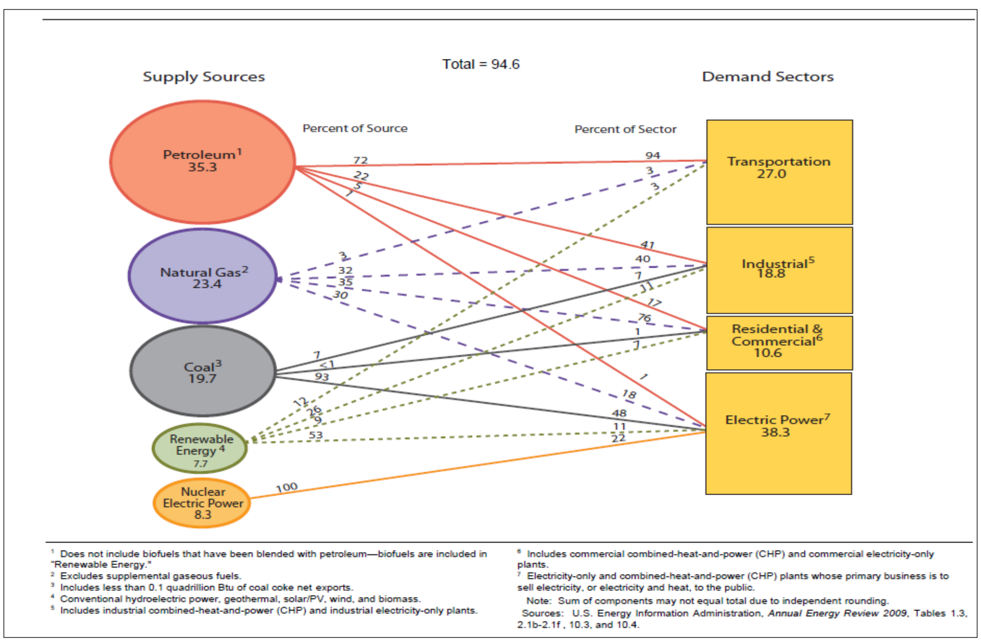
Figure 1.1 Cumulative installed capacity (red), and annual installed capacity (blue), to achieve 20% of electrical power from wind by 2030.



Source: AWEA 20% Vision

At present, renewable sources including wind, hydro, geothermal etc. account for about 11 percent of total U.S. electrical demands, (ref: Figure 1.2.) Wind energy presently accounts for about 2 percent of the electricity generated in the U.S., up from 0.8 percent only about three years ago.

Figure 1.2 Primary Energy Flow by source and sector, 2009. (Quadrillion BTU.)



Wind energy utilization growth in the United States can be observed from the data in Table 1.1 below: This observed exponential growth supports future projections (e.g. the 20 X 30 scenario.)

Table 1.1 U.S. Wind Energy Capacity Growth since 1999.

Year	U.S. MW	Change	% Change
1999	2,472	N/A	N/A
2000	2,539	67	2.71%
2001	4,232	1,693	66.68%
2002	4,687	455	10.75%
2003	6,350	1,663	35.48%
2004	6,723	373	5.87%
2005	9,147	2,424	36.06%
2006	11,575	2,428	26.54%
2007	16,907	5,332	46.06%
2008	25,410	8,503	50.29%
2009	34,863	9,453	37.20%

Table 1.2 breaks out the generating capacity figures for the consortium states in this report, showing trends and also ultimate wind capacity by 2030. (Source: U.S. Office of Energy Efficiency and Renewable Energy.)

Table 1.2 Consortium States Wind Energy Year-end Wind Energy Capacity since 1999 (MW), and the Capacity Goals envisioned per state to meet the 20% by 2030 Scenario.

As of	Iowa	Montana	Nebraska	South Dakota	Utah	Wyoming
12/31/1999	242.420	0.100	2.820	0.000	0.000	72.515
12/31/2000	242.420	0.100	2.820	0.000	0.225	90.635
12/31/2001	324.170	0.100	2.820	2.600	0.225	140.635
12/31/2002	422.650	0.360	13.980	3.014	0.225	140.635
12/31/2003	471.820	1.145	13.980	44.264	0.225	284.635
12/31/2004	633.993	1.145	13.980	44.264	0.225	284.635
12/31/2005	836.303	136.860	73.380	44.264	0.885	288.455
12/31/2006	932.228	145.860	73.380	44.264	0.885	288.455
12/31/2007	1,272.928	152.895	71.880	98.264	0.885	288.455
12/31/2008	2,791.178	271.495	116.880	186.764	19.785	676.255
12/31/2009	3,603.928	374.995	152.880	313.164	223.285	1,099.255
2030 Goal	>10,000	5000–10,000	5000-10,000	>10,000	1000-5000	>10,000

Based on these existing capacity figures and the projected numbers at year 2030 build-out, the projected commercial-scale wind development in consortium states would be approximately as shown in table 1.3:

Table 1.3 MW Increases Necessary in Consortium States from 2010 to 2030 to meet 20% Standard

Iowa	Montana	Nebraska	South Dakota	Utah	Wyoming
>6,400	**4625-9625**	**4847-9847**	**>9687**	**1000-5000**	**>8900**

1.2 TECHNOLOGY DESCRIPTION

Wind turbines using conventional three-blade horizontal-axis wind turbine (HAWT) designs dominate the market, and it is anticipated that this domination will continue due to the well-known advantages of this geometry. First and foremost, HAWTs capitalize on the stronger winds that occur at heights above the ground. The increase in wind speed with elevation (characterized at any given site by a wind shear exponent) coupled with the fact that wind power increases with the *cube* of the wind speed, means that units with tall towers generate more power. The airfoils (blades) in the HAWT design always move perpendicular to the wind, thus efficiently receiving power through the entire 360° path of rotation. Variable pitch controls optimize aerodynamics, and yaw controls ensure that the turbines are positioned to 'face the wind' to capture the maximum power available in a given wind regime. Today's large wind turbines utilize modular construction, relatively straightforward assembly and installation, and mass production of interchangeable components.

Vertical-axis wind turbine (VAWT) technology, in contrast with the success of HAWT designs, has not made significant inroads with regard to usage for commercial-scale power generation. Some small-scale VAWT units are being marketed for light-duty, low output applications, and it is conceivable that technological developments could make these VAWT turbines viable energy producers. VAWT varieties include Savonius and Darrieus configurations, as well as a few unique models. A conventional VAWTs ability to utilize wind from any prevailing direction makes them appealing, and location of generators and power electronics at ground level is a potential advantage. However, testing results from all sizes of VAWT turbines have shown difficulties in overcoming inherent disadvantages in wind resource utilization and aerodynamics. Some unique structural problems also exist with many VAWT installations.

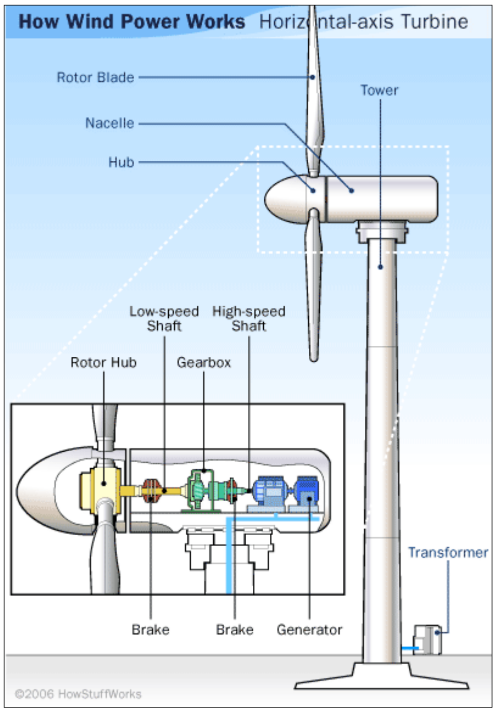
Size is an advantage in any design paradigm, since wind power is a function of area (the square of the diameter) and the larger sizes also capitalize on wind-speed increases at elevation.

Figure 1.3 Horizontal and Vertical Axis Wind Turbines

Wind technology development can be examined from a variety of perspectives, including development and production of individual components, of integrated turbine sub-systems, of complete single turbine assemblies, and as development of multi-turbine generating facilities of multiple scales.

Markets also exist for smaller, household or community-scale installations, off-grid home units, and models scaled appropriately for distributed energy schemes. Technology developments touch the entire life-cycle of any turbine and associated electrical generation facility - including installation equipment and procedures, operation and maintenance equipment and procedures, transportation and logistics operations, ancillary systems, and repair/decommissioning. Workforce development and economic opportunities exist in all of these areas.

Figure 1.4 Components of a Horizontal Axis Wind Turbine



1.3 TECHNOLOGY DEVELOPMENT PROGRESS

After decades of engineering refinement, today's wind machines have evolved and are now addressing many of the reliability and dispatchability issues that have limited them in the past. Many wind facilities now offer availability values of 98 percent or higher. Wind power plants use arrays of dozens to hundreds of individual turbines to achieve these levels.

Wind turbines using conventional three-blade HAWT designs dominate the market, and it is anticipated that this domination will continue due to the well-known advantages of this geometry.

The scale of HAWT turbine units has increased dramatically since the 1980s, equating to fewer, larger turbines needed to achieve a given output. While 1.5 to 2.6 MW is presently the size class specified for wind farms, units up to 10 MW rated output are in testing phase and larger turbines are on the drawing board. Despite a steadily increasing size trend, extrapolation of this trend line to predict ever-increasing land-based wind turbine systems may be off the mark.

As wind turbine systems increase in size, installation and transportation difficulties will become significant. Many experts feel these factors will limit the increase in size of conventional land-based turbines to a class not much larger than what is available today. However, some off shore systems may offer larger turbines because their components could be delivered with ships.

1.4 ISSUES CRITICAL TO DEPLOYMENT

Manufacturing/Building of Emerging Technology

In order to meet national wind energy implementation goals while addressing strain on transportation infrastructure, there is an increasing need for distributed, regional manufacturing capacity – especially for large wind turbine components such as blades and towers, in locations near areas with large commercial wind energy development potential. Reinforced concrete towers may supplant conventional, tubular steel turbine tower manufacturing techniques. Regional production/acquisition of materials and concrete plus fabrication of concrete towers would be more likely to increase local or regional job prospects.

Construction

Transmission infrastructure is a weak link in bringing wind energy to market. Initiatives to spur transmission capacity growth are critical to wind development throughout the consortium states, especially in the more remote regions such as Montana and Wyoming.

Education and Job Skills Training

Workforce development to support the high levels of wind energy generation facilities envisioned under the 20X30 initiatives is a critical undertaking. Many 1- and 2-year programs for energy technicians are already in existence or under development, including (for example) Iowa Lakes Community College in Estherville, IA and programs at four Montana campuses including MSU-GF COT in Great Falls, Montana Tech in Butte, MSU-Billings, and MSU-Northern in Havre. The primary education and job skills training programs will need to focus on unique work-at-heights training in addition to conventional civil engineering project skills. These skill sets are critical to the installation and maintenance of turbine systems.

1.5 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Social Constraints

Intelligent siting of turbines and wind farms is critical to the process. Wind farms can take up hundreds of acres of farmland, rangeland and other landscapes on private and public land. Siting wind farms requires careful consideration to minimize impact to viewsheds, and biological and cultural resources while ensuring they can be efficiently connected to available transmission systems.

Securing right-of-way for both wind farms and transmission systems presents a significant challenge. Wind farm developers and electricity transmission companies must secure a number of local, state, federal and sometimes international permits in addition to negotiating with private and public landowners to acquire property or easements before wind farms and transmission systems can be constructed.

Environmental Constraints

The primary environmental issues associated with wind development include habitat disruption, flyway intrusion, construction activity disruption of breeding grounds and bisection and fragmentation of critical habitat areas. Site selection of turbines and farms is a critical step in the process of developing wind energy in all consortium states.

Transportation Constraints

The physical size of the components – primarily blades and tower segments – of commercial-scale wind turbines presents numerous transportation issues. The maximum feasible size of land-based turbine units is being rapidly approached.

Political Constraints

The current political issues for deployment of wind generation facilities come from local challenges to siting of wind farms and transmission systems, broader state and national challenges to renewable portfolio standards and tax policies that favor and subsidize wind energy development. The national debate on the need for climate change legislation and potential limits on energy produced by fossil fuels will also greatly impact future wind energy development.

Funding Sources

Private funding for wind energy installations is a function of the business goals of the corporations involved. Research and development funding through the U.S. Department of Energy, the U.S. Department of Labor, and several government laboratories has traditionally been available on a competitive basis.

1.6 POTENTIAL JOB IMPACTS

Job creation for wind farm developments in the Consortium states is expected to be significant. The National Renewable Energy Laboratory Jobs and Economic Development Impact (JEDI) models were consulted to determine expected impacts in the Consortium states. Wind generation development is expected to create 5,503 temporary construction jobs and 222 permanent operations and maintenance jobs in the Consortium states. Table 1.4 demonstrates the construction, operations and maintenance and total jobs impacts in each of the Consortium states. The data were calculated according to the number of 200 MW facilities using 2 MW turbines to be constructed to meet each state's necessary capacity to comply with the 20% by 2030 Initiative.

Table 1.4 Wind Energy Development Jobs Impacts in Consortium States

State	Construction Jobs	Operations/Maintenance Jobs	Total Jobs
Iowa	903	33	936
Utah	1007	45	1052
Nebraska	919	34	953
Montana	959	45	1004
South Dakota	956	35	991
Wyoming	759	30	789
	5503	**222**	**5725**

Chapter 2. Commercial Scale Carbon Capture and Sequestration

SME Information

John Talbott, Deputy Director and Project Manager; Big Sky Carbon Sequestration Partnership

Mr. Talbott assumed duties as the project manager for BSCSP in July of 2006. Mr. Talbott was formerly the Director of the Institute for Policy Outreach at Virginia Tech, a sponsored research center that specialized in public policy development, implementation and evaluation. Talbott spent 18 years in state government including a stint as a cabinet level agency director before moving to Virginia to assume duties at the Institute for Policy Outreach and to complete a PhD program in public administration and policy at Virginia Tech. Talbott holds a BS in Wildlife Ecology from the University of Wyoming and an MPA from Virginia Tech in public administration and policy. Research interests are focused on identifying institutional forms for improving public policy and regulatory regimes that enhance adaptation and mitigation strategies for climate change. Since coming to BSCSP, he has initiated exploratory research that will utilize gap analysis to describe a pragmatic approach to development of a regulatory framework for CCS within the region.

Lindsey Tollefson, Outreach and Communications Manager; Big Sky Carbon Sequestration Partnership

Lindsey Tollefson joined the BSCSP as the Outreach and Communications Manager in 2007. Her work is focused on community engagement, providing information on carbon sequestration and the partnership's projects to the public and assisting with project management. She recently conducted a study to assess environmental groups view on carbon sequestration and published a white paper on energy and carbon sequestration in the Big Sky region. Prior to joining the partnership in January 2007, she worked as an environmental consultant on water quality at PBS&J and as a research associate at the Big Sky Institute. Lindsey holds a B.S. in biology from Montana State University and a M.S. in environmental science from Florida International University.

2.1 Background

Coal remains the most abundant and utilized fuel source for electricity generation in the Consortium states and the nation. According to the Energy Information Administration, coal-fired electricity generation accounts for about 40 percent of the nation's electricity supply. Coal is particularly important in the Consortium states of Wyoming and Montana, which rank first and fifth respectively in the nation for coal production. Coal production in Wyoming exceeded 442.5 million tons in 2011[5] and employed nearly 7,000 workers. In Montana, coal production was about 44.7 million tons in 2011[6], employing 1,218.

According to the Montana Coal Council, Montana ranks first in the nation for recoverable coal reserves while Wyoming is third. In Montana, coal mining employs over 1,200 with a payroll over $85 million[7]. According to the Energy Information Administration and the federal Bureau of Labor Statistics, coal mining and related industries in Wyoming employ almost 20,000 with a payroll over $1.35 billion. Coal-fired generation accounts for over 90 percent of Wyoming's electricity production and nearly 70 percent of Montana's. Coal is a significant component of electricity generation in other Consortium states as well (71 percent in Iowa, 60 percent in Nebraska, 23 percent in South Dakota and 78 percent in Utah).

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[5] Fugleberg, Jeremy. *Wyoming Coal Production Rebounds*. Casper Star Tribune. February 10, 2011
[6] Montana Coal Council, www.mtcoal.com, from Montana Department of Labor and Industry, Safety Bureau
[7] Montana Coal Council, www.mtcoal.com, from individual coal production companies

As these employment and generation statistics demonstrate, coal remains a critical component of the economies and energy portfolios of the Consortium states. However, the future of coal as an electricity generation resource will be impacted by recent and expected state and federal limits on air emissions from coal-fired power plants. Recent limits on emissions of mercury, sulfur dioxide, and particulates have required coal-fired electricity generators to install expensive emissions control equipment and limit hours of operation. Recently enacted regulations on CO_2 emissions from new coal-fired electricity generation plants and existing ones undergoing upgrades will require development and installation of expensive carbon capture equipment and may discourage the industry from building new plants. Many existing coal-fired power plants could be retired as well.

If coal-fired electricity generation is to remain a viable option for energy production in the Consortium states and the nation given the recent and anticipated greenhouse gas rulemaking, a safe, reliable method to capture and sequester CO_2 emissions must be developed. While the federal Department of Energy and emissions control companies around the world are working on technologies to capture and compress CO_2 from new and existing coal-fired power plants, research programs like the Big Sky Carbon Sequestration Partnership at Montana State University in Bozeman, Montana are identifying underground reservoirs that could permanently and safely sequester CO_2.

This report did not address terrestrial carbon sequestration—the storage of carbon in forests or in the soils of farm and range land. Terrestrial carbon sequestration is not an emerging technology and is already being implemented. Moreover, it is not technology-intensive[8].

2.2 TECHNOLOGY DESCRIPTION

Carbon capture and storage (CCS) is a process for capturing CO_2 emissions from existing stationary sources such as power plants using coal, oil, or natural gas, cement kilns, paper plants, refineries, ethanol plants, and other industrial sources. The process has three primary steps: 1) the CO_2 is captured at the source, 2) the CO_2 is transported to a suitable storage location and 3) the CO_2 is injected into geologic formations deep underground for permanent safe storage.

[8] Big Sky Carbon Sequestration Partnership

Figure 2.1 Geologic Carbon Sequestration Options

Source: Big Sky Carbon Sequestration Partnership

The process for capturing CO_2 from existing stationary sources involves diverting the gases from the combustion of fossil fuels that would normally exit through the smoke stack through a chemical plant to remove the CO_2. Suitable storage sites are located in porous rock formations deep underground that are overlaid by non-porous formations called cap rocks that permanently trap the CO_2 in place. Figure 2.2 displays the process for chilled ammonia carbon capture from coal-fired electricity generation—one of several carbon capture processes under development.

Figure 2.2 Chilled Ammonia Carbon Capture Process

Source: American Electric Power

2.3 TECHNOLOGY DEVELOPMENT PROGRESS

Internationally, large-scale demonstrations of geologic storage have been conducted at several locations including Norway, Algeria, Canada and Australia. Within the U.S. a large project is ongoing in Louisiana and six additional large-scale projects are slated to begin within the next two years. Numerous pilot projects have been completed in deep saline aquifers, shales, and deep unmineable lignite and bituminous coal seams. A pilot scale injection in mafic rocks (lava flows) is to be completed in the fall of 2010. Full chain CCS projects[9] within the U.S. are currently limited by commercial scale deployment of CO_2 capture technology. Yet, most experts agree that commercial scale deployment of all available technologies for capture and storage will be available by 2020.

2.4 TECHNOLOGY PRODUCTION AND DEPLOYMENT

Retrofitting the existing fleet of coal-fired power plants, ethanol plants, refineries and other industrial sources of greenhouse gas emissions (GHG) would be a daunting exercise. In many cases, it may make more economic sense to retire older coal-fired power plants and replace that generation capacity with new generation coal facilities, natural gas fired facilities or renewable energy. In either case, the construction of capture facilities for existing plants would have a sizeable, albeit currently unquantified, impact on manufacturing and construction jobs.

Coal would continue to be used to supply the new coal-fired power plants, such as supercritical pulverized coal plants or Integrated Gasification and Combine Cycle (IGCC) plants. Plants fitted with CCS are predicted to incur an energy penalty of 30 percent or "parasitic load" that is additional power

[9] Full chain CCS projects are those projects that include capture, transportation and sequestration. An example would be a capture facility placed on a coal fired power plant that captures, compresses, and transports the CO_2 to an injection site for storage and long term monitoring, verification and accounting.

required to power the CCS facility. Consequently, an equivalent percentage of power generation capacity would need to be developed to meet existing base load.

2.5 NATURAL RESOURCE HARVESTING

If carbon capture equipment is developed and CCS becomes a viable option for the permanent storage of CO_2, states with significant coal mining operations would be expected to require a 30 percent increase in employment. A 30 percent increase in total coal mining output would be required to offset the 30 percent energy penalty placed on coal-fired electricity generation plants and lost base load generation.

2.6 MANUFACTURING/BUILDING OF EMERGING TECHNOLOGY

Nationally, CCS is expected to create an additional 6,000 manufacturing jobs for manufacturing components of the capture facility and pipelines[10]. These jobs will be located in heavy industrial areas such as Pennsylvania and the Upper Midwest. Very few of these jobs are expected to be located in Consortium states.

2.7 CONSTRUCTION

Using a national scenario to replace 65 GW (6,500 MW) of generation capacity, BBC Research and Consulting[11] reports that three advanced coal CCS facilities could be constructed by 2025 based on the geographic distributions from prior EPA studies and that a range of values for use of the CO_2 for enhanced oil recovery (EOR) is reasonable and possible, particularly for early adopters of CCS technology.

Estimated construction costs of building the three new advanced coal facilities are approximately $6.3 billion. The construction is anticipated to support a cumulative total of 83,000 job-years in various sectors through 2025. The construction and operation of facilities in other parts of the country may lead to additional economic benefits. Except for coal mining effects, these secondary effects are not captured in the estimated state-level economic benefits[12].

Other economic activity that can result from wide scale deployment of CCS includes the benefits of increased oil and gas production from EOR and Enhanced Coal Bed Methane (ECBM). A recent report released by Advanced Resources International[13] projects that nearly 2.5 billion barrels of oil could be produced from the Williston Basin of Montana and North Dakota using EOR techniques. The amount of CO_2 required to produce that amount of oil is equivalent to 130 million metric tonnes or roughly nine years of CO_2 emissions from Montana's Colstrip Steam Electric Station. The net value of the CO_2 to the Colstrip plant if sold to an EOR operation at $45/tonne is estimated to be $5.8 billion. Using an oil price of $70 per barrel (Base Case), assuming a delivered CO_2 cost of $45 per metric ton, and subtracting $10 per metric ton for transportation and handling, the revenue potential offered by the CO_2-EOR market [within the United States] could reach $260 billion. In addition, the sale of captured CO_2 emissions to the CO_2-EOR industry would enable power companies to avoid the costs and challenges of storing CO_2. The

[10] Clean Air Task Force, Estimating the Economic Impacts of Carbon Capture and Storage, April, 2010.
[11] Jeavons, D., Employment and Other Economic Benefits from Advanced Coal Electric Generation With CCS, BBC Research and Consulting, Denver, CO, 2009.
[12] Ibid
[13] Kuuskraa, V., Ferguson, R., 2008, Storing CO2 with Enhanced Oil Recovery, DOE/NETL-402/1312/02-07-08, National Energy Technology Laboratory, Pittsburgh, PA

result is that by 2020, over 40,000 jobs could be created from CO_2-EOR, rising to approximately 350,000 by 2030[14].

Table 2.1 Economic Benefits from CCS Construction

Economic Benefits from Construction (one-time)		
Economic Measure	**Direct Benefit**	**Total Benefit**
Output	$6.3 billion	$11.3 billion
Value-added	$2.6 billion	$5.2 billion
Employment	43,129 job-years	82,061 job-years
Labor Income	$2.3 billion	$3.9 billion

2.8 MARKETING

CCS technology would be marketed to the electrical generation industry that relies on fossil fuels and to the oil and gas refining industry, cement and iron production industry, ethanol production industry and any large stationary source that emits 100,000 tons of CO_2 per year or greater. No job information is currently available although it is likely to exceed 100 jobs for the Rocky Mountain States.

2.9 MAINTENANCE

Using the same scenario described above for deployment of three new supercritical coal plants with CCS, the annual maintenance and operations costs are expected to be $486 million (including coal mining) that represents nearly 3,400 jobs.

2.10 EDUCATION AND JOBS SKILLS TRAINING

CCS is an emerging technology and as such will require training in a number of the hard sciences including but not limited to: 1) chemical, mechanical, environmental, industrial, systems, reservoir, and electrical engineering; and 2) geology, geochemistry, geophysics, hydrogeology, and reservoir geology. Other disciplines that address permitting, regulatory compliance, public involvement, business planning, economics, public and private finance, plant and sequestration site operations, and geospatial representations will also be required. The U.S. DOE recently awarded $7 million in grants to begin the process of training current and future instructional staff to allow integration of these skills into existing curricula and skilled training programs.

Natural Resource Harvesting Education Requirements

The early deployment of CCS will likely result in a substantial increase in the use of CO_2 for EOR and methane recovery from un-mined coal seams (ECBM). This will require the expansion of the existing workforce as the demand for skilled workers in the engineering and geology disciplines grows and a similar expansion would occur in the construction trades for skilled workers to construct and operate recycling plants, pipelines, and other ancillary operations.

Because EOR and ECBM produce additional fossil fuels resulting in the emissions of additional amounts of CO_2, additional monitoring and reporting requirements are being contemplated by the U.S. Environmental Protection Agency (USEPA) to insure that more CO_2 is sequestered than what is produced. This will require a skilled workforce to adequately monitor both injection and production and

[14] http://switchboard.nrdc.org/blogs/ljohnson/comprehensive_climate_and_ener.html

emissions accounting may ultimately involve voluntary or involuntary markets and an associated increase in demand for finance and accounting jobs.

Manufacturing/Building Education Requirements

Newer generation facilities including supercritical plants, IGCC, oxycombustion, or circulating fluidized bed plants will require some adaptation of the capture facility to accommodate the capacity, efficiency, altitude, and potential for disposal or use of the CO_2.

Geologic storage will require specialized education and experience to properly characterize the site, development of the permitting plan, outreach and education plan, and the monitoring, verification and accounting (MVA) plan. Once planning is complete, actual monitoring of the CO_2 will require expertise for modeling and imaging the plume, conducting geochemical and geomechanical tests of the target layers and confining layers, leakage detection, and ongoing protection of water resources.

Construction Education Requirements

Specialized education and experience for CCS construction will reside principally in the construction of injection and monitoring wells, although some specialized experience may be required for the capture facility due to the use of new generation compression equipment and the use of materials that can withstand the corrosive effects of CO_2 gas handling.

Marketing Education Requirements

Because this is an emerging technology, marketing of the approach for CCS will require specialized education to actually describe the technology, construction and maintenance, and the likely costs and financing of the project.

Maintenance Education Requirements

Maintenance requirements for the capture facilities and sequestration facilities at commercial scale are a nascent science. As such, information sharing and continuing education will be required to minimize maintenance costs and reduce plant down time and operating costs.

2.11 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Economic Constraints

Over the last several years the EIA has conducted a number of carbon management studies[15]. These studies have found that, in general, CCS is not considered, as of yet, a key part of the solution. The reason, according to EIA's cost model, is that using CCS with coal or gas-fired power is not economically competitive with other options for generating power with low CO_2 emissions.

Social Constraints

Public opposition to deployment of CCS remains a concern and opposition has successfully stopped two demonstration projects over concerns that the CO_2 could leak and create a situation not unlike that which occurred in Cameroon near Lake Nyos in 1986. A limnic eruption or lake overturn occurred at Lake Nyos when CO_2 erupted from deep lake suffocating wildlife, livestock and humans. The eruption of naturally occurring CO_2 from the lake killed over 1,700 people and hundreds of livestock. Dissolved CO_2 seeped from springs beneath the lake and was trapped in deep water by hydrostatic pressure. This caused a mixture of gas and water that triggered the eruption. Fears have also been expressed about potential seismic activity and contamination of groundwater by CO_2.

EPA has developed proposed regulations under the Underground Injection Control Program (UIC) of the Safe Drinking Water Act (SDWA) that would impose very stringent requirements on the siting and monitoring of geologic sequestration sites. Education and outreach efforts of the Regional Carbon Sequestration Partnership Program have found that with a robust education and outreach program stakeholders become much more informed about the opportunities and risks of CCS and opposition and project delays are minimized. The very nature of CCS will require that sites be selected with minimal population density and in properly characterized geologic sinks that can adequately store the gas for tens of thousands of years. Current estimates suggest that there are sufficient sinks in the U.S. to store several hundred years of the country's combined emissions.

Environmental Constraints

Currently, numerous researchers as well as companies involved in CCS are developing technologies and best practices to ensure that CCS is safe, effective and minimizes environmental impacts. Numerous state and federal regulations will govern the permitting, operations, monitoring, and closure of CCS projects. For projects that involve obtaining federal permits, the environmental review guidelines under National Environmental Policy Act (NEPA) must be followed.

This review process will result in either a categorical exclusion, an environmental assessment or an environmental impact study. In Montana, depending on project location and ownership of surface and mineral rights, CCS activities and the permitting thereof will also be governed by several land management agencies. Table 2.2 shows an example of the environmental considerations and regulatory requirements that must be addressed for the proposed project at Kevin Dome in Montana by the Big Sky Carbon Sequestration Partnership.

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[15] Energy Market and Economic Impacts of a Proposal to Reduce Greenhouse Gas Intensity with a Cap and Trade Systems, U.S. DOE, Energy Information Administration, January, 2007; Energy Market Impacts of Alternative Greenhouse Gas Intensity Reduction Goals, U.S. DOE, Energy Information Administration, March, 2006; Energy Market Impacts of a Clean Energy Portfolio Standard - Follow-up, U.S. DOE, Energy Information Administration, February, 2007.

Because the current site selected for the proposed injection does not include any lands or minerals administered by the Bureau of Land Management (BLM), the responsible land management agency for this project will be the Montana Department of Natural Resources Conservation (DNRC). The DNRC administers the surface and mineral estates of state trust lands. The Montana Department of Environmental Quality, Montana Board of Oil and Gas, and US EPA all have statutory and regulatory authority governing other components of the proposed project. The MBOG within the Montana Department of Natural Resources and Conservation oversees the drilling of oil and gas wells and injection wells. The production wells and monitoring wells will be permitted by MBOG and the injection well will be permitted by the EPA. The necessary permits, respective agencies, and estimated time necessary for approval are identified in the table below.

Table 2.2 Regulatory Requirements

Permitting Activity	Responsible Agency	Time Requirements (in days)
Drilling		
File Application for Permit to Drill (APD)	Montana Board of Oil and Gas (MBOG), Montana Department of Natural Resource Conservation (DNRC), Montana Department of Environmental Quality (DEQ) and the Environmental Protection Agency (EPA)	120
Drilling Plan	MBOG, DNRC, DEQ, EPA	180
Surface Use Plan of Operations (SUPO)	MBOG, DNRC	180
Pipeline Permitting		
	MBOG, DEQ, Office of Pipeline Safety (OPS), DNRC, ROWs to be obtained from individual landowners	180
On Site Visit		30
Cultural Survey	State Historic Preservation Office (SHPO)	120-240
Threatened and Endangered Species Survey	United States Fish and Wildlife Service (USFWS) or Montana Department of Fish, Wildlife and Parks (FWP)	120 -240
UIC Application		
Class V Injection Well	DEQ, EPA, MBOG	120-180
Monitoring Wells	MBOG	120
Water Rights	DEQ	5 days – investigation only as the need for a water right is not expected
Temporary Use Permit	DNRC	60
NEPA and MEPA – Categorical Exclusion (CX) or Environmental Assessment (EA)	DEQ, EPA, MBOG, DNRC	365
Record of Decision (ROD)	EPA, MBOG, DEQ, DNRC	180-365
Stipulations	DNRC, FWP, MBOG, SHPO, Surface Owner	90

Transportation Constraints

Between 15,000 miles and 66,000 miles of pipeline will need to be constructed by 2030, depending on how much CO_2 must be sequestered and the degree to which EOR is involved. The upper end of the forecast range is of the same order of magnitude as the miles of existing U.S. crude oil pipelines and products pipelines[16].

If a pipeline crosses federal land, permits from federal agencies will need to be acquired and National Environmental Policy Act compliance undertaken. The U.S. Bureau of Land Management (BLM) can regulate CO_2 pipelines under the Mineral Leasing Act (MLA), as a commodity shipped by a common carrier. EOR pipelines are regulated under MLA; or BLM can regulate under Federal Land Policy Management Act (FLPMA).

Political Constraints

The principal political constraint to deployment of CCS is the lack of legislative action that places a price on carbon.

There is significant opposition from the electric power generation groups and other stationary sources of CO_2 emissions to any regulation that would increase power costs. The U.S. Chamber of Commerce and representatives of the mining industry and agricultural groups also oppose limits placed on greenhouse gases as a "jobs killer" by sending jobs overseas to countries without limits on these emissions.

The U.S. Senate is expected to endorse a proposal soon to strip the U.S. Environmental Protection Agency of its authority to regulate greenhouse gases, despite opposition from key Senate Democrats[17]. If these efforts are successful, limits on carbon emissions would not materialize and CCS would not be developed.

Finally, many environmental groups oppose CCS due to continued use of fossil fuels and mining rather than seeking new sources of renewable energy. For example, a Big Sky Carbon Sequestration pilot project was originally opposed because some members of the public saw the test as supporting the eventual construction of a coal fired power plant and they opposed the test because they were opposed to the plant. The project location was subsequently moved to another location and after additional public outreach efforts, the opposition dissipated.

2.12 FUNDING SOURCES

The principal source of funding for CCS research is the U.S. DOE Fossil Energy Program[18]. The DOE requested $179.9 million this purpose in 2010. CCS is the primary pathway that DOE is pursuing to enable the sustainable use of coal as part of the nation's clean, secure energy portfolio in a carbon-constrained future. CCS funding is intended to support CCS site selection and characterization, regulatory permits, community outreach, and completion of site operations plans for large-scale, geologic carbon storage tests. It will also fund large-scale injections and infrastructure development. The funding will also pursue research on low-cost/low energy penalty carbon capture technologies for power plants.

Essential to the DOE CCS program is the Regional Carbon Sequestration Partnerships, which unite public and private entities in an effort to complete and evaluate small- and large-scale CO_2 injection tests across

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[16] http://www.pipelineandgastechnology.com/Construction/ForecastsReviews/item55699.php
[17] Bravender, Robin. March 25, 2011. www.politico.com
[18] http://www.carboncapturejournal.com/displaynews.php?NewsID=385

the nation with the aim of developing best practices and supporting the regulatory development process. The DOE is also supporting several other programs to advance commercialization of CCS.

Chapter 3. Bio-fuels and Biolubricants

3.1 Background

According to the National Renewable Energy Laboratory, biomass (forest and agricultural residues—municipal and solid waste) can be converted directly into liquid fuels to help meet transportation fuel needs. The two most common types of biofuels are ethanol and biodiesel.

Ethanol is an alcohol most commonly made by fermenting biomass through a process similar to brewing beer. Ethanol is commonly made from starches and sugars but emerging technologies will make it possible to produce ethanol from cellulose, the fibrous materials that make up the bulk of most plant matter.

Ethanol can also be produced by a process called gasification. Gasification uses high temperatures and a low-oxygen environment to convert biomass into synthesis gas—a mixture of hydrogen and carbon monoxide. The synthesis gas—or syngas—can then be chemically converted into ethanol and other fuels.

Biodiesel is made by combining alcohol with vegetable oil, animal fat or recycled cooking grease. It can be used as an additive to reduce vehicle emissions or in its pure form as a renewable alternative fuel for diesel engines.

Microscopic algae has also emerged as a potentially viable source for the production of liquid transportation fuels. Research scientists are evaluating the feasibility of growing feedstocks of microorganisms that use the sun's energy to combine carbon dioxide with water to create biomass more efficiently and rapidly than plants. Some oil-rich microalgae strains are capable of producing the feedstock for a number of transportation fuels while mitigating the effects of CO_2 emissions from sources such as coal-fired power plants.

Biolubricants are biodegradable and non-toxic forms of lubricants developed as corrosion inhibitors and extreme pressure-wear protectants. They are available in two forms: vegetable oil-based and as synthetic esters (manufactured from mineral oil-based products). Biolubricants are increasingly made from biological materials or renewable domestic agricultural materials such as plant, animal, marine and forestry materials.

This report examines the potential jobs impacts for the following emerging biofuels technologies:

1) algae/cyanobacterial production of 2^{nd} and 3^{rd} generation biofuels;
2) biochemical conversion to 2^{nd} and 3^{rd} generation biofuels;
3) biodiesel;
4) production of bio-oils from lignocellulose (pyrolysis); and
5) lignocellulosic ethanol.

3.1.1 Algae/Cyanobacterial Production of 2nd and 3rd Generation Biofuels

SME Information

William Gibbons received his PhD in 1987 in Agronomy/Microbiology from South Dakota State University. He is a professor of industrial microbiology at South Dakota State University and has served as Associate Director of the Center for Bioprocessing Research and Development since 2006. Dr. Gibbons has 30 years experience in production of fuels, chemicals, and biomaterials from biomass. His research interests have focused on bioreactor design, improvement of microbial strains, and process analysis.

Zhengrong Gu received his PhD in 2006 in Chemical and Biochemical Engineering from Iowa State University. He is an assistant professor of Agricultural and Biosystems Engineering at South Dakota State University. Dr. Gu has 8 years experience in bioseparation processing and production of fuels, chemicals, and proteins from biomaterials. His research interests have focused on bioseparation process in producing biorenewables, improvement of separation processes in biorefinery, and process analysis.

3.1.2 TECHNOLOGY DESCRIPTION

Ethanol and biofuels can be produced from algae or cyanobacteria from three mechanisms: (1) photoautotrophic – feeding carbon dioxide (CO_2) to algae to promote growth and then conversion of algae into oils using light as the energy source; (2) chemoheterotrophic – supplying algae with sugars and other nutrients to promote growth and then conversion of algae into oils; and (3) mixotrophic – supplying algae with CO_2 and organic compounds as sources of carbon to produce oils. Sources of CO_2 for photoautotrophic processes could be coal-fired electricity generation plants, providing reductions in greenhouse gas emissions.

3.1.3 NATURAL RESOURCE HARVESTING

Ethanol and biofuels feedstocks for algae or cyanobacteria production come from two primary sources:

1) Photoautotrophic – CO_2 (coal or natural gas power plants, ethanol plants, methane digestors), and

2) Heterotrophic and Mixotrophic – domestic/livestock wastewater and food processing waste.

3.1.4 TECHNOLOGY DEVELOPMENT PROGRESS

Companies focusing on algal oil production via photosynthesis include Aurora Biofuels, Exxon Mobil, Green Fuel Technologies and Solix Biofuels. Companies using heterotrophic metabolism routes include LS9, which is developing a “Renewable Petroleum” platform that uses engineered bacteria to convert biomass sugars directly into third generation biofuels. Solazyme is engineering microalgae to convert biomass sugars into algal oil, which can then be converted into third generation biofuels.

3.1.5 TECHNOLOGY PRODUCTION AND DEPLOYMENT

Photosynthetic algal technology will likely be deployed initially in either of two formats. One could be large, open pond systems in the southern US, where the climate would be suitable for year-round production. The other deployment format could be photobioreactor systems, placed in buildings or greenhouses.

For the case of heterotrophic algal systems using biomass derived sugars, these facilities could be deployed in a similar fashion to corn or biomass ethanol plants, since the processes will be relatively similar and thus have similar requirements.

3.1.6 NATURAL RESOURCE HARVESTING JOBS

The primary natural resource to be harvested for photosynthetic algae would be water. This could be a significant issue in the southwestern US, since evaporation rates could be as high as 1,500 gal water/gal oil produced. Photobioreactor systems would be placed in buildings or greenhouses. These would be located adjacent to facilities (e.g., coal power plants or ethanol plants) that generate carbon dioxide and waste heat that could be used in the algal process. Co-locating will minimize transportation costs and also allow for other synergistic opportunities. Another opportunity for co-location would be proximity to domestic or livestock wastewater treatment facilities or food processing facilities that would provide fixed carbon (sugars, proteins, etc.) to support algal growth (as well as low grade heat). In these situations there would be no “harvesting” of natural resources, but instead just a transfer of materials from an existing processing facility to the algae system. For the case of heterotrophic algal systems using biomass derived sugars, these facilities could be deployed in a similar fashion to corn or biomass ethanol plants, since the processes will be relatively similar and thus have similar requirements.

The size of an algal system is still an open question. Advocates of open pond systems in the southwest have calculated that replacing all the petroleum used in the US would require 15,000 square miles of algal ponds (roughly 13 percent of the land surface of Arizona). In the rest of the US, enclosed photobioreactor systems will be required due to low temperatures. These systems will require co-locating with other industries that can provide CO_2 or nutrients, along with waste heat. Thus the size of these algal facilities can be predicted based on resource availability. An average 100-million gallon/yr corn ethanol plant produces over 550 tons/day of CO_2, and could thus produce 15-20 million gallons of algal oil/yr. For the purposes of this report, a base-size algal oil plant producing 20 million gallons per year was assumed for analysis of potential jobs impacts. Because of the geographic location of the Consortium states, it was assumed that the base-size algal oil plants would use photobioreactors, cell harvesting systems, oil recovery/purification systems and oil conversion technology. These unit operations generally mirror the conversion, recovery, and purification steps in corn ethanol production, so it is reasonable to use the labor needs of corn ethanol to estimate those in an algal system. On this basis, a 20-million gallon/yr algal oil facility would have 30-40 jobs. A typical 500 MW coal fired power plant produces 3.7 million tons CO_2/yr, and could thus produce 240 million gal of algal oil/yr, creating 50-75 jobs.

For the photoautotrophic route of algal oil production, CO_2 is the primary natural resource required, and it can readily be obtained at several types of processing facilities (e.g., coal or natural gas power plants, ethanol plants, methane digestors, etc). Ethanol fermentation facilities produce a clean CO_2 stream that can be used as is, and thus may be the initial sites for deployment of algal oil technology. For combustion power plants and methane digestors, technologies may be needed to separate and clean CO_2 to remove chemicals that could inhibit algae. Developing, building, and using this CO_2 cleaning technology could provide several hundred new jobs. For heterotrophic or mixotrophic algal oil production, domestic/livestock wastewater and food processing waste streams represent “captured” natural resources that are already available and that can be used with little or no additional treatment. To minimize transportation costs, algal systems will likely be constructed adjacent to the facilities providing CO_2, organic waste streams, and other resources (waste heat). Water used in the system will be recycled, with a minimal amount (~5-10%) needed for makeup volume. Thus there will be minimal impact of jobs to harvest and transport feedstocks to support algal growth in these cases.

If, however, sugars from terrestrial biomass are used for algal growth, there would be significant impact on jobs for production, harvest, and transport of these feedstocks. The job impact would be similar to that expected for biomass derived fuels, which DOE expects could be at least 200,000 new jobs for biomass harvest, densification, transport, pretreatment, and hydrolysis.

3.1.7 MANUFACTURING JOBS

Industries that will be affected by producing 3rd generation biofuels from algae or cyanobacteria, are listed in Table 3.1.1.

Table 3.1.1 Manufacturing jobs for algae/cyanobacteria systems

Production stages	Instruments/Materials	Manufacturing/Building Industries	Jobs per plant
Algae cultivation	Shallow pool / closed photobioreactor:	Plastic industries (leakage proof and transparent plastic membranes, tubes, cylinders, liquid storage tanks)	5
	Solid tolerant sludge pump systems	Mechanic industries for pumps, valves and piping,	3
	Aspiration systems for aquaculture		3
	Artificial illumination, LED or energy saving illumination equipment	Illumination equipment industries	
	Fertilizers (minerals)	Fertilizer producers	1
Cells harvest	Filtration system, filtration media or membranes,	Mechanic industries for pumps, valves and piping. Producer for filtration media or membranes	1
Fuel extraction and production	Oil extraction systems/oil processing reactors	Mechanic industries for pumps, valves, piping, extraction tanks, liquid-liquid separation tanks, distillation/evaporation instruments, reactors, flammable liquid packing/shipping instruments Producer for pervaporation media or membranes	5
	Biofuel harvest and purification process instruments. Fuels packing and shipping		3
Co-products	Drying and packing	Mechanic industries for sludge or solid delivering instruments, drying, packing equipments	1
Total			22

As shown in Table 3.1.1, multiple mechanic industries and manufacturing industries will be significantly impacted by the innovative 3rd generation algae or cyanobacteria based fuel technology. In those industries, multiple job positions will be needed such as engineering managers, mechanical and electrical engineers, tool and die makers, metal and plastics workers, etc.

3.1.8 CONSTRUCTION JOBS

Site preparation and construction would occur adjacent to existing operations that provide carbon dioxide and waste heat. In land-locked situations this could be an issue, since algal systems will have a significant footprint for photobioreactor placement. Fortunately, however, most coal power plants and ethanol production facilities are located in rural areas where land access is less of an issue. Site preparation and facility construction would be similar to that in corn-based ethanol, with the primary difference being that instead of fermentors, the algal system will use modular photobioreactors, most likely located in greenhouses spread out over a much larger footprint. During the construction stage, several hundred workers will be required to construct each algae or cyanobacterial process plant. Construction would require about 45 jobs per plant and would include construction managers, laborers, inspectors, equipment operators, engineers, electricians, etc.

3.1.9 MARKETING JOBS

Initially this technology would be marketed to coal power plants, ethanol production facilities, and operations that have human, animal, or food processing waste streams that could be used as feedstocks. After the technology is proven-out with these “captured” and low value feedstocks, the industry will likely transition to greenfield operations. Marketing would be done by the engineering, design, and construction firms that would develop these technologies, using their existing staffs. Thus job impact would be minimal.

3.1.10 MAINTENANCE JOBS

For producing biofuels based on algae and cyanobacteria, some maintenance requirements will be similar to traditional aquaculture operations (i.e., maintenance of systems for pumping, aspirating, piping and drying). However the algae/cyanobacteria process will include several distinct downstream processing operations that will have additional maintenance requirements. Table 3.1.2 lists necessary maintenance positions for producing biofuel from algae and cyanobacteria.

Table 3.1.2 Maintenance jobs for algae/cyanobacteria systems

Production stages	Maintenance need	Job position	Jobs per plant
Incubation	Piping and plastic reactors operating, cleaning and repairing	Operator for liquid or aquaculture type systems, electricians, pipelayers, pipefitters, roofers and plumbers	1-3
	Solid tolerant sludge pump operating, cleaning and repairing		1-3
	Aspiration systems operation, maintenance and repairing		1
	Artificial illumination systems repairing	Electricians	1-3
	Fertilizers application	Photobioreactor workers	1-3
Cells harvest	Filtration system operating, cleaning and repairing Filtration media or membranes cleaning	Electricians, Chemical and mechanic cleaning operator	1-2
Fuel extraction and production	Oil extraction systems/oil processing reactors cleaning, repairing	Operator for oil extraction systems, chemical reactors and fuel pumping/packing systems. Electricians, pipelayers, pipefitters, and plumbers for flammable liquid operations.	1-2
	Biofuel harvest and purification process instruments. Fuels packing and shipping		1-3
Co-products	Drying and packing		1
Total			8-21

3.1.11 EDUCATION AND JOBS SKILLS TRAINING

As an innovative industry, algae and cyanobacterial based 3rd generation biofuel processes will increase job opportunities in traditional mechanical and plastic industries for manufacturing required instruments and materials. Moreover, it will create new jobs in instrument installation and construction, photobioreactor operation, downstream bioprocessing, and management. These positions will require novel training and education programs for workers currently employed in the 1st generation biorefinery industry, and future or potential workers in the labor pool.

Natural Resource Harvesting Education Requirements

Natural resource harvesting will not be needed to produce biofuels from algae and cyanobacteria, using either CO_2 and photosynthesis, or organic waste streams. In these cases cultivation will occur in enclosed photobioreactors, with inputs transported via pipes from adjacent processing facilities. If algae or cyanobacteria are grown heterotrophically on biomass sugars, then biomass resources such as crop residues, woody feedstocks, or native grasses could be harvested and processed to provide this sugar. DOE estimates that up to 200,000 workers could be employed for such feedstock logistics operations.

Biochemists and engineers will be needed, however, to operate and monitor operation of the photobioreactors that the algae or cyanobacteria are grown in. These biochemists and engineers should have educational backgrounds in biochemistry, plant science or agricultural-biological science, biochemical engineering or/and analytical sciences. Table 3.1.3 lists the details about new positions for algae and cyanobacteria production.

Table 3.1.3. Education/training for natural resource harvesting and processing jobs

Position	Education	Experiences/skill
Strain breeder or molecular biologist	PhD in Microbiology, molecular biology, molecular biochemistry or related science/engineering major	Biotechnology manipulate the genetic material of algae or cyanobacteria. Planning and conducting research.
Process development scientist	MS or BS in Microbiology, Chemical Biological engineering, agricultural engineering or related science/engineering major	Cell incubation, microbial fermentation, seed tank maintenance i.e. prepare and maintain seed strain cultures, in place cleaning.
Assay analyst for cell incubation	MS or BS in Microbiology, chemistry, biochemistry, Chemical Biological engineering, agricultural engineering or related science/engineering major	Prepare samples and chemicals for assay, prepare and operate required equipment and tools for analysis (chromatography, microscope and other instruments).Data analysis and statistics.

Manufacturing/Building Education Requirements

Multiple positions will be needed for mechanical and manufacturing industries to manufacture instruments and materials for 3rd generation algae or cyanobacteria based fuel technology. Those jobs will require education and training programs as shown in Table 3.1.4.

Table 3.1.4 Manufacturing jobs for algae/cyanobacteria systems

Position	Education	Experiences/skill
Engineering managers	Mechanical or Chemical or Bioprocess Engineering MS or BS or PhD	Experience to coordinate and direct projects, make detailed plans to accomplish goals and directing the integration of technical activities.
Mechanical engineers	Mechanical or Chemical or Bioprocess Engineering MS or BS	Design moving parts of pumps, aspirators, augers, sludge pumps and other equipments according to blueprints, technical drawings, schematics, and computer-generated reports. Be familiar with use of drafting tools or computer-assisted design (CAD) or drafting equipment and software. Have experience in designing, evaluating, installing, operating, and maintaining mechanical products, equipment, systems and processes.
Electrical and electronics engineers	Mechanical or Chemical or Bioprocess Engineering or Electric engineering (automatic control), MS or BS	Design automatic control and electrical parts for equipment or systems. Direct and coordinate manufacturing, construction, installation, maintenance, support, documentation, and testing activities to ensure compliance with specifications, codes, and customer requirements.
Tool and die makers	Three or four years of college or several years of vocational training in specific tool and die fabrication.	Previous work-related skill, knowledge, or experience to produce tool and die for manufacturing parts is required. Must have passed the licensing exam.
Mechanical engineering technicians	Mechanical or Chemical or Bioprocess Engineering or Electric engineering (auto-control), MS or BS	Experience for quality control and testing parts before assembling. Extensive skill of raw materials, production processes and other techniques for maximizing the effective manufacture and quality improvement.
Forming/extruding /drawing machine operators	High school or specific training in operation	Experience: setup procedures, select, install, change, machine dies and parts, according to specifications. Skill for troubleshooting, maintenance, and minor repair of equipment.
Metal workers and plastic workers, Boilermakers for manufacturing evaporator and boilers.	High school or specific training in operation	Experience for: operation in producing metal and plastic parts: machine tool cutting, using computer control programmers, assembling electric motor, welding/soldering/brazing, assembling experience for (pumps, aspirators, augers, sludge pumps and other equipments), skill to produce or fabricate liquid storage tanks, liquid handling systems, biomass dryers, reactors, filtration/pervaporation membranes, packing instruments and illumination systems and other specified instruments.
Quality control inspectors:	BS or MS in Mechanical or Electric engineering	Monitor the entire production stage, making sure that individual parts, as well as the finished product, meet the standards set by the company

Construction Education Requirements

It is anticipated that design/construction firms will be the key suppliers of this technology to the industry. It is likely that firms currently designing and building corn and biomass ethanol plants will find this market for algal systems to be attractive. These firms will have the additional advantage that their intimate knowledge of ethanol production facilities will allow them to design in adjacent algal systems to take the greatest advantage of potential synergies. Positions that would be available with such companies could include those listed in Table 3.1.5.

Table 3.1.5 Construction jobs for algae/cyanobacteria systems

Position	Education	Experiences/skill
Construction managers and first-line managers of construction trades and extraction workers.	MBA or BS in civil engineering; BS in Construction Science or Construction Management	Experience for managing construction project as well as monitoring contractors and builders.
Construction laborers and helpers	High school	Experience for using brick, block, stone, steel/metal/plastic/woody frame and glass/polymer membrane in construction.
Construction and building inspectors	Civil engineering	Experience in inspecting quality of chemical/biochemical/fuel production/ aquaculture/bioenergy plants according to federal/state regulations
Construction equipment operators	High school	Experience in driving wheel loader, excavator, bulldozer, motor grader, road roller, asphalt paver, backhoe loader and using mobile heavy equipment mechanics. Skill for safety practice of working close to fuel production plants.
Civil and environmental engineers and technicians	Civil engineering	Skill to design or follow blueprints of chemical/biochemical/fuel production/ aquaculture/bioenergy processes as well as direct construction laborers to work following blueprints.
Well drillers	High school	Experience in underground water well drilling. Skill for locating underground water layer and site.
Electrical engineers, technicians and telecommunications line installers and repairers.	BS in electrical engineering or high school with EE certificate; apprenticeship program for line installers	Experience in installing and designing electrical lines and automatic control lines for instruments, which will be placed in plants or facilities with flammable liquid or gases and high humidity.
Floor Sanders and Finishers	High school; possible apprenticeship program	Experience in floor flattening and finishing, especially in floor sealing by using filler compound and coats
Pipelayers	High school; possible apprenticeship program	Experience: be familiar with installing pipe systems for chemical/biochemical/fuel plants and green house/pool/aquaculture systems.

Marketing Education Requirements

The design/construction firms noted above will also likely be the primary agents marketing this technology. These firms already have strong relationships with the owners/operators of the ethanol facilities they have constructed, and would thus be in a strong position to market algal technology as an add-on to improve the bottom line. These firms would also have the advantage of being able to provide on-going maintenance/repair services as they do now for corn/biomass ethanol plants. Those marketing positions will require industrial or research skill and experience in bioenergy or biofuel or other bioproducts production processes. For education, BS in engineering or science and MBA will be the best combination, but experience in bioenergy or bioproduct market will be more important for senior positions.

Maintenance Education Requirements

There are some special education and skill requirements for persons to work in maintenance for producing biofuel from algae and cyanobacteria. The details are listed in Table 3.1.6.

Table 3.1.6. Maintenance jobs for algae/cyanobacteria systems

Job position	Education	Skill and experience
Operator for liquid or aquacultural systems	BS or college education in Microbiology, Chemical Biological engineering, agricultural engineering or related science/engineering major	Experience in cell incubation in controlled environment or greenhouse, clean in place, sterilization in place and bio-safety. Skill for operating solid tolerant sludge pumps, aspiration systems, clean room, photobioreactor or bioreactors. Skill for batch record, fertilizers application and bio-burden control.
Roofers and plumbers, pipelayers, pipefitters	BS or college education in civil or mechanic engineering or related science/engineering major. These are also apprenticeship occupations—may require specialty training in addition to the apprenticeship.	Experience for piping and roof repairing in green house and bio facilities. Skill for cleaning and sterilization in biofacility. Skill for plumbing for flammable liquid operations.
Electricians	BS or college education in electric engineering or related science/engineering major. These are also apprenticeship occupations—may require specialty training in addition to the apprenticeship.	Experience for repairing and maintaining aspiration and pump systems, artificial illumination system, filtration system, and control system in fermentation processes. Skill for explosive proof electrical instruments for flammable liquid operations.
Chemical and mechanic operator	BS or college education in chemical engineering or related science/engineering major. May also require training and licensure.	Experience for operating filtration system cleaning in place, sterilization in place and filtration media/membranes cleaning. Skill for batch record and automatic control
Operator for oil extraction systems, chemical reactors and fuel pumping/packing systems.	BS or college education in chemical engineering or related science/engineering major	Experience for oil extraction systems, oil processing reactors, cleaning in place, Skill for operating biofuel harvesting and purification process instruments. Skill for fuels packing and shipping. Skill for solid biomass or bioproducts drying and packing.

3.1.12 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

The primary technical constraint for algae systems in Consortium states is that the climate will require enclosed, indoor production systems to permit continuous operation. For heterotrophic production on organic wastes, the system will be able to use more traditional reactors, since light would not be needed. Thus this type of system will be more similar to corn ethanol production. However for CO_2 using processes that require light, a larger footprint will be needed for photobioreactors, whether they are place in greenhouses or use artificial light.

Economic Constraints

Development: First generation algal oil systems are now in the pilot stage. Commercialization will require scaling up to demonstration stage facilities, and the cost for this development should be in the same range as DOE has provided for lignocellulosic ethanol ($25-50 million per facility). Developing algae that directly produce fuels and chemicals is a step behind the algal oil platform in terms of development, and this will require significant research and development funding to develop and optimize these strains. This funding should be on the order of at least $10-20 million per year to solicit high quality proposals.

Deployment: Costs for this technology are anticipated to be approximately $3-4 per gallon of oil produced. This range reflects the variability in costs between using waste materials as the source of fixed carbon to that of using CO_2 via photosynthesis. Improvements to algal productivity can have a large impact on costs and there is great potential here since it is a relatively new area. Other uncertainties at this point would be whether waste feedstocks or CO2 use would be negative cost feedstocks.

Social Constraints

One main advantage of algal systems is that the process uses waste or low value resources that otherwise would have negative environmental impacts. This technology does not impact the food vs. fuel controversy and there appear to be no negative social issues with this technology. Hence it should benefit from strong public support. The main public opposition could come if engineered algae or cyanobacteria were used in the process.

Environmental Constraints

Algae or cyanobacteria based biofuel technology will not have significant environmental constraints compared to corn ethanol. There are six major environmental constraints for all biofuel systems.

1) **Land -** Algae or cyanobacteria do not compete with food crops for land. In addition, the biofuels yield of algae or cyanobacterial system on unit land can be 10 times that of traditional crops based biofuels.
2) **Water -** Traditional algae biofuel systems, which use open ponds, will have significant issues regarding water evaporation. However this can be avoided by use of enclosed, recirculating photobioreactors. In addition, salty water, seawater or wastewater can be used if specific algae or cyanobacterial strain are used.
3) **CO2 -** Algae and cyanobacterial systems can be used to produce biofuel from CO_2. As the result, this biofuel system will be a carbon neutral fuel production system. To produce biofuel in large amounts, the algae facility should be located close to a constant CO_2 supply, such as coal burning or ethanol production plants.
4) **Fertilizer/nutrient -** The critical environment constraint of traditional algae based biofuels is fertilizer, which is similar to all biofuel systems. To reduce fertilizer consumption, several methods will be developed in the future: 1) specific strains which need less minerals or nutrients such as nitrate, phosphate and potassium to grow; 2) recycle bio-debris after oil or biofuel harvesting, for third generation biofuel, which will be produced in sealed bioreactor or green house systems; 3) integrate algae or cyanobacterial plants with agricultural (animal or crops systems) or municipal waste water treatment systems. The nutrients in wastewater can be cleaned by algae, while algae growth depends on free fertilizers.
5) **Energy -** For traditional algae biofuel systems, cells are harvested from low concentration slurries and dried before oil extraction. Then the oil is converted to biodiesel with acid catalytic reactions in methanol. The result is an overwhelming energy and chemical consumption of traditional algae. But

for third stage algae or cyanobacterial systems, biofuel products such as oil or hydrocarbon can be harvested directly from slurry, which will avoid drying and harvesting cells, oil extraction and other down stream process. There are only two bottlenecks for harvesting 3rd generation biofuels from algae/cyanobacterial systems. One is high expression level and high tolerance to biofuels, which can be solved by developing new strains with those properties using transgenic technology or hybrid strategy. The other bottleneck is separation methods for concentrating and purifying low concentration products. This will depend on development of new separation materials.

6) **Climates -** Algae and cyanobacterial can only be incubated in water above 20^o C. To allow for production in consortium states, potential solutions include 1) greenhouses with sunlight and waste heat from adjacent processing facilities, or 2) greenhouses using geothermal energy—suitable for many areas in Consortium states.
7) **Gene pollution -** Although transgenic or recombinant DNA technology can help improve yield of biofuel and reduce nutrient consumption of algae or cyanobacterial systems, gene pollution will be a big issue for large scale production. For 3rd generation algae/cyanobacterial biofuel systems, technology methods such as high efficient air filtration system, in-line chemical sterilization, steam in place and sterilization filtration will be used to prevent gene escape from the systems. For algae and cyanobacterial cultures, federal or state regulations must be closely followed. Any liquid discharge for the system will be sterilized with high-pressure steam and all solids waste will be burned at high temperatures greater than 1000^o C.

Transportation Constraints

Algae or cyanobacteria based biofuel technology will not have as many transportation constraints as corn ethanol or other biomass sources, because it is not necessary to transport large amounts of feedstock materials (except if biomass sugars are to be used instead of sunlight and CO_2). The only potential bottleneck would be for transporting products. The 3rd generation biofuels will be drop-in replacements for current fuels, so this issue should be minimal. They should be transported in a similar manner to gasoline, diesel, and jet fuel.

Political Constraints

Potential political constraints for algal production of fuels would likely come from two sources: 1) opposition to genetically modified organisms being used in the process; and 2) opposition based on objections to the costs involved with the process.

3.1.13 FUNDING SOURCES

Federal agencies including the federal Department of Energy (DOE), the US Department of Agriculture, the National Science Foundation and the US Department of Defense have strong research based programs supporting development of biofuels. These agencies also support Small Business Innovation Grant Programs to encourage commercialization of innovative biofuel technologies. The DOE has taken the additional step of creating the “Demonstration of Integrated Biorefinery Operations” program to help speed commercialization of biofuel processes. Since 2007, this program has awarded over $1.1 billion.

3.2 Biochemical conversion to 2nd and 3rd generation biofuels

SME Information

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3.2.1 TECHNOLOGY DESCRIPTION

The biochemical route for 2nd and 3rd generation biofuel production involves similar unit operations (pretreatment, hydrolysis, fermentation, separation) as the process used to convert corn into the first generation biofuel, ethanol. The feedstock for 2nd and 3rd generation biofuels is lignocellulosic biomass, which can be in the form of crop residues, forestry residues, components of municipal solid waste, or dedicated biomass sources such as fast growing trees or native grasses. These feedstocks are first subject to physical, chemical, or biological pretreatments to reduce particles size and disrupt the protective matrix of lignin that surrounds the cellulose and hemicelluloses fibers. The pretreated material is then subjected to chemical or enzymatic hydrolysis to convert the fiber polymers into fermentable sugars. In some processes, this hydrolyzed solution is then centrifuged or filtered to remove the lignin and other non-fermentable components, so that fermentors receive only sugars. In other processes the hydrolyzed solution is sent directly to fermentors where yeasts are used to produce ethanol (2nd generation biofuel) or bacteria such as *Clostridium* are used to produce butanol (3rd generation biofuel). Researchers are evaluating other microbes (native or genetically modified) to provide a range of other infrastructure compatible, energy dense 3rd generation biofuels such as longer chain alcohols, alkanes, and alkenes. The biofuel is then recovered from the fermented solution, typically via distillation. Non-fermentable solids are separated from the process water and are used to generate process steam and electricity, while process water is recycled to the greatest extent possible.

The overall design and layout of 2nd and 3rd generation biofuel facilities will be relatively similar to corn ethanol facilities due to this similarity in unit operations. The primary difference may be in the size of these facilities. Due to the established infrastructure for corn storage and transport, corn ethanol plants are now typically in the 100-120 million gallon/yr (MMGY) range. On the other hand, harvest, storage and transportation infrastructure for lignocelluloses biomass feedstocks is not as well developed; although in certain regions there are established infrastructure networks for woody biomass and forage crops. Therefore it is likely that 2nd and 3rd generation biofuel facilities will be in the 20-40 MMGY range. The upper size limit will likely be determined by the amount of biomass that can be economically delivered to the plant gate. This will be affected by biomass yields per acre, competing uses/markets, price, and feedstock logistic issues.

Biomass-based fuel production systems may be able to avoid the food vs. fuel controversy that corn-based ethanol has faced. A certain amount of crop residues (e.g. corn stover, wheat straw) can be sustainably removed, while maintaining the productivity of the soil. Forest and wood processing wastes, and municipal solid waste components would also not compete for arable lands. Dedicated energy crops such as fast growing trees or native grasses can be grown on landscapes subject to erosion, periodic flooding, or other factors that would prevent their use for crop production. Yields would likely be lower than could be achieved on highly productive farm ground, but this would avoid the food vs. fuel issue. However if lands typically used for crop production are diverted into biomass production, then an argument could be made that fuel production would impact food production. Partially mitigating this argument would be the continued improvements in crop yields due to advanced breeding and molecular biology. For example, major crop genetics companies expect to double average yields of corn and soybeans by 2030, meaning that less land will be needed to produce the same amount of food. Of course the world's population (and hence food demand) will also continue to grow.

Inputs for production of biomass used for 2nd and 3rd generation biofuels will be substantially less than that for corn (ethanol) or soybeans (biodiesel). These biomass resources are typically perennial plants, so that annual planting is not needed. These plants also require less fertilization, water, and herbicides/pesticides. Biomass-to-fuel conversion processes should be similarly efficient to corn ethanol production in term of water and energy recycling, but will have the major advantage of being able to generate their own process heat and power from the lignin residues (as opposed to natural gas or other fossil fuels typically used in 1st generation biofuels). Thus compared to corn-based ethanol, 2nd and 3rd generation biofuels should emit less pollution.

3.2.2 TECHNOLOGY DEVELOPMENT PROGRESS

Production of ethanol from biomass (2nd generation biofuel) has been a research focus for the past 30 years, with the key impediment being the recalcitrance of the biomass itself. Lignocellulosic biomass is a structural material which nature has designed to resist breakdown. Scientists and engineers have focused on developing pretreatment processes to open the structure of biomass for enzymatic attack, while molecular biologists have sought to increase the productivity and efficiency of cellulase enzymes that hydrolyze (a chemical process in which a certain molecule is split into two parts by the addition of a molecule of water) the fibers into fermentable sugars.

Projected costs for biomass ethanol (>$2-3/gallon) have been substantially greater than actual costs ($1-1.25/gallon) for corn-based ethanol. For this reason the DOE initiated the "Demonstration of Integrated Biorefinery Operations" program in 2006 to help cost-share construction costs for pilot or demonstration scale facilities to convert biomass to ethanol. Three rounds of grants have since been awarded, and the initial awardees are expected to begin production in 2011-2012. Six proposals were funded in 2007 at a federal investment of $385 million. Biochemical processes included POET, which is constructing a 25 MMGY corn cob/stover conversion facility adjacent to one of its 100 MMGY corn ethanol plants in Emmetburg, IA. Abengoa (Kansas) is constructing an 11.4 MMGY facility to use corn stover, wheat straw, and other feedstocks, while Iogen is establishing a similar facility in Idaho. In 2008 DOE announced that 9 second round awardees will receive a total of $240 million. Biochemical processes included Verenium's 1.5 MMGY facility in Louisiana, and Zeachem's 0.25 MMGY facility in Oregon. In 2009 DOE announced funding of $482.7 million for 18 pilot and demonstration scale facilities Awardees planning biochemical processes included Amyris Biotechnologies (California), ADM (Illinois), ICM, Inc (Missouri) and Logos Technologies (California). These facilities are expected to begin operation in 2013-2014.

Production of 3rd generation biofuels from biomass is further behind, with butanol being the leading candidate. British Petroleum and DuPont are refurbishing an ethanol facility in Great Britain to make butanol, and companies such as Chevron and Weyerhaeuser are exploring this opportunity. Various research teams are working to develop improved microbes for butanol production. Pilot scale facilities for butanol production should become operational in 2010-2011. Besides butanol, other companies are exploring options to produce drop-in replacements for currently used fuels. For example, Flambau River Biofuels (WI) received funding in the second round of DOE's biorefinery program to construct a 6 MMGY wood-to-diesel facility that should be operational in 2012-2013. The company LS9 is engineering bacteria to produce other 3rd generation biofuels and plans to test pilot scale systems in the next 12-24 months.

3.2.3 TECHNOLOGY PRODUCTION AND DEPLOYMENT

Initial deployment of 2nd and 3rd generation biofuel processes using corn stover is already occurring at certain corn-based ethanol facilities. Co-locating allows for several synergistic opportunities. For example, lignin from the biomass plant can provide all its thermal energy, as well as meeting part of the needs for an adjacent corn-based plant. Excess nutrients from the corn ethanol plant can help enhance fermentation of biomass-derived sugars. Furthermore, downstream unit operations for ethanol recovery, purification, storage and shipping can be shared by the two processes. Similarly, some woody biomass conversion processes are being co-located at pulp mills to take advantage of delivery and pretreatment infrastructure.

As 2nd generation biofuel processes are proven-out, they will likely expand into green-field plants located close to specific feedstocks. The same is likely to be true for 3rd generation biofuel processes. In both cases, the size of the facilities will be limited by the amount of feedstock that can be economically delivered to the plant gate. The consensus at this point is that 20-40 MMGY facilities will be the norm, and thus labor projections were based on this size plant. Because these systems will generally mirror the conversion process used in corn ethanol, it is reasonable to use labor requirements of corn ethanol to estimate biomass fuel labor needs. On this basis a 20-40 MMGY 2nd and 3rd generation biofuel facility would have 40-50 employees.

3.2.4 NATURAL RESOURCE HARVESTING JOBS

A significant aspect of 2nd and 3rd generation biofuel production will be the infrastructure for harvest, collection, storage, and transport of the biomass (Table 3.2.1). The DOE has projected that at least 200,000 new jobs could be created for biomass logistics. This would be in addition to jobs that could be re-directed from providing woody wastes or forage materials to less competitive markets.

Table 3.2.1. Natural resource harvesting jobs for 2nd and 3rd generation biofuels produced via biochemical route

Production stages	Instruments/Materials	Job positions	Jobs per plant
Biomass harvesting, densification, and storage	Agricultural machines such as harvesters, planters, irrigation systems (pump and piping), trucks, and hay balers, hydraulic compressor or extruder	Mechanic industries for producing needed equipment. Customized harvesters and planters may be needed. Mobile grinding, compression, or extrusion equipment for biomass densification.	15
Biomass transport	Trucking	Truck drivers, forklift operators	5-10
Biomass quality control, impact of removal	Testing instruments for quality and composition	Agricultural or Chemical Engineers	2
Total			22-27

3.2.5 MANUFACTURING/BUILDING JOBS

Industries that will be affected by producing 2nd/3rd generation biofuels using biochemical conversion are listed in Table 3.2.2.

Table 3.2.2 Manufacturing jobs for 2nd/3rd generation biofuels produced via biochemical route

<table>
<tr><th>Production stages</th><th>Instruments/Materials</th><th>Job positions</th><th>Jobs per plant</th></tr>
<tr><td>Pretreatment*</td><td>Pretreatment instruments such as industrial scale pressure cooker, boiler and other pulping/food processing equipment</td><td>Vendors for food or pulping processing equipment.</td><td>5</td></tr>
<tr><td>Saccharification*</td><td>Saccharification reactors.

Enzymes or catalysts</td><td>Vendors for saccharification reactors and enzymes/catalysts</td><td>5</td></tr>
<tr><td>Fermentation</td><td>Fermentation systems similar to corn ethanol or other bioproducts systems include:

fermentor, solid tolerant sludge pump, air or oxygen or nitrogen pump, reservoirs</td><td>Vendors for fermentation equipment and systems</td><td>10</td></tr>
<tr><td>Clarification</td><td>Filtration systems, filtration media or membranes, centrifugation or integrated membrane fermentor</td><td>Mechanic industries for pumps, valves and piping. Companies that produce filtration media, membranes or centrifuges</td><td>5</td></tr>
<tr><td>Fuel (ethanol or soluble alcohol) recovery</td><td>Distillation or pervaporation, adsorption (molecular sieve)</td><td rowspan="2">Mechanic industries for pumps, valves, piping, extraction tanks, liquid-liquid separation tanks, distillation/evaporation equipment and reactors.

Producer of pervaporation media or membranes and adsorbents</td><td>5</td></tr>
<tr><td>Fuel (volatile hydrocarbon or insoluble product) recovery</td><td>Adsorption or condenser and phase separation process instruments.</td><td>5</td></tr>
<tr><td>Fuel shipping</td><td>Fuel shipping infrastructure</td><td>Mechanic industries for flammable liquid shipping</td><td>5</td></tr>
<tr><td>Co-products</td><td>Drying and packing</td><td>Mechanic industries for sludge or solids drying and handling equipment</td><td>3</td></tr>
<tr><td>Total</td><td></td><td></td><td>43</td></tr>
</table>

*Depends on development of strains. If transgenic microbes can ferment biomass directly without pretreatment or saccharification, these two steps can be avoided. The cost and energy efficient will be improved significantly.

As shown in Table 3.2.2, various mechanical, chemical, and manufacturing industries will be significantly impacted by Biochemical conversion to 2nd/3rd generation biofuels. In those industries, multiple job positions will be needed such as:

1) Engineering managers (designation of instruments and systems) (3 jobs/plant)
2) Mechanical engineers (design moving parts of pumps, aspirators, augers, sludge pumps and other equipments) (5 jobs/plant)
3) Electrical and electronics engineers (design automatic control and electrical parts) (3 jobs/plant)
4) Tool and die makers (produce tools or dies for manufacturing parts) (5 jobs/plant)
5) Mechanical engineering technicians (testing parts before assembling) (5 jobs/plant)
6) Forming/extruding/drawing machine operators (produce metal and plastic piping, valves and connectors) (10 jobs/plant)
7) Metal workers and plastic workers include: machine tool cutting setters, operators, and tenders; computer control programmers and operators; electric motor assemblers; welding, soldering, and brazing workers; and other assemblers and fabricators (produce parts for instruments such as pumps, harvester, planter, irrigation systems, augers, slurry pumps, pretreatment reactor/systems, fermentors, distillation systems, and other equipment; produce or fabricate liquid storage tanks, liquid handling systems, biomass dryers, filtration/pervaporation membranes, packing instruments and other specified instruments) (20 jobs/plant)
8) Boilermakers for manufacturing evaporator and boilers. (8 jobs/plant)
9) Quality control inspectors: monitor the entire production stage, making sure that individual parts, as well as the finished product, meet the standards set by the company (5 jobs/plant)
10) Operators in fertilizer productions processes (2 jobs/plant)
11) Chemical engineers or biotechnology scientists for developing new separation media or membranes and adsorbents. (1 job/plant)
12) Chemical engineers or biotechnology scientists and operators for bioprocesses for producing new separation media or membranes and adsorbents as well as novel enzymes. (1 job/plant)

3.2.6 CONSTRUCTION JOBS

Site preparation and construction for 2nd generation biofuel production (lignocellulosic ethanol) is initially occurring adjacent to existing ethanol plants or wood pulping operations where the upstream feedstock handling and pretreatment steps can be used in the process. Eventually 2nd generation plants will be built in greenfield operations based on feedstock availability. Third generation 3rd biofuel facilities will be significantly different from ethanol plants, and therefore are likely to be constructed initially near wood pulping operations or at greenfield sites close to feedstock resources. Site preparation and facility construction would be similar to that in corn-based ethanol in terms of hydrolysis, fermentation, and product recovery. The primary differences will be in feedstock storage and handling, pretreatment, and co-product handling and use. The jobs impact for site preparation and construction of a 20-40 MMGY facility for would be 300-500.

During the construction stage, multiple job positions will be required and impacted by building these innovative 2nd and 3rd generation biofuel processes:

1) Construction managers and first-line managers of construction trades and extraction workers, who will manage the building or construction project, as well as monitor contractors and builders. (1-2 jobs/plant)
2) Construction laborers who will use brick, block, stone, and steel/metal/plastic/ woody frame to build plants. (20 jobs/plant)
3) Construction and building inspectors to inspect quality of plants according to federal/state regulations (2 jobs/plant)

4) Construction equipment operators for driving wheel loader, excavator, bulldozer, motor grader, road roller, asphalt paver, backhoe loader and using mobile heavy equipment (3-5 jobs/plant)
5) Civil and environmental engineers and technicians, who design or follow blueprints for innovative 2nd and 3rd generation processes, as well as direct construction laborers. (2 jobs/plant)
6) Well drillers (water supply is important for biomass hydrolysis and downstream processing) (2 jobs/plant)
7) Electrical engineers, technicians and telecommunications line installers and repairers who will install electrical lines and automatic control lines for instruments (2 jobs/plant)
8) Floor Sanders and Finishers (4-5 jobs/plant)
9) Pipelayers to install pipe systems (4-5 jobs/plant)

3.2.7 MARKETING JOBS

Initially the technology for producing 2nd and 3rd generation biofuels will be marketed to corn-based (1st generation) ethanol production facilities to take advantage of synergies such as sharing process energy, nutrients, and infrastructure. Wood pulping operations would be another co-location opportunity for early deployment due to their material handling and processing infrastructure. After the technology is proven-out at these locations, the industry will likely transition to greenfield operations. Marketing will be done by the companies that design and construct these facilities.

3.2.8 MAINTENANCE JOBS

Biochemical production of 2nd and 3rd generation biofuels will require similar maintenance to that of corn ethanol or biobased chemicals industries. This would include maintenance of systems for generating process steam, pumping, mixing, aspirating, piping and drying. Some additional maintenance requirements would focus on upstream material handling and processing. Table 3.2.3 lists necessary maintenance position for this technology.

Table 3.2.3 Maintenance jobs for 2nd/3rd generation biofuels produced via biochemical route

Production stages	Maintenance need	Job positions	Jobs per plant
Biomass harvesting	Maintenance of biomass production/harvest and densification instruments. Evaluation of biomass growth and environment impact. Quality control of biomass feedstock	Maintenance engineer, technician and electricians for biomass production/harvest and densification instruments	5
Pretreatment*	Operation and maintenance of pretreatment systems	Maintenance engineer or technician Electricians, chemical operators and engineer, analytical scientist	3~5
Saccharification*	Operation and maintenance of saccharification reactors		3~5
Fermentation	Operation and maintenance of fermentation systems	Operator for fermentation systems, electricians, maintenance engineer or technicians, pipelayers, pipefitters and plumbers	3~5
Clarification	Operation and maintenance of clarification systems	Electricians, Chemical and mechanic cleaning operator	2
Fuel (ethanol or hydrocarbon or other fuel) and co-products recovery	Operators and maintenance workers for separation units for biofuels and co-products	Chemical or biochemical operators, engineers and technicians Electricians, pipelayers, pipefitters, and plumbers for flammable liquid operations.	2
Fuel shipping	Fuel shipping and packing		3~5
Total			21-29

3.2.9 EDUCATION AND JOBS SKILLS TRAINING

Production of 2nd and 3rd generation biofuels is a sequential outgrowth of 1st generation biofuel production. In areas such as biomass production and logistics many additional jobs in traditional areas will be created to supply biorefineries with needed feedstock (DOE estimates 200,000 jobs nationwide). Similarly, the biorefineries themselves will create a significant number of additional jobs. Industries providing enzymes, microbes and other supplies for these facilities will create new and expanded job opportunities as well. These biorefineries will also increase job opportunities in traditional mechanical and plastic industries for manufacturing required equipment, instruments, and materials. These positions will require novel training and education programs for workers currently employed in the 1st generation biorefinery industry and future or potential workers in labor pool.

Natural Resource Harvesting Education/Training

For 2nd and 3rd generation biofuel production, biomass harvesting, densification, transport, and storage are critical new areas. To achieve sustainable biomass production, agricultural workers, scientists, biochemists and engineers, who are in charge of operating or monitoring those biomass production and logistics processes will be needed. They should have education backgrounds in biochemistry, plant science, biological science, biochemical engineering or/and analytical sciences. These are listed in Table 3.2.4.

Table 3.2.4 Education/training for natural resource harvesting jobs for 2nd/3rd generation biofuels produced via biochemical route

Position	Education	Experiences/skill
Agricultural operators	High school	Biomass handling, harvest, densification, transportation and storage.
Agricultural mechanical technicians	Agricultural or Mechanical engineering BS or college (AS)	Maintenance, troubleshooting and repairing of harvest and densification equipment.
Agricultural scientists or engineers	Agricultural or Mechanical engineering BS or MS	Quality control of biomass (harvested and densified). Evaluation of impact of biomass removing on environment, soil and wildlife.

Manufacturing/Building Education and Training

Multiple job positions will be needed for several mechanical and manufacturing industries, which are critically needed for manufacturing instruments and materials for 2nd/3rd generation biochemical technologies. These jobs will require specific education and training programs. To produce fermentable sugars from lignocellulosic biomass, innovative enzymes and catalysts must be developed and commercialized. Table 3.2.5 lists the educational requirements for the various positions that will be required.

Table 3.2.5 Education/training for mechanical jobs for 2nd/3rd generation biofuels produced via biochemical route

Position	Education	Experiences/Skills
Engineering managers	Mechanical, Chemical, or Bioprocess Engineering; MS or BS or PhD	Experience to coordinate and direct projects, make detailed plans to accomplish goals and directing the integration of technical activities.
Mechanical engineers	Mechanical, Chemical, or Bioprocess Engineering; MS or BS	Design moving parts of pumps, aspirators, augers, sludge pumps and other equipment according to blueprints, technical drawings, schematics, and computer-generated reports. Use drafting tools or computer-assisted design (CAD) or drafting equipment and software. Experience in design, evaluation, installation, operation, and maintenance of mechanical equipment, systems and processes
Electrical and electronics engineers	Mechanical, Chemical, or Bioprocess Engineering or Electric engineering (automatic control); MS or BS	Design automatic control and electrical parts for equipment or systems. Direct and coordinate manufacturing, construction, installation, maintenance, support, documentation, and testing activities to ensure compliance with specifications, codes, and customer requirements.
Tool and die makers	Three or four years of college or several years of vocational training in specific tool and die fabrication.	Previous work-related skill, knowledge, or experience to produce tool and die for manufacturing parts. Must have passed the licensing exam.
Mechanical engineering technicians	Mechanical, Chemical, or Bioprocess Engineering or Electric engineering (auto-control); MS or BS	Experience in quality control and testing parts before assembling. Extensive skill in raw materials, production processes and other techniques for maximizing quality manufacturing.
Forming, extruding, drawing machine operators	High school or specific training in operation	Experience: setup procedures, select, install, change, machine dies and parts, according to specifications. Skill in troubleshooting, maintenance, and minor repairs.
Metal workers and plastic workers. Boilermakers for manufacturing evaporators and boilers.	High school or specific training in operation; apprenticeship program for boilermakers	Experience in: producing metal and plastic parts, machine tool cutting, using computer control programmers, assembling electric motors, welding/soldering/brazing, assembling experience (for pumps, aspirators, augers, and other equipment), skill to fabricate liquid storage tanks, liquid handling systems, biomass dryers, reactors, filtration/pervaporation membranes, and other specified instruments.
Quality control inspectors	BS or MS in Mechanical or Electrical engineering	Monitor the entire production stage, making sure that individual parts, as well as the finished products, meet the standards

Table 3.2.6 Education/training for enzymes and catalysts related jobs

Position	Education	Experiences/Skills
Engineering managers or principle scientists	Chemical or Bioprocess Engineering; MS or BS or PhD	Experience in coordinating and directing projects, making detailed plans, directing integration of technical activities (for developing innovative enzymes and catalysts).
Biochemical or Chemical engineers	Chemical, Biochemical, or Bioprocess Engineering; MS or BS	Design production processes, trouble shooting and technique support for innovative enzymes or catalysts.
Bioprocess operators	High school or specific training in operations in food, biochemical or biopharmaceutic or related areas	Experience in production of enzymes or catalysts. Skill to operate pumps, aspirators, augers, sludge pumps and other equipment, liquid storage tanks, liquid handling systems, biomass dryers, reactors, filtration membranes, refrigeration storage systems and other specified instruments.
Quality control inspectors	BS or MS in biochemistry or analytical chemistry	Monitor the entire production stage, making sure that enzymes or catalysts produced in separate batches meet standards

Construction Education and Training

It is anticipated that design/construction firms for ethanol, chemical and other fuel related processes will be the key suppliers of this technology to the industry. Firms currently designing and building corn and biomass ethanol plants will find this market for 2nd and 3rd bio-fuel systems to be attractive. These firms will have the additional advantage that their intimate knowledge of ethanol production facilities will allow them to design-in adjacent 2nd generation biofuel and similar 3rd generation biofuel systems to take the greatest advantage of potential synergies. For persons who are looking jobs in this construction market, some specified education or professional training will be needed for the various positions listed in Table 3.2.7.

Table 3.2.7 Education/training for Construction jobs

Position	Education	Experiences/Skills
Construction managers, first-line managers of construction trades.	MBA or BS in civil engineering; BS in construction science or construction management	Experience in managing construction projects as well as monitoring contractors and builders.
Construction laborers	High school; apprenticeship program	Experience in using brick, block, stone, steel, metal, plastic, or wood frames
Construction and building inspectors	Civil engineering	Experience in inspecting quality of chemical/biochemical/fuel production/bioenergy plants according to federal/state regulations
Construction equipment operators	High school; apprenticeship program	Experience in driving wheel loader, excavator, bulldozer, motor grader, road roller, asphalt paver, backhoe loader and using mobile heavy equipment. Skill in safety procedures.
Civil and environmental engineers and technicians	Civil engineering	Skill to design or follow blueprints for chemical/biochemical/fuel production /bioenergy processes. Direct construction laborers to work following blueprints.
Well drillers	High school; apprenticeship program	Experience in underground water well drilling.
Electrical engineers, technicians, and telecom line installers	BS in electrical engineering or high school with EE certificate; apprenticeship program	Experience in installing and designing electrical lines and automatic control lines for instruments
Floor sanders and finishers	High school; apprenticeship program	Experience in floor flatting, finishing, and sealing
Pipelayers	High school; apprenticeship program	Experience: be familiar with installing pipe systems for processing plant systems.

Marketing Education and Training

The design/construction firms noted above will also likely be the primary agents marketing this technology. These firms already have strong relationships with the owners/operators of the ethanol facilities they have constructed, and would thus be in a strong position to market 2nd and 3rd generation biofuel technology as an add-on to improve the bottom line. These firms would also have the advantage of being able to provide on-going maintenance/repair services as they do now for 1st generation biofuel plants. These marketing positions will require industrial or research skills and experience in bioenergy or biofuel or other bioproducts production processes. For education, BS in engineering or science and MBA will be the best combination, but experience in bioenergy or bioproduct market will more important for senior positions.

Maintenance Education and Training

There are some special skills required to work in maintenance for a biofuel production facility, as listed in Table 3.2.8.

Table 3.2.8 Maintenance Jobs Education and Training

Job position	Education	Skills and Experiences
Agricultural operators, technicians, scientists or engineers	BS or MS in Agricultural Engineering	Experience of evaluating biomass growth and environmental impact, as well as quality control of biomass feedstock and logistics
Mechanical engineers and technicians	BS or MS from Mechanical Engineering; machine maintenance/repair will require vo-tech education in equipment repair	Experience in maintenance and repairing of agricultural machines, pulping, fermentation, distillation, adsorption and other processing systems, as well as flammable liquid handling and storage systems.
Process maintenance personnel	High school or some college education in microbiology, chemical/biological engineering, agricultural engineering or related science/engineering area.	Experience for pulping or other pretreatment processes, enzymatic or chemical hydrolysis, fermentation, clean in-place, sterilization in-place and bio-safety. Skill for operating sludge pumps, aspiration systems, clean rooms and bioreactors. Knowledge of in bio-burden control.
Roofers, plumbers, pipelayers, and pipefitters	BS or college education in civil or mechanical engineering or related science/engineering major; apprenticeship program	Experience in repairing buildings, piping, clean in-place systems, and skills for plumbing flammable liquid operations.
Electricians	BS or college education in electric engineering or related science/engineering major; apprenticeship program	Experience in repairing and maintaining electrical systems for the process. Skill for explosive proof electrical instruments for flammable liquid operations.
Process development scientist	MS or BS in microbiology, chemical engineering, agricultural engineering or related science/engineering majors	Experience in maintaining and repairing analytical and process control equipment

3.2.10 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

The primary constraints to 2nd and 3rd generation biofuel production in the consortium states will be feedstock and water availability and transportation infrastructure. In most cases, facility siting and size will be determined by the amount of feedstock available within an economical transportation radius. In western states water availability might also be an issue, however, processing technology continues to reduce net water usage. Suitable transportation infrastructure is obviously related to feedstock availability, but is an equally important issue for shipment of biofuels to market. Since 2nd and 3rd generation biorefineries will generate their own process heat and power from lignin, access to power utilities is less of a concern than with corn ethanol.

Economic Constraints

Second generation biofuel processes have been under research and development for the past 30 years. In 2006 the DOE initiated the “Demonstration of Integrated Biorefinery Operations” program to assist companies in developing pilot or demonstration-scale commercial facilities to speed deployment. Three rounds of awards have been made, providing support of $25-100 million per facility. With this investment the DOE expects that industry will be able to move biomass-to-ethanol technology into full commercialization with minimal additional direct support. However the biofuel requirements of the “Energy Independence and Security Act” of 2007 will ensure market demand/access.

Third generation biofuel processes will build upon the pretreatment and hydrolysis technology developed for 2nd generation processes, but will require significant R&D funding to develop appropriate microbes and separation processes for the new fuels. Once this technology has been developed, deployment will be facilitated by the prior deployment of 2nd generation biofuels. However it is likely that some level of demonstration plant funding will be needed to prove-out the technology to the satisfaction of private investors.

Social Constraints

There is a diverse pool of biomass resources that are not being fully utilized that could be directed to production of 2nd and 3rd generation biofuels with minimal impact on other industries or interest groups. The DOE has estimated that over 1 billion tons of such resources would be available each year. Further expansion of 2nd and 3rd generation biofuels may create some level of competition for feedstocks and/or land use. For example, use of crop residues (stover, straw) could compete with uses for livestock bedding or feed. Similarly, converting grasses to biofuels could compete with livestock feed use, or expanded grass production could displace crop production in some locations. Production of fast growing trees for biofuels could compete with production of timber for lumber markets. Competition for these land and biomass resources will drive up prices for all users.

Environmental Constraints

Production of 2nd and 3rd generation biomass fuels will have fewer environment constraints than 1st generation biofuels (corn-based ethanol). However there are still 6 potential environmental constraints for this biofuel system:

1) **Land:** Herbaceous or woody biomass may not compete directly with food crops for land. In addition, the biomass yield/acre of native grass or fast growing woody biomass can be 3~6 times that for corn and other traditional feedstocks. Use of margin land or wildlife habitat for biomass production could significantly impact wildlife. To minimize this, biomass sources and harvesting strategies that minimize negative impacts on wildlife systems will need to be employed. Diverse plantings of biomass crops would also be preferred over monocultures.
2) **Water:** Water is often a limiting resource in the consortium states, and biomass strains should be selected for drought and salt tolerance. In addition, the impacts of planting and harvesting practices on water resources and water quality need to be evaluated.
3) **CO_2:** Native grasses or woody biomass utilize CO_2 during the growth process, and the portion of fixed carbon that is used for root growth provides for a degree of carbon sequestration. Hence, at worst, 2nd/3rd generation biofuel processes should be carbon neutral, and in many cased could actually be carbon negative.
4) **Fertilizers/nutrients:** A critical environment constraint of 1st generation biofuels is fertilizer. Biomass feedstocks for 2nd/3rd generation biofuels are generally more nutrient efficient compared to corn, and do not require the same degree of annual fertilization. However, as will all plants, biomass feedstocks will respond favorably to fertilization. To minimize fertilizer use, several approaches are under development: 1) specific strains that require less minerals and nutrients, 2) recycling nutrient-rich coproducts and/or process water after biofuel production, to recycle most nutrients back to field, 3) integrating biomass production with animal or municipal waste water treatment systems to provide nutrients, and 4) developing specific harvest strategies to allow the plants to re-mobilize nutrients back into the roots before harvest of the above-ground parts of plants.
5) **Energy:** As with 1st generation biofuels, energy and chemical use are significant for issues for 2nd/3rd generation biofuel processes. There are several key issues to address: 1) energy efficient densification technology and systems, 2) energy efficient pretreatment process, which can produce fermentable sugars from lignocellulosic biomass with lower environmental footprint, 3) novel microbial stains with high product tolerance and expression levels, and 4) energy saving product separation and recovery systems, which depend on development of new separation methods and materials.
6) **Climate:** Some biomass feedstocks are geographically limited to warmer climates (e.g. sugar or energy cane). However there are a multitude of herbaceous and woody plants that grow well throughout the consortium states. Plant breeders, molecular biologists, agronomists, and forestry biologists are working to create improved varieties that perform well under intensive cultivation systems where climatic variability, disease pressure and other factors may affect yield.
7) **Gene pollution:** For 2nd and 3rd generation biomass biofuel systems, technology methods such as high efficiency air filtration systems, in-line chemical sterilization, steam in-place and sterilization filtration will be used to prevent the escape of genetically altered microbes used in the process. For genetically modified organism (GMO) fermentation broth or microbial systems, federal and state regulations must be strictly followed. Any liquid discharge for the system will be sterilized with high pressure steam, all solids waste will be burned at high temperature > 1000^0 C. Development and use of GMO plants as the feedstocks for these processes will follow established protocols now in place for agronomic crops.

Transportation Constraints

Perhaps the most significant constraint to 2nd and 3rd generation biofuels will be the logistics of harvesting, storing and transporting large quantities of biomass. Unlike corn and other grains, most biomass resources lack a well-developed transportation infrastructure. Perhaps the closest would be the systems for harvest and transport of woody biomass that supports the pulp/wood products industry. Some infrastructure is also present in localized markets for forage crops. Issues that are problematic for biomass transport include its low bulk density and poor flowability. Therefore, highly efficient densification technology and on-site pretreatment systems for biomass will be keys for reducing transportation costs and energy consumption.

The other transportation bottleneck is shipment of products. Corn based ethanol faces significant hurdles, as it is not considered an infrastructure compatible fuel, and 2nd generation biofuels (ethanol from biomass will face the same issues). Third generation biofuels are infrastructure compatible, and should therefore move into the fuel distribution network seamlessly. However, these fuels will be produced in more rural areas, and therefore transport to metropolitan areas will be required.

Political Constraints

One source of potential political constraints for 2nd/3rd generation biofuels would be if genetically modified organisms were used in the process. These could include GMO plants that would provide the biomass source for processing, and/or microorganisms that have been genetically modified to improve their ability to convert biomass into fuels. While GMO crop plants are widely used and generally accepted in the US, release of genetically modified trees or grasses will likely receive a greater degree of scrutiny due to the potential interaction with native trees and grasses. Genetically modified microbes used in the conversion process would be easier to contain within the process, and it is likely that regulations will require that altered genetic material cannot leave the processing plant. However, this might limit the types of process co-products that could be sold from the plant.

Another potential political constraint could be resource use to support the biorefinery. Land and water used to produce the biomass, along with the biomass itself, represent resources that have (or could have) competing uses. Diversion of crop land for biomass production could elicit the food vs. fuel argument. Biomass harvest from landscapes currently used for wildlife habitat could cause kick-back from conservation/wildlife groups. It is unlikely that irrigation will be used for biomass crops, but water used in biomass processing could also be a political concern in more arid regions.

3.2.11 FUNDING SOURCES

Federal agencies including the DOE, USDA, NSF, and DOD have strong research based programs supporting development of biofuels. These agencies also support Small Business Innovation Grant Programs to encourage commercialization of innovative biofuel technologies. The DOE has taken the additional step of creating the "Demonstration of Integrated Biorefinery Operations" program to help speed commercialization of biofuel processes. Since 2007, this program has awarded over $1.1 billion.

3.3 Biodiesel

SME Information

Edward Gray, President, ANTARES Group Inc. Mr. Gray Edward E. Gray, P.E. is an owner and the president of ANTARES, a consulting engineering firm specializing in advanced energy technologies for industry, power production and transportation. Mr. Gray served as the co-chair of the biomass power supply working group under the Clean Energy Development Advisory Council for the Western Governors. He has served as technical advisor to the Maryland Governor's Energy Task Force and testified before the Maryland House and Senate committees on behalf of energy legislation encouraging the use of renewable energy. Mr. Gray also served as the chairman for the Biomass Eligibility Working Group for the NYS PSC proceeding on the Renewable Portfolio Standard for New York.

Mr. Gray has had an active role in the development and implementation of biomass and solar energy projects for power generation for 25 years. Under his leadership, Antares has been actively supporting development of projects for biomass power in the Southeast, Midwest and West and Biorefinery projects using lignocellulosic feedstocks in the Southeast and West. The company has been a leader in developing and implementing partnerships with industry, the national labs and universities to apply new conversion technologies and feedstocks to the producing of power and fuels from biomass.

Mr. Gray was actively involved in efforts to examine the potential for the National Bioenergy Initiative involving the cooperation of the EPA, Department of Energy and Department of Agriculture. As part of the effort he led the development of the Agripower model designed to examine a wide array of impacts for deployment of Biomass Power systems. In particular rural economic benefits and national environmental benefits were forecast for a variety of deployment scenarios. Mr. Gray also led a team of experts (EPRI, Princeton, Westinghouse, and Colorado School of Mines) to prepare a competitive assessment of biomass power generation technologies for the Office of Science and Technology Policy.

Tim Rooney, Project Manager, ANTARES Group Inc. Mr. Rooney is a forester and project manager with 12 years expertise in renewable energy resource assessment with an emphasis on biomass energy. His experience with biomass resource assessment includes evaluation of urban waste, forestry residues, wood products residues, agricultural residues and short-rotation biomass crops. Tim has expertise developing regional economic supply estimates supported by the use of Geographic Information Systems (GIS) for biomass resources. Tim has a Master of Science in Forestry from SUNY College of Environmental Science and Forestry and a Bachelor’s in Biology from the University of Rochester.

Dr. Arthur Wiselogel, Senior Scientist, ANTARES Group Inc. Art Wiselogel has 30 years of experience in biofuels, agronomy, and forestry as a project manager, personnel manager, scientist, and analyst. Prior to joining Antares, Art served as a Senior Manager at BBI International developing ethanol projects, as a project manager on a contract with the US Department of Energy’s Golden Field Office, as a lead scientist on biomass feedstock research, Feedstock Program Manager, and Biofuels Project Coordinator at the National Renewable Energy Laboratory. Art has also worked as a project coordinator, tree physiologist, forest geneticist, and forester at the University of Georgia, Texas A&M University, Texas Forest Service, and Westvaco Corp. Art has a Doctorate from Texas A&M University where he studied Forest Genetics and Tree Breeding, a Master’s of Science in Agriculture from Oklahoma State University, and a Bachelor of Science in Forest Science from Mississippi State University.

3.3.1 TECHNOLOGY DESCRIPTION

Biodiesel is a renewable transportation fuel that can be used by diesel combustion engines without any modification. Biodiesel is typically blended with petroleum-based diesel at 5%, 10% or 20% by volume. The technology is fully commercialized and well understood. The emerging technology for biodiesel is the use of non food-grade oil seed crops. As of August 2010 there are 148 operational biodiesel plants in the US with a production capacity of 2.264 million gallons[19]. Only about a third of that capacity is expected to be used[20]. Biodiesel can be made from fats, oils, and grease. The most common feedstock for biodiesel production in the U.S. is soybean oil. Biodiesel plants that use soybean oil tend to be larger plants because of their proximity to high concentrations of soybean acres in the Midwest and Plains States.

Biodiesel is the term that refers to the fuel product from transesterification. Transesterification is a chemical process that converts fatty acids to Ethyl esters. The process is a chemical reaction between the oils and an alcohol (often methanol, because of its low cost) that is catalyzed by a basic chemical such as sodium hydroxide or potassium hydroxide. The reaction occurs in a reactor vessel at low temperatures and pressures. The reaction produces crude biodiesel and crude glycerin, which naturally separate in a settling tank. The crude biodiesel is refined to the final product by a washing process. The glycerin co-product has multiple uses with the most common being a component of soaps and lotions.

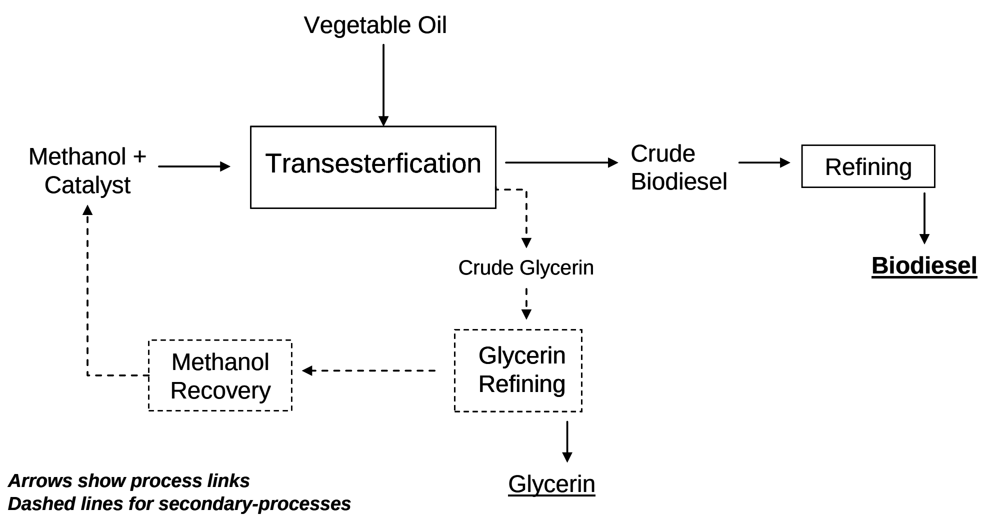

Figure 3.3.1 Biodiesel process flow diagram

Step advancement in the basic biodiesel process continues to be developed. Most of these advancements are designed to increase efficiency, reduce production cost, and improve fuel performance.

Biodiesel contains 118,296 Btu/gallon. This compares well with No. 2 diesel fuel, which has 129,500 Btu/gallon. At a 10% blend level the resulting B10 fuel has less than 1% fewer Btu/gallon than No. 2 diesel[21].

Biodiesel is considered a clean fuel because it is nontoxic, biodegradable, and is much less polluting than petroleum diesel. The use of biodiesel fuel results in lower emissions of almost every pollutant: carbon dioxide, sulfur dioxide, particulates, carbon monoxide, air toxins and unburned hydrocarbons. Biodiesel is

[19] BBI International, Advanced Biofuels Workshop
[20] EIA, 2002
[21] EPA, 2002

in demand for specialized uses where its air emission characteristics are a major advantage, such as in school and city buses, marine craft, and diesel engines operating in enclosed areas, such as mines. Biodiesel fuel meets the registration requirements for fuels and fuel additives established by the Environmental Protection Agency (EPA) under the federal Clean Air Act.

3.3.2 TECHNOLOGY DEVELOPMENT PROGRESS

Biodiesel production is fully commercialized. The emerging technology for production of biodiesel is the use of non food-grade oil seed crops. Facilities are located throughout the U.S. with size and location primarily dictated by the fat, oil, or grease feedstock availability and price. The biodiesel industry is currently over-built with approximately two thirds of the production capacity idle due to the economics of production. Most plants in operation have access to low cost local feedstocks (waste fats and grease) or low cost international oils (palm oil from South and Central America).

The use of virgin oils from oil seeds has proven to be expensive due to the market value of the oils. Some biodiesel plants are an integrated part of oil seed processing facilities. These processing facilities primary product is meal. For example, in a 60 lbs bushel of soybeans only 10% to 12% by weight is oil and the rest is meal. Biodiesel from these facilities is usually only produced when it makes economic sense.

Since feedstock cost typically make up 75% or more of the cost of production of biodiesel, advancements in production technology only have a limited impact on the commercial development of biodiesel. The developments of low cost sources of oils are required to expand the production of conventional biodiesel. Jatropha and algae are examples of potential sources of non-food grade oils that are currently under development for use as biodiesel feedstocks.

3.3.3 TECHNOLOGY PRODUCTION AND DEPLOYMENT

New development of biodiesel facilities using oil seeds is not currently economically feasible due to the market price for the oils. Since feedstock cost is the primary cost component for biodiesel only limited reductions in cost can be obtained through step improvement of transesterification biodiesel technology. Without the development of non-food grade sources of oil the deployment of biodiesel technology using oil seed crops is unlikely and only limited deployment of facilities near sources of low cost fats and oils is feasible. Industrial oilseed crops that are an alternative to food grade oils that could potentially be grown in Consortium states (e.g., cranbie) have not been grown on a commercial basis.

3.3.4 POTENTIAL JOB IMPACTS

Existing biodiesel facilities do not support net job growth in the feedstock production sectors. Construction of a biodiesel facility may result in 50 to 150 temporary positions during the construction phase. Ongoing operation and maintenance of a 10 MMGY biodiesel production facility would create approximately 17 to 20 new jobs, including three management and administrative positions, approximately 12 to 15 plant operations staff and two chemist/technician positions.

3.3.5 EDUCATION AND JOB SKILLS TRAINING

Biodiesel is a transportation fuel additive or replacement fuel primarily produced using food-grade oil seed crops such as soy. Any growth in biodiesel will come from this existing agricultural crop base or an expansion thereof, unless a non-food grade oil seed crop is developed for biodiesel production. The information in the following subsections describes 1) what kind of jobs would be needed to support technology deployment 2) educational requirements, occupational experience and job training/certification requirements, and 3) educational/institutional resources available to support these efforts within the Consortium states.

Natural Resource Harvesting Education and Training

Biodiesel production currently uses food grade oil seed crops such as soy or canola. Table 3.3.1 provides job descriptions by skill level and training /educational requirements needed for agricultural crop production. New job creation in the feedstock production area would be limited unless a non food-grade oil seed crop is developed and produced for biodiesel.

Table 3.3.1 Natural Resource Management Job Descriptions

Job category by skills level	BLS Job description	Minimum training requirements
Technical & managerial		
Logging and farm management	11-9013 Farmers, Ranchers, and Other Agricultural Managers Plan, direct, or coordinate the management or operation of farms, ranches, greenhouses, aquacultural operations, nurseries, timber tracts, or other agricultural establishments. May hire, train, and supervise farm workers or contract for services to carry out the day-to-day activities of the managed operation. May engage in or supervise planting, cultivating, harvesting, and financial and marketing activities.	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Skilled technician		
Heavy equipment mechanic	49-3042 Mobile Heavy Equipment Mechanics, Except Engines Diagnose, adjust, repair, or overhaul mobile mechanical, hydraulic, and pneumatic equipment, such as cranes, bulldozers, graders, and conveyors, used in construction, logging, and surface mining. Illustrative examples: Forklift Mechanic, Bulldozer Mechanic, Construction Equipment Mechanic or Farm Equipment Mechanic 49-3041—diagnose adjust, repair, or overhaul farm machinery and vehicles, such as tractors, harvesters, dairy equipment, and irrigation systems.	Applied associates degree and/or long-term apprenticeship/on-the-job training
Agricultural equipment operator	45-2091 Agricultural Equipment Operators Drive and control farm equipment to till soil and to plant, cultivate, and harvest crops. May perform tasks, such as crop baling or hay bucking. May operate stationary equipment to perform post-harvest tasks, such as husking, shelling, threshing, and ginning. Illustrative examples: Tractor Operator, Hay Baler, Combine Operator	State-specific requirements for heavy equipment operators; on-the-job training
Entry-level skilled or semi-skilled		
Farm laborer	45-2092 Farm workers and Laborers, Crop, Nursery, and Greenhouse Manually plant, cultivate, and harvest vegetables, fruits, nuts, horticultural specialties, and field crops. Use hand tools, such as shovels, trowels, hoes, tampers, pruning hooks, shears, and knives. Duties may include tilling soil and applying fertilizers; transplanting, weeding, thinning, or pruning crops; applying pesticides; or cleaning, grading, sorting, packing, and loading harvested products. May construct trellises, repair fences and farm buildings, or participate in irrigation activities.	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	State-specific requirements for truck driving

Manufacturing Education and Training

Manufacturing major components for a biofuels facility is likely to occur outside the region unless the specific equipment manufacturer is based within one of the Consortium states. It will require specific technical experience that is unlikely to be developed within the Consortium states for the development of individual projects. For this reason, this is unlikely to be a major new source of technical employment. However, manufacture of specific parts and components during the manufacturing/fabrication or following plant construction could be a source of employment. Job types likely to be required include positions in welding, plumbing, electricians, sheet metal fabrication and related positions that can be met with the existing labor force. Job creation from this aspect of biomass technology deployment can be absorbed by the existing workforce.

Construction Education and Training

Construction of a biodiesel plant will require anywhere from 50 to 150 jobs at any given time during the construction period. Most of these positions can be filled using the existing construction workforce, and will include skill sets such as heavy equipment operation, electrical, plumbing, pipe-fitting, welding, metal fabrication, concrete pouring/finishing, and truck driving. It is likely that a limited number of the positions could include mid-level construction and engineering management positions. Some will be met using contract staff, but some will be hired from the local work force. Individual projects do not need a dedicated workforce strategy for this job sector.

Marketing Education and Training

Marketing job functions related to biofuels technology deployment can be broken down into several broad categories; 1) Technology marketing – or the recruiting of project development and financial capital resources; 2) Fuel sales – including the negotiation of purchase agreements with refiners, certification of fuels as eligible for various market-based and governmental tax and other incentives, and 3) Feedstock procurement – recruiting and management of farmers, forest landowners and forestry professionals and coordination of biomass supply procurement effort. These are not likely to be major areas of job growth as these functions will be performed by management or existing consultants with specialized expertise.

Maintenance Education and Training

Operation and maintenance of the facility is the next largest contributor to employment impacts for a biofuels facility. The skill sets mirror those for agribusiness and forest products manufacturing on the feedstock procurement side, and chemical manufacturing or petroleum and natural gas processing on the plant side. Table 3.3.2 provides job descriptions and training/educational requirements for biofuels.

Table 3.3.2 Biofuels Job Descriptions

Job categories by skill level	BLS Job description	Minimum training requirements
Technical & managerial		
Plant manager	11-3051 Industrial Production Managers Plan, direct, or coordinate the work activities and resources necessary for manufacturing products in accordance with cost, quality, and quantity specifications. Illustrative examples: Production Control Manager, Plant Manager, Manufacturing Director	4-year accredited degree program in engineering, technical and/or finance/business with >10 years experience relevant production management experience
Plant engineer	17-2141 Mechanical Engineers Perform engineering duties in planning and designing tools, engines, machines, and other mechanically functioning equipment. Oversee installation, operation, maintenance, and repair of equipment such as centralized heat, gas, water, and steam systems. Illustrative examples: Engine Designer, Tool and Die Engineer, Heating and Cooling Systems Engineer, Combustion Engineer	4-year accredited engineering program (mechanical most likely) + minimum 5 to 10 years in relevant production environment
Fuel procurement manager	11-3061 Purchasing Managers Plan, direct, or coordinate the activities of buyers, purchasing officers, and related workers involved in purchasing materials, products, and services. Includes wholesale or retail trade merchandising managers and procurement managers. Illustrative examples: Purchasing Director, Procurement Manager, Contracting Manager	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Business manager	11-3031 Financial Managers Plan, direct, or coordinate accounting, investing, banking, insurance, securities, and other financial activities of a branch, office, or department of an establishment. Illustrative examples: Financial Director, Comptroller or 11-3051 Industrial Production Manager, 11-3071 Transportation, Storage, and Distribution Managers, or 11-1021 General and Operations Managers	4-year degree in business and finance or equivalent professional experience with experience in manufacturing
Skilled technician		
Maintenance supervisor	51-1011 First-Line Supervisors of Production and Operating Workers Directly supervise and coordinate the activities of production and operating workers, such as inspectors, precision workers, machine setters and operators, assemblers, fabricators, and plant and system operators. Excludes team or work leaders. Illustrative examples: Printing Worker Supervisor, Machinist Supervisor, Assembly Line Supervisor	Applied associates degree and/or long-term apprenticeship/on-the-job training plus5 years or more experience in power production or utility environment
Boiler operator	51-8021 Stationary Engineers and Boiler Operators Operate or maintain stationary engines, boilers, or other mechanical equipment to provide utilities for buildings or industrial processes. Operate equipment, such as steam engines, generators, motors, turbines, and steam boilers. Illustrative examples: Boiler Room Operator, Boiler Engineer, Heating, Ventilation, and Air Conditioning (HVAC) Mechanic Boiler Operator	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state boiler operator certification

Job categories by skill level	BLS Job description	Minimum training requirements
Industrial equipment mechanic	49-9041 Industrial Machinery Mechanics Repair, install, adjust, or maintain industrial production and processing machinery or refinery and pipeline distribution systems. Excludes "Millwrights" (49-9044), "Mobile Heavy Equipment Mechanics, Except Engines" (49-3042), and "Maintenance Workers, Machinery" (49-9043). Illustrative examples: Hydroelectric Machinery Mechanic, Foundry Equipment Mechanic, Boilerhouse Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Boilerhouse mechanic	47-2011 Boilermakers Construct, assemble, maintain, and repair stationary steam boilers and boiler house auxiliaries. Align structures or plate sections to assemble boiler frame tanks or vats, following blueprints. Work involves use of hand and power tools, plumb bobs, levels, wedges, dogs, or turnbuckles. Assist in testing assembled vessels. Direct cleaning of boilers and boiler furnaces. Inspect and repair boiler fittings, such as safety valves, regulators, automatic-control mechanisms, water columns, and auxiliary machines. Illustrative examples: Boiler Tester, Boiler Mechanic, Boiler Installer	Applied associates degree and/or long-term apprenticeship/on-the-job training
Accounting/ Administrative	43-3031 Bookkeeping, Accounting, and Auditing Clerks Compute, classify, and record numerical data to keep financial records complete. Perform any combination of routine calculating, posting, and verifying duties to obtain primary financial data for use in maintaining accounting records. May also check the accuracy of figures, calculations, and postings pertaining to business transactions recorded by other workers. Excludes "Payroll and Timekeeping Clerks" (43-3051). Illustrative examples: Mortgage Accounting Clerk, Bookkeeper, Accounts Receivable Clerk	Associates degree in accounting/finance with 2 years or more bookkeeping experience in manufacturing environment
Chemist	19-2031 Chemists Conduct qualitative and quantitative chemical analyses or experiments in laboratories for quality or process control or to develop new products or knowledge. Excludes "Geoscientists, Except Hydrologists and Geographers" (19-2042) and "Biochemists and Biophysicists" (19-1021). Illustrative examples: Industrial Chemist, Research and Development Chemist, Inorganic Chemist, Food Chemist	4-year degree in chemistry plus 2 years lab experience in manufacturing/quality control; 2 year associates degree plus relevant training and professional experience
Entry-level skilled or semi-skilled jobs		
Janitorial/ maintenance assistant	37-2011 Janitors and Cleaners, Except Maids and Housekeeping Cleaners Keep buildings in clean and orderly condition. Perform heavy cleaning duties, such as cleaning floors, shampooing rugs, washing walls and glass, and removing rubbish. Duties may include tending furnace and boiler, performing routine maintenance activities, notifying management of need for repairs, and cleaning snow or debris from sidewalk. Illustrative examples: School Custodian, Window Washer, Industrial Plant Custodian	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state licensing requirements

3.3.6 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Biodiesel as currently produced is dependent on a variety of oil seeds and waste or byproduct fats and organic oils. Feedstock cost and availability are the primary challenges to large-scale deployment of Biodiesel in the Consortium states.

Economic Constraints

Biodiesel production facilities have much lower unit capital costs than lignocellulosic ethanol facilities and are efficient to build on a smaller scale with the exception of the oil seed crushing facilities which are built to serve multiple outlets (i.e. not dedicated to biodiesel production) and are much larger in capacity. In the case of biodiesel the seed oil feedstock is the expensive part of the proposition but it is also a high quality feedstock that requires much less processing than most biomass feedstocks. The exceptions are waste oil and fat feedstocks but they tend to be produced in much smaller volumes from dispersed generators. Low capital costs have made this technology attractive for small scale production facilities in rural areas. The average size of biodiesel plants in the United States in 2007 was 12 MGY[22].

Researchers at Iowa State University estimated the amortized capital and operating costs for 30 and 60 MMGY biodiesel plant to be $2.35 and $2.32 per gallon of biodiesel capacity, respectively (Ginder, 2007). However, feedstock costs typically make up 75% or more of the cost of production of biodiesel. Soy oil prices are currently around 40¢ a pound[23] The feedstock costs alone are $3.00 a gallon to produce a gallon of biodiesel. Adding production costs brings the cost of make biodiesel above $4.00 a gallon. This price is over a dollar a gallon higher than wholesale petroleum diesel. Iowa 100 percent biodiesel prices (B100) for the week ending September 3, 2010 range from $3.16 to $3.32 per gallon according to the USDA AMS Northwest Commodity News. There are significant subsidies to biodiesel production that assist with bringing product to market, but profit margins are very slim for biodiesel at this time. At this level of production cost only low blending levels (2% to 5%) are attractive to the general public. This greatly hampers the inclusion of biodiesel into the U.S. transportation fuels market.

The development of low cost sources of oils are required to reduce the production cost of biodiesel and expand the production. There are a wide variety of oilseed crops under various stages of development and field-testing in the Consortium region. Selection of crops needs to take into account local climate, hydrology and soils, along with other site factors. Testing of crop varieties for yield and pest resistance using field trials and optimization of planting and harvesting is a multi-year process. Several crops that have been evaluated for use in Great Plains regions include camelina, industrial flax, rapeseed, crambe and brassicaceae, commonly known as brown mustard [24]. Algae is another possibility for production of an industrial oil but the technology has not been demonstrated on a commercial scale.

Social Constraints

The social constraints are few for biodiesel blends such as B20 which requires little or no change from a driver perspective. Use of B100 as a total diesel replacement fuel requires some modification of maintenance on the behalf of vehicle owners, which to some extent constrains its expansion. A more significant limitation on both fuel types is the relatively low number of refueling stations, which requires users to drive longer distances to refuel. The National Biodiesel Board provides information on how to locate refueling stations but their scarcity will limit market growth.

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[22] Biodiesel 2020: A Global Market Survey, 2nd Edition, Emerging Markets Online, Houston TX, February 2008
[23] GLG News, 2010
[24] Walsh, Marie E. Potential New Bioenergy and Bioproduct Crops, University of Tennessee. Feb. 15, 2007

Environmental Constraints

Key environmental concerns related to biodiesel production relate primarily to perceived conflicts related to agricultural land for food and energy production, carbon neutrality of biofuels, soil/land productivity, and long-term sustainability of biofuels production both in the U.S. and internationally.

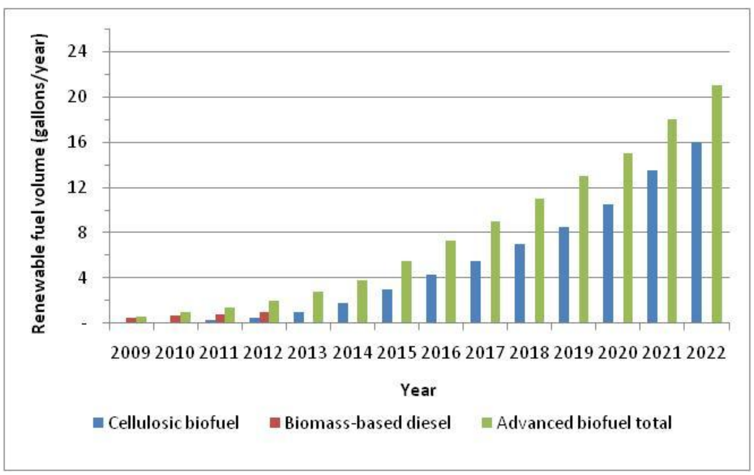
Political Constraints

The political issues for biodiesel fall into two main categories; 1) siting 2) federal renewable energy requirements and 3) perceptions of a food vs. fuel production conflict and ongoing policy debates.

Siting – Siting issues are not typically significant for small and medium scale biodiesel production facilities; they are frequently located in rural areas and the facilities are similar to other agricultural processing facilities, and so they can achieve acceptance with local populations. For very large facilities, the barriers may be more extensive and can include air, water, community and siting issues that affect other large energy and chemical production facilities.

Federal renewable fuels requirements - In 2008, the U.S. Congress passed renewable fuels legislation known as EISA which requires the EPA to set renewable fuels target usage levels (US Environmental Protection Agency, www.epa.gov/lawsregs/laws). Biomass-based diesel requirements, including biodiesel and renewable diesel from waste greases, oils and algae, reach 1 billion gallons per year in 2012. The requirements are explicitly defined up until 2012 and will be determined thereafter through an EPA rulemaking process, but will be no less than 1 billion gallons.

Figure 3.3.1. RFS2 Biofuels Usage Target Levels set by EISA



Source: EPA, http://www.epa.gov/otaq/renewablefuels/420f10007.pdf. Note that biomass-based diesel requirements after 2012 will be determined by separate EPA ruling.

The targets and resulting policy incentives and mandates are known as Renewable Fuel Standards 2 (RFS2). The RFS2 does not dictate how renewable transportation fuels will be used as a fuel. It does dictate how much and when. It is up to the producers of transportation fuel to figure out how to get biofuels into the U.S. transportation fuels system. The EPA dictates what constitutes allowable transportation fuels for use in the U.S.

Potential for conflict between food and fuel production. Recent fluctuations in demand for soybeans and soy oil both domestically and internationally due to increases in demand for both food and renewable fuels resulted in price increases that have been relevant for both biodiesel and corn ethanol production, but it has perhaps affected biodiesel economics more severely. The relative contributions of increased food and fuel demand to the increase in soy prices is a matter of debate and analysis. Nevertheless, the price increases have sparked a debate regarding the potential for sustainable simultaneous growth in food and fuel production using the available agricultural land base that will continue to affect policy and markets in the future. At least temporarily, the relatively slow growth in soy and canola-based biodiesel use has quelled this debate in the U.S. However, as requirements for increased biodiesel production ramp up due to RFS2 requirements, the discussion will continue even if the emphasis on production is on the use of industrial oilseed crops, as there still may be increased utilization of productive agricultural land for industrial oilseed rather than food crops.

3.4 Lignocellulosic Ethanol

SME Information

ANTARES Group, Inc.

3.4.1 TECHNOLOGY DESCRIPTION

There are a number of advanced biofuel technologies being developed that may be available in the 2010 to 2025 time frame. The key difference between these and current commercial technologies is the types of biomass feedstocks used for production. Current technologies typically use grain and oil seed crops, while the advanced technologies use lignocellulosic biomass such as wood, switchgrass and agricultural residues. Although these biomass feedstocks are generally more difficult to convert to biofuels, they are not a human food source and can be much less expensive than grain and seed crops. Lignocellulosic ethanol production is divided into two primary processes: hydrolysis/fermentation and thermochemical/fermentation.

3.4.2 TECHNOLOGY DEVELOPMENT PROGRESS

Federal Renewable Fuel Standards have mandated at least 7.5 billion gallons of renewable biofuels in the nation's fuel supply by 2012. More importantly, the terminology used in the fuel standards creates an important distinction between grain ethanol and lignocellulosic ethanol. As an "advanced biofuel," cellulosic ethanol counts over twice as much as corn ethanol toward this goal, at 2.5 instead of one compliance unit. This combined with the Obama Administration's emphasis on advanced, non-grain biofuels, has meant that much research and development as well as grants and subsidies are being funneled into the technology.

3.4.3 PRODUCTION AND DEPLOYMENT

The production process for lignocellulosic ethanol includes planting and/or harvesting the feedstock in the field, transportation of the baled feedstock from the field to the plant via truck, and conversion to ethanol in the plant. Each of these steps requires the employment of many individuals with specialized job training for each specific task. The construction process begins with upfront engineering, architecture, site permitting and planning, financing, manufacturing, and construction. This process may take up to three years and require hundreds of workers. Upon completion, and during regular operation, a plant will require normal system maintenance to sustain normal operating conditions. There are also downstream jobs involving product distribution and marketing.

The job requirements in the ethanol plants will experience economies of scale. For example, a typical 20 million gallon plant might have a staff of about 35 people (including about 5 for management), while a 100 million gallon plant may only have a staff of about 50 people[25].

[25] Bluffton News Banner, July 2008

Table 3.4.1 Lignocellulosic Ethanol Job Creation for 20 MMGY Facility

Job creation by category	Sugar platform	Thermochemical platform
Annual biomass use (dry tons)	250,000	285,714
FTEs		
Harvesting Jobs	36	43
Plant O&M Jobs	32	32
Construction Jobs	200	200
FTEs per unit of capacity		
Harvesting Jobs	1.8	2.15
Plant O&M Jobs	1.6	1.6
Construction Jobs	10	10

Note: MMGY = million gallons per year

3.4.4 NATURAL RESOURCE HARVESTING

Lignocellulosic ethanol can be produced from a wide variety of biomass feedstocks. These include agricultural plant wastes (corn stover, wheat straw, sugarcane bagasse), plant wastes from industrial processes (sawdust, paper pulp, distiller's grains) and energy crops grown specifically for fuel production, such as switchgrass and miscanthus grass. The level of job creation depends on the feedstock being used.

Table 3.4.2 summarizes job creation for 20 MMGY lignocellulosic ethanol plant that uses wood for both sugar and thermochemical platforms.

Table 3.4.2 Summary of natural resource job creation for lignocellulosic ethanol 20MMGY facility

Job creation by category	Responsibilities/skill set	Sugar platform	Thermo-chemical platforms
Truck driver (53-3032 Heavy and Tractor-Trailer Truck Drivers)	Log and chip van deliveries	10	12
Logging and farm management (11-9013 Farmers, Ranchers, and Other Agricultural Managers)	Supervise multiple logging crews, act as fuel aggregator negotiate with landowners	1	1
Heavy equipment mechanic (49-3042 Mobile Heavy Equipment Mechanics)	Repair and maintain logging equipment	5	6
Logging supervisor (45-1011 First-Line Supervisors of Farming and Forestry)	Supervise logging crew	5	6
Logging equipment operator (45-4022 Logging Equipment Operators)	Operate logging equipment	15	18
	Total fuel procurement	**36**	**43**

3.4.5 MANUFACTURING/BUILDING

There are few equipment manufacturers that sell and service equipment for the ethanol biofuel industry. These equipment manufacturers typically have regional engineering sales representatives. It is unlikely that a new manufacturing or fabrication manufacturing facility would be needed to serve the development of a biomass power industry in the coalition states.

3.4.6 CONSTRUCTION

The construction phase may last up to a period of three years and employ hundreds of people living in the consortium states. Prior to construction, site criteria should be identified and ranked in terms of importance. Proper siting of an ethanol plant is among the most important aspects of project development. Feedstock and energy costs are typically among the highest input costs, but other factors are important in determining production cost estimates, including feedstock type, cost and availability; energy requirements; transportation; water requirements; and size and location.

3.4.7 MARKETING

Development of new biofuels production facilities will require downstream services such as marketing, physical delivery and financial services to customers. There will be a strong demand for cost-effective services to energy partners in the consortium states. The key is to develop a strong network of producers, marketers, blenders and retailers.

3.4.8 MAINTENANCE

Table 3.4.3 Summary of maintenance job creation for a lignocellulosic ethanol 20MMGY facility

Job creation by category	Responsibilities/skill set	Jobs
Management		
Plant manager (11-3051 Industrial Production Managers)	Responsible for all personnel and plant decisions, including hiring, training, fuel contracts, maintenance contracts, equipment purchases, external communications, and scheduling	1
Business manager (11-3031 Financial Managers)	Support the general plant manager, manages personnel records, completes company payroll, manages human resources, and insurance.	1
Fuel procurement manager (11-3061 Purchasing Managers)	Purchasing and parts searching; managing inventory. This is likely a part-time position	1
Accounting/administrative (43-3031 Bookkeeping, Accounting, Auditing)	Receives visitors, answers phone, office administrative duties including bookkeeping assistance	1
	Total management	**4**
Plant and fuel yard staff		
Plant engineer (17-2141 Mechanical Engineers)	General plant engineering, plant performance evaluation, maintenance planning, capital projects planning, reporting, etc.	1
Fuel procurement manager (11-3061 Purchasing Managers)	Manages wood purchases, deliveries, payment issues, and manages wood yard	1
Maintenance supervisor (51-1011 First-Line Supervisors)	5 total shifts to allow for coverage during vacations, etc.	5
Boiler operator (51-8021 Stationary Engineers/ Boiler Operators)	5 total shifts to allow for coverage during vacations, etc.	5
Industrial equipment mechanic (49-9041 Industrial Mechanics)	Water treatment and instrument technicians, other mechanics.	5
Boilerhouse mechanic (47-2011 Boilermakers)	One shift, Monday - Friday, plus overtime as needed	2
Electrician (47-2111 Electricians)	One shift, Monday - Friday, plus overtime as needed	2

Chemist (19-2031 Chemists)	One shift, Monday - Friday	1
Janitorial/maintenance assistant (37-2011 Janitors and Cleaners)	General labor	5
Front-end loader operator (53-7051 Industrial Truck and Tractor Operators)	5 total shifts as a baseline for a front-end loader fed fuel yard. More automated yard using stacker-reclaimers could reduce numbers	5
	Total plant staff	**32**

3.4.9 EDUCATION AND JOB SKILLS TRAINING

Educational requirements and job training needs for deployment of biofuels technologies (including lignocellulosic ethanol, biodiesel, and bio-oils) are similar across this broad technology area because they have similar resource needs, supporting manufacturing/supply industries, and construction processes.

Natural Resource Harvesting Skills and Training

For wood biomass, the bulk of job creation is in the logging and transportation sectors. Each state has its own requirements and/or training/certification programs for logging operators and heavy truck/tractor trailer operators.

The bulk of the jobs for agricultural biomass suppliers will be in the farming and transportation sectors. Education and training opportunities overlap with those for the wood biomass supply chain.

Management of businesses dedicated to the collection, processing and sales/distribution of agricultural biomass or bioenergy crop enterprise development would likely require at least a four-year degree plus significant production and business financial experience.

Agricultural equipment operation and maintenance for bioenergy requires specialized experience and knowledge of agricultural equipment such as tractors, harvesters, chipping/screening and grinding, planting, irrigation systems, herbicide and pesticide application equipment and others.

Manufacturing Skills and Training

Manufacturing major components for a biofuels facility is likely to occur outside the region unless the specific equipment manufacturer is based within one of the Consortium states.

Construction Skills and Training

Construction of a biofuels plant will require anywhere from 150 to 400 jobs at any given time during the construction period for a lignocellulosic ethanol plant. Most of these positions can be filled using the existing construction workforce, and will include skill sets such as heavy equipment operation, electrical, plumbing, pipe-fitting, welding, metal fabrication, concrete pouring/finishing, and truck driving.

Marketing Skills and Training

Marketing functions related to biofuels technology deployment can be grouped into several categories; 1) Technology marketing – or the recruiting of project development and financial capital; 2) Fuel sales – including the negotiation of purchase agreements with refiners, certification of fuels as eligible for market and governmental incentives, and 3) Feedstock procurement – recruiting and management of suppliers and coordination of biomass procurement effort. These will not be major areas of job growth as these functions will be performed in-house or by a small number of consultants with specialized expertise.

Maintenance Skills and Training

Operation and maintenance of the facility is the next largest contributor to employment impacts for a biofuels facility. The skill sets mirror those for agribusiness and forest products manufacturing on the feedstock procurement side, and chemical manufacturing or petroleum and natural gas processing on the plant side.

3.4.10 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Lignocellulosic derived bio-oils and ethanol will directly compete for use of similar biomass feedstocks (woody and herbaceous plant matter). In contrast, biodiesel as currently produced is dependent on a variety oils seeds and waste or byproduct fats and organic oils. All three face different challenges for future deployment and development.

Economic Constraints

Fuel supply reliability and cost are crucial for the economic operation of a lignocellulosic biorefinery. The key factors for biomass feedstock costs are collection costs, distance to source and competition for the resource.

Social Constraints

Forest and agricultural landowner preferences are crucial in determining landowner willingness to provide forest or agricultural biomass to a biomass energy facility. A significant proportion of the forest land ownership in Montana, South Dakota, Wyoming and Utah is part of the National Forest system managed by the United States Forest Service. Due to variability in wood biomass availability from federal land, close coordination and planning between project developers and federal land managers is required when assessing appropriate project scale and fuel supply economics.

Environmental Constraints

The U.S. EPA recently finalized emission limits for both existing and new construction boilers and process heaters[26]. The new proposed standards place particularly strict emissions limits on new projects.

Boilers burning 10 percent or more biomass (and not coal or other solid fuels) are regulated under one of 10 biomass subcategories (five for new units, five for existing units)[27]. Biomass units are now subject to strict limits on particulate matter, carbon monoxide, dioxin/furan, and mercury. This could prevent the implementation of new biomass projects due to high costs for annual emissions testing and additional pollutant control equipment.

The implementation of these rules will likely also require a state-level regulatory rulemaking process. This may affect on-site energy generation options at biofuels facilities.

Political Constraints

The political issues for lignocellulose biofuels fall into two main categories; 1) siting and 2) federal renewable energy requirements.

3.4.11 FUNDING SOURCES

[26] http://www.epa.gov/airquality/combustion

[27] Stoel Rives, LLP, Energy Law Alert: Boiler Hazardous Air Pollutant Emission Rules Released By EPA 2/24/2011

Numerous funding sources are available for biomass research and technology deployment including education and training infrastructure development, such as the U.S. Department of Energy, the U.S. Forest Service, USDA Rural Development and the USDA Forest Service Forest Products Laboratory. Solicitations are highly competitive and often require multiple submissions to succeed in obtaining funding.

3.5. Production of bio-oils from lignocellulose

SME Information

ANTARES Group Inc.

3.5.1 TECHNOLOGY DESCRIPTION

Converting lignocellulosic feedstocks to bio-oils begins with pyrolysis as the primary conversion process. Crude bio-oils can be upgraded from there to clean hydrocarbon fuels via hydrotreatment followed by hydrocracking at a petroleum refinery. In the upgrade process the bio-oil is typically mixed with petroleum products during some stage in the refining process, which enables usage of advanced refinery technologies and economies of scale. In the following discussion, the general method of biomass pyrolysis will first be reviewed, followed by an analysis of the development of bio-oil co-processing in refineries. Pyrolysis production of bio-oil has already been demonstrated as a fuel for industrial steam generation and there are continuing efforts to demonstrate its value as a combined heat and power fuel in select markets.

3.5.1.1 Biomass Fast Pyrolysis

Pyrolysis of biomass for bio-oil production is a rapid thermal process conducted in an environment without oxygen to prevent combustion. By controlling temperatures and reaction times, pyrolysis can be used to convert solid biomass materials into a liquid oil comprised of low molecular weight fragments of the lignin, cellulose and hemicellulose. A variety of biomass feedstocks have been used for pyrolysis, including wood, bark, paper, bagasse, corn fibers and other agricultural residues. The bio-oil yield primarily depends on the processing conditions with the rate of heat transfer and product vapor residence time being the key parameters. Feedstock composition, principally the ash component, can also be a factor but plays a lesser role. Under optimum process conditions liquid yields of 60-80 percent by weight can be realized[28]. The bio-oil product is an oxygenated fuel that consists primarily of carbon, hydrogen and oxygen and small amount of nitrogen and sulfur. The exact composition of the product depends on the feedstock composition and the reaction conditions.

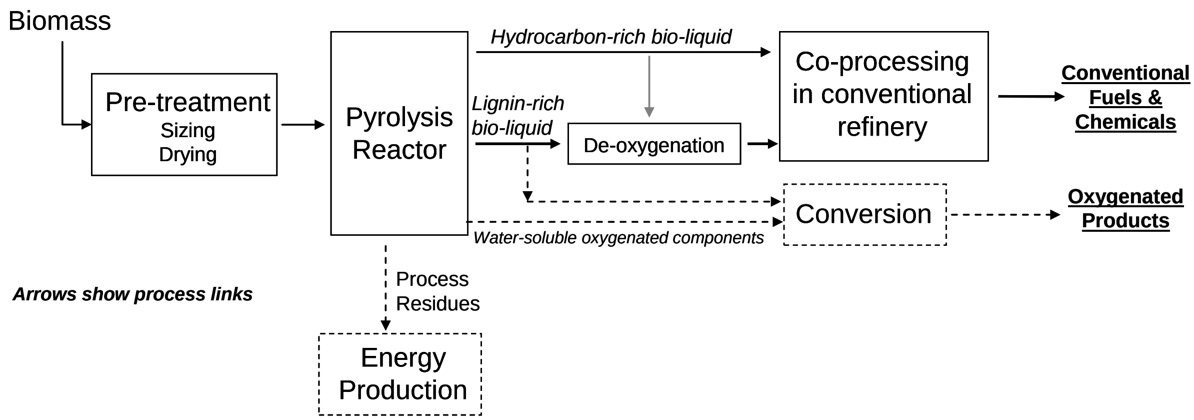
3.5.1.2 Co-processing bio-oil in petroleum refineries

Crude pyrolysis oil can be used directly to produce heat and power. However, upgrading bio-oil to a hydrocarbon fuel via hydrotreatment and hydrocracking can significantly increase the value of the product by producing fungible gasoline and diesel fuels. Fungible commodities have individual units that are capable of mutual substitution. Hydrotreating and hydrocracking are well-developed processes currently used for rejecting nitrogen, oxygen and other heteroatoms from crude petroleum oils. This potential upgrading approach is the focus of efforts to co-refine pyrolysis oils with petroleum.

Figure 3.5.1 shows a potential arrangement for producing pyrolysis oil and co-processing in a petroleum refinery. The biomass feedstock is first sized and dried for pyrolysis. After the reaction, the pyrolysis oil is separated into components - the oil fraction and pyrolytic lignin are co-processed to produce conventional fuels while the water-soluble components are converted into oxygenated products. Process residues are used for energy generation.

[28] Ensyn Group Inc. Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. 2001

Figure 3.5.1 Schematic diagram of the LCGa upgrading/pyrolysis process
Based on figure in Solantausta (2006)



Pyrolysis oil contains a mixture of products including water-soluble oxygenated compounds (derived from the hemicellulose), and insoluble pyrolytic lignin[29]. The pyrolytic lignin is a lower molecular weight version of lignin, which results from the thermal conversion of biomass feedstocks. This component of the pyrolysis oil is lower in oxygen and has a higher energy content than the water soluble portion. It can be separated out via gravity separation or by adding water to the pyrolysis oil to precipitate out the insoluble pyrolytic lignin portion. Hydrotreatment of the pyrolytic lignin requires less hydrogen than the pyrolysis oil because of the lower oxygen content, and can also be done at mild reaction conditions.

3.5.2 PERFORMANCE AND COST ANALYSIS

Bio-oil yield is affected by a number of factors, including feedstock composition, reaction temperature and heat transfer rate, and amount of inert gas in the reaction environment. Furthermore, the mineral matter in biomass acts as a catalyst for cracking and polymerization during pyrolysis, which affects the composition of the bio-oil product[30]. However, despite the importance of many factors in bio-oil production, the heating value of the product is relatively constant (on a dry basis) at about 7,500-8,000 Btu/lb.

3.5.3 ENERGY AND ENVIRONMENTAL BENEFITS

Bio-oil can be used directly as a substitute for petroleum fuel oil in boilers and gas turbines. This makes it potentially a more flexible fuel for cofiring or replacement of fossil fuel in oil fired conversion systems. Alternately, bio-oil can be further treated to produce refined fuels or natural chemicals such as adhesives, resins, polymers and flavorings. The liquid fuel form is generally twice as dense as the wood chips from which it is derived which can save on distribution costs. It is more easily transferred among transportation modes (e.g. tanker truck to rail tanker). Product acidity, viscosity and stability create additional challenges for storage, handling and transport.

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[29] Honeywell UOP. Refining biofeedstock innovations. 2005

[30] Large-Scale Pyrolysis Oil Production: A Technology Assessment and Economic Analysis. Ringer, Putsche and Scahill. 2006

3.5.4 TECHNOLOGY DEVELOPMENT PROGRESS

Until recently there were only two very active companies that developed commercial pyrolysis oil technologies - Ensyn Corporation and DynaMotive Energy Systems Corporation. Each company has a patented pyrolysis technique and a wide range of experience producing bio-oil from different feedstocks. Their products have been tested and used in various applications. By 2005 Ensyn had 7 commercial RTP™ biomass plants, and the largest plant can process 160 green tons of wood per day (Ensyn Corporation n.d.). DynaMotive Energy Systems Corporation reached commercialization in 2004 with a 110 ton/day biomass pyrolysis BioTherm™ plant in Ontario. DynaMotive also completed their first modular 220 ton/day biomass pyrolysis plant in December 2006 (Dynamotive Energy Systems Corporation 2006).

Ensyn and Tokol recently announced that they have formed a partnership to build the world's largest commercial fast pyrolysis plant in High Level, Alberta. The partnership, High North BioResources Limited Partnership, has been formed to build and operate a CHP plant capable of processing 400 bone-dry tonnes of biomass per day into 22.5 million U.S. gallons of pyrolysis oil annually. The facility will also be capable of producing a renewable resin ingredient that can be used in the manufacture of wood panel products. Tolko is a major producer and marketer of lumber, veneer, plywood, oriented strand board, and kraft papers, with manufacturing operations across Western Canada.

One of the main issues with crude bio-oil is the lack of stability over time. According to Ringer, Putsche and Scahill (2006), bio-oil viscosity increases with time at much faster rate than petroleum products. Such highly viscous oil cannot be used as motor fuel. Furthermore, the separation between aqueous and organic phases that accompanies the increase in viscosity is also a problem for usage. Char fines in the bio-oil seem to be a critical factor causing this lack of stability. Advanced technologies that can successfully remove fine particles can increase the shelf life of the product and are under development.

Within the Consortium region, Avello® Bioenergy, Inc. was initially formed in early 2009 by Dr. Robert C. Brown and three mechanical engineering graduate students to commercialize fast pyrolysis technology developed at Iowa State University. The goal is to use advanced separation methods to improve the crude oil product properties while capturing the biochar as a soil amendment. The company is in an early startup phase.

UOP, a specialist in refining process technologies, became active in renewable fuel technology, forming a separate Renewable Energy & Chemicals business in late 2006. Since then, UOP has commercialized the UOP/Eni Ecofining™ process to produce green diesel fuel from biological feedstocks and has also developed process technology to produce renewable jet fuel under a contract from the U.S. Defense Advanced Research Projects Agency (DARPA). One of the key barriers for development of the co-processing technology is that refineries are unwilling to experiment with processing for small quantities of pyrolysis oil that may detrimentally affect their catalysts or end product (UOP 2005). A typical U.S. petroleum refinery generates 150,000 barrels per day (bpd), while the total production of pyrolysis oil is only a small fraction of that amount (UOP 2005).

BTG is a Dutch company that has specialized in Bioenergy process development. BTG has demonstrated a pyrolysis oil production facility on a semi-commercial scale in Malaysia (8 million liter/yr) based on agricultural residues. Through its daughter company BTG BioLiquids (BTG-BTL), a new facility is being developed and implemented with a capacity of 5 million gallons of renewable oil annually in Hengelo, The Netherlands.

3.5.5 POTENTIAL JOB IMPACTS

Table 3.5.1 Summary of job creation for bio-oil production for 5 MMGY facility

Job creation by category	Pyrolysis
Average plant size	5 MMGY
Annual biomass use (dry tons)	313,087
FTEs	
Harvesting Jobs	85
Plant O&M Jobs	31
Construction Jobs	100
FTEs per unit of capacity	
Harvesting Jobs	17.00
Plant O&M Jobs	6.20
Construction Jobs	20.00

Note: MMGY = million gallons per year

Subsequent sections describe in more detail the job impacts of bio-oils production by functions (e.g., natural resource harvesting, manufacturing, construction, etc.).

Natural Resource Harvesting Jobs

A wide variety of resources can be used for bio-oils production, but as with power, wood is the predominant biomass fuel used for bio-oil in its limited current commercial applications. Except for mill residues, the use of biomass as a fuel will create new jobs collecting, processing, and transporting the biomass. Most of the jobs created will require the use of heavy equipment and all that entails. These jobs do require skilled operators, but not advanced education beyond high school.

Table 3.5.2 Job creation for 5 MMGY wood-fueled pyrolysis bio-oil plant

Job creation by category	Responsibilities/skill set	Jobs
Truck driver (53-3032 Heavy and Tractor-Trailer Truck Drivers)	Log and chip van deliveries	24
Logging and farm management (11-9013 Farmers, Ranchers, and Other Agricultural Managers)	Supervise multiple logging crews, act as fuel aggregator negotiate with landowners	1
Heavy equipment mechanic (49-3042 Mobile Heavy Equipment Mechanics)	Repair and maintain logging equipment	12
Logging supervisor (45-1011 First-Line Supervisors of Farming and Forestry)	Supervise logging crew	12
Logging equipment operator (45-4022 Logging Equipment Operators)	Operate logging equipment	36
	Total Jobs	**85**

Manufacturing/Building Jobs

There are a limited number of pyrolysis equipment manufacturers that sell and service equipment. These equipment manufacturers typically have regional engineering sales representatives. It is unlikely that a new manufacturing or fabrication manufacturing facility would be needed in Consortium states. However, parts and materials suppliers for maintenance and operation of field and plant equipment will produce some additional need for skilled mechanics, metal work, electrical/plumbing and retail sales and warehouse positions for parts suppliers.

Construction Jobs

Construction of a biomass pyrolysis plant will require anywhere from 125 to as many as 400 construction workers and management staff depending on the size of the facility.

Marketing Jobs

The direct job impact for developing and attracting biomass project developers and financing is minimal, and would likely be served by existing economic development, industry leadership and private sector developers and members of the financial community. Additional marketing functions include power marketing, administration of government and market-based incentives for renewable energy resource use and feedstock procurement. These are all roles likely to be played by employees or consultants at the plant, and job impacts are included in that section.

Operations and Maintenance Jobs

A biomass pyrolysis facility operates twenty-four hours a day, seven days a week with little interruption except for scheduled maintenance one or two weeks a year and potential unscheduled interruptions on as limited a basis as possible. Plant staff members are needed at the fuel receiving, storage and handling facility, move/maintain piles using front-end loaders and operate and maintain any automated stacking and fuel reclaim equipment and associated conveyance equipment. In the plant itself, boiler operators and maintenance staff are required three shifts a day with additional staff to cover for vacation and medical leave situations, along with general industrial equipment maintenance and janitorial staff. A plant engineer oversees plant operations while operational and maintenance supervisors manage plant crews. A plant technician with some laboratory training and experience is often needed to conduct fuel sampling and moisture testing/quality control. Office labor positions include a plant manager, bookkeeper and fuel procurement manager. A business manager may also be present.

Table 3.5.3 Plant management and operational staff requirements for a pyrolysis facility.

Job creation by category	Responsibilities/skill set	Pyrolysis 5 MMGY
Management		
Plant manager (11-3051 Industrial Production Managers)	Responsible for all personnel and plant decisions, including hiring, training, fuel contracts, maintenance contracts, equipment purchases, external communications, and scheduling	1
Environmental Manager	Responsible for environmental reporting, filings and oversight.	1
Business manager (11-3031 Financial Managers)	Support the general plant manager, manages personnel records, completes company payroll, manages human resources, and insurance.	1
Fuel procurement manager (11-3061 Purchasing Managers)	Purchasing and parts searching; managing inventory. This is likely a part-time position	1
Accounting/administrative (43-3031 Bookkeeping, Accounting, Auditing)	Receives visitors, answers phone, office administrative duties including bookkeeping assistance	1
	Total management	**5**
Plant and fuel yard staff		
Plant engineer (17-2141 Mechanical Engineers)	General plant engineering, plant performance evaluation, maintenance planning, capital projects planning, reporting, etc.	1
Fuel procurement (11-3061 Purchasing Managers)	Manages wood purchases, deliveries, payment issues, and manages wood yard	1
Maintenance supervisor (51-1011 First-Line Supervisors)	5 total shifts to allow for coverage during vacations, etc.	5
Boiler operator (51-8021 Stationary Engineers/ Boiler Operators)	5 total shifts to allow for coverage during vacations, etc.	5
Industrial equipment mechanic (49-9041 Industrial Mechanics)	Water treatment and instrument technicians, other mechanics.	5
Boilerhouse mechanic (47-2011 Boilermakers)	One shift, Monday - Friday, plus overtime as needed	1
Electrician (47-2111 Electricians)	One shift, Monday - Friday, plus overtime as needed	2
Chemist (19-2031 Chemists)	One shift, Monday - Friday	1
Janitorial/maintenance assistant (37-2011 Janitors and Cleaners)	General labor	5
Front-end loader operator (53-7051 Industrial Truck and Tractor Operators)	5 total shifts as a baseline for a front-end loader fed fuel yard. More automated yard using stacker-reclaimers could reduce	5
	Total plant staff	**31**

3.5.6 EDUCATION AND JOB SKILLS TRAINING

Educational requirements and job training needs for deployment of biofuels technologies (including lignocellulosic ethanol, biodiesel, and bio-oils) are similar across this broad technology area because they have similar resource needs, supporting manufacturing/supply industries, and construction processes. Bio-oil production (through pyrolysis processes) is an intermediate chemical product that can be converted to a number of different fuels, lubricants and chemicals. Because bio-oils are only produced on a limited scale and are not widely used for transportation fuels or other chemical intermediaries, we discuss bio-oils only up to the point of production of the bio-oil.

The information in the following subsections describes 1) what kind of jobs would be needed to support technology deployment 2) educational requirements, occupational experience and job training/certification requirements, and 3) existing educational/institutional resources available to support these efforts within the Consortium states.

Natural Resource Harvesting Education and Job Skills

Biofuel technology dictates the type of resource to be utilized and the resulting natural resource harvesting characteristics. Bio-oil production can use wood, agricultural residues or dedicated herbaceous energy crops.

Table 3.5.4 Natural Resource Management Education and Job Skills

Job category	BLS Job description	Minimum training requirements
Technical & managerial		
Logging and farm management	11-9011 Farmers, Ranchers, and Other Agricultural Managers Plan, direct, or coordinate the management or operation of farms, ranches, greenhouses, aquacultural operations, nurseries, timber tracts, or other agricultural establishments. May hire, train, and supervise farm workers or contract for services to carry out the day-to-day activities of the managed operation. May engage in or supervise planting, cultivating, harvesting, and financial and marketing activities.	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Skilled technician		
Heavy equipment mechanic	49-3042 Mobile Heavy Equipment Mechanics, Except Engines Diagnose, adjust, repair, or overhaul mobile mechanical, hydraulic, and pneumatic equipment, such as cranes, bulldozers, graders, and conveyors, used in construction, logging, and surface mining. Illustrative examples: Forklift Mechanic, Bulldozer Mechanic, Construction Equipment Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Logging supervisor	45-1011 First-Line Supervisors of Farming, Fishing, and Forestry Workers Directly supervise and coordinate the activities of agricultural, forestry, aquacultural, and related workers. Illustrative examples: Fish Hatchery Supervisor, Cranberry Bog Supervisor, Corral Boss	Applied associates degree and/or long-term apprenticeship/on-the-job training; Optional private sector/non-profit and/or state training and certification
Logging equipment operator	45-4022 Logging Equipment Operators Drive logging tractor or wheeled vehicle equipped with one or more accessories, such as bulldozer blade, frontal shear, grapple, logging arch, cable winches, hoisting rack, or crane boom, to fell tree; to skid, load, unload, or stack logs; or to pull stumps or clear brush. Illustrative examples: Grapple Skidder Operator, Lumber Stacker Operator, Logging Tractor Operator, Log Hauler	State-specific requirements for heavy equipment operators and optional private sector/non-profit and/or state training and certification
Agricultural equipment operator	45-2091 Agricultural Equipment Operators Drive and control farm equipment to till soil and to plant, cultivate, and harvest crops. May perform tasks, such as crop baling or hay bucking. May operate stationary equipment to perform post-harvest tasks, such as husking, shelling, threshing, and ginning. Illustrative examples: Tractor Operator, Hay Baler, Combine Operator	State-specific requirements for heavy equipment operators; on-the-job training

Job category	BLS Job description	Minimum training requirements
Entry-level skilled or semi-skilled		
Forestry technician	45-4011 Forest and Conservation Workers Under supervision, perform manual labor necessary to develop, maintain, or protect areas such as forests, forested areas, woodlands, wetlands, and rangelands through such activities as raising and transporting seedlings; combating insects, pests, and diseases harmful to plant life; and building structures to control water, erosion, and leaching of soil. Includes forester aides, seedling pullers, and tree planters. Illustrative examples: Wetlands Conservation Laborer, Reforestation Worker, Rangelands Conservation Laborer, Forestry Laborer	On-the-job training
Farm laborer	45-2092 Farm workers and Laborers, Crop, Nursery, and Greenhouse Manually plant, cultivate, and harvest vegetables, fruits, nuts, horticultural specialties, and field crops. Use hand tools, such as shovels, trowels, hoes, tampers, pruning hooks, shears, and knives. Duties may include tilling soil and applying fertilizers; transplanting, weeding, thinning, or pruning crops; applying pesticides; or cleaning, grading, sorting, packing, and loading harvested products. May construct trellises, repair fences and farm buildings, or participate in irrigation activities.	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	State-specific requirements for truck driving

For wood biomass, the bulk of job creation is in the logging and transportation sectors. Each state has its own requirements and/or training/certification programs for logging operators and heavy truck/tractor trailer operators. Heavy equipment operators often require training for use of excavators, skid steers, feller-bunchers, skidders and other mechanized forestry equipment. It is helpful to have a commercial driver's license. Heavy equipment mechanics learn through a combination of vocational/technical training, apprenticeship and on-the job training. Training is offered through community colleges, technical colleges and equipment manufacturers.

Acting as a professional forester does require significant training and work experience. The Society of American Foresters offers the Certified Forester program that, while voluntary, gives credibility to foresters and may be required to be listed as a consulting forester by state forestry agencies. A four-year degree and a proven work track record are required, along with continuing education.

The bulk of the jobs for agricultural biomass suppliers will be in the farming and transportation sectors. Education and training opportunities overlap with those for the wood biomass supply chain. However, opportunities for agronomy, agribusiness management and specialized agricultural equipment and maintenance training are available. Several university-based research, cooperative extension and training programs are gearing up for development of an agricultural bioenergy industry, and these are often separate and unique to the agricultural community. Private/non-profit training programs exist that conduct training and certification for a variety of technician programs.

Management of businesses dedicated to the collection, processing and sales/distribution of agricultural biomass or bioenergy crop enterprise development would likely require at least a four-year degree plus significant production and business financial experience. Some agronomy and agribusiness programs will have a biomass energy component, though it is not likely that many currently offer applied or practical training and educational programs specific to bioenergy. Other degree programs that may offer valuable experience include agricultural and biological engineering or mechanical engineering.

Agricultural equipment operation and maintenance for bioenergy requires specialized experience and knowledge of agricultural equipment such as tractors, harvesters, chipping/screening and grinding, planting, irrigation systems, herbicide and pesticide application equipment and others. These positions such as equipment operators and mechanics require apprenticeship and on-the-job training but increasingly require associates or other certificate programs available through community colleges or private technical training institutions.

Manufacturing Education and Job Skills

Manufacturing major components for a biofuels facility is likely to occur outside the region unless the specific equipment manufacturer is based within one of the Consortium states. It will require specific technical experience that is unlikely to be developed within the Consortium states for the development of individual projects. For this reason, this is unlikely to be a major new source of technical employment. However, manufacture of specific parts and components during the manufacturing/fabrication or following plant construction could be a source of employment. Job types likely to be required include positions in welding, plumbing, electricians, sheet metal fabrication and related positions that can be met with the existing labor force. Job creation from this aspect of biomass technology deployment can be absorbed by the existing workforce.

Construction Education and Job Skills

Construction of a pyrolysis plant will require anywhere from 50 to 150 jobs at any given time during the construction period. Most of these positions can be filled using the existing construction workforce, and will include skill sets such as heavy equipment operation, electrical, plumbing, pipe-fitting, welding, metal fabrication, concrete pouring/finishing, and truck driving. It is likely that a limited number of the positions could include mid-level construction and engineering management positions. Some will be met using contract staff, but some will be hired from the local work force. Individual projects do not need a dedicated workforce strategy for this job sector.

Marketing Education and Job Skills

Marketing job functions related to biofuels technology deployment can be broken down into several broad categories; 1) Technology marketing – or the recruiting of project development and financial capital resources; 2) Fuel sales – including the negotiation of purchase agreements with refiners, certification of fuels as eligible for various market-based and governmental tax and other incentives, and 3) Feedstock procurement – recruiting and management of farmers, forest landowners and forestry professionals and coordination of biomass supply procurement effort. These are not likely to be major areas of job growth as these functions will be performed by management or existing consultants with specialized expertise.

Operations and Maintenance Education and Job Skills

Operation and maintenance of the facility is the next largest contributor to employment impacts for a biofuels facility. The skill sets mirror those for agribusiness and forest products manufacturing on the feedstock procurement side, and chemical manufacturing or petroleum and natural gas processing on the plant side.

Table 3.5.5 Plant Operations and Maintenance

Job categories by skill level	BLS Job description	Minimum training requirements
Technical & managerial		
Plant manager	11-3051 Industrial Production Managers Plan, direct, or coordinate the work activities and resources necessary for manufacturing products in accordance with cost, quality, and quantity specifications. Illustrative examples: Production Control Manager, Plant Manager, Manufacturing Director	4-year accredited degree program in engineering, technical and/or finance/business with >10 years experience relevant production management experience
Plant engineer	17-2141 Mechanical Engineers Perform engineering duties in planning and designing tools, engines, machines, and other mechanically functioning equipment. Oversee installation, operation, maintenance, and repair of equipment such as centralized heat, gas, water, and steam systems. Illustrative examples: Engine Designer, Tool and Die Engineer, Heating and Cooling Systems Engineer, Combustion Engineer	4-year accredited engineering program (mechanical most likely) + minimum 5 to 10 years in relevant production environment
Fuel procurement manager	11-3061 Purchasing Managers Plan, direct, or coordinate the activities of buyers, purchasing officers, and related workers involved in purchasing materials, products, and services. Includes wholesale or retail trade merchandising managers and procurement managers. Illustrative examples: Purchasing Director, Procurement Manager, Contracting Manager	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Business manager	11-3031 Financial Managers Plan, direct, or coordinate accounting, investing, banking, insurance, securities, and other financial activities of a branch, office, or department of an establishment. Illustrative examples: Financial Director, Comptroller	4-year degree in business and finance or equivalent professional experience with experience in manufacturing
Skilled technician		
Maintenance supervisor	51-1011 First-Line Supervisors of Production and Operating Workers Directly supervise and coordinate the activities of production and operating workers, such as inspectors, precision workers, machine setters and operators, assemblers, fabricators, and plant and system operators. Excludes team or work leaders. Illustrative examples: Printing Worker Supervisor, Machinist Supervisor, Assembly Line Supervisor	Applied associates degree and/or long-term apprenticeship/on-the-job training plus5 years or more experience in power production or utility environment
Boiler operator	51-8021 Stationary Engineers and Boiler Operators Operate or maintain stationary engines, boilers, or other mechanical equipment to provide utilities for buildings or industrial processes. Operate equipment, such as steam engines, generators, motors, turbines, and steam boilers. Illustrative examples: Boiler Room Operator, Boiler Engineer, Heating, Ventilation, and Air Conditioning (HVAC) Mechanic Boiler Operator	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state boiler operator certification

Job categories by skill level	**BLS Job description**	**Minimum training requirements**
Industrial equipment mechanic	49-9041 Industrial Machinery Mechanics Repair, install, adjust, or maintain industrial production and processing machinery or refinery and pipeline distribution systems. Excludes "Millwrights" (49-9044), "Mobile Heavy Equipment Mechanics, Except Engines" (49-3042), and "Maintenance Workers, Machinery" (49-9043). Illustrative examples: Hydroelectric Machinery Mechanic, Foundry Equipment Mechanic, Boilerhouse Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Boilerhouse mechanic	47-2011 Boilermakers Construct, assemble, maintain, and repair stationary steam boilers and boiler house auxiliaries. Align structures or plate sections to assemble boiler frame tanks or vats, following blueprints. Work involves use of hand and power tools, plumb bobs, levels, wedges, dogs, or turnbuckles. Assist in testing assembled vessels. Direct cleaning of boilers and boiler furnaces. Inspect and repair boiler fittings, such as safety valves, regulators, automatic-control mechanisms, water columns, and auxiliary machines. Illustrative examples: Boiler Tester, Boiler Mechanic, Boiler Installer	Applied associates degree and/or long-term apprenticeship/on-the-job training
Accounting/administrative	43-3031 Bookkeeping, Accounting, and Auditing Clerks Compute, classify, and record numerical data to keep financial records complete. Perform any combination of routine calculating, posting, and verifying duties to obtain primary financial data for use in maintaining accounting records. May also check the accuracy of figures, calculations, and postings pertaining to business transactions recorded by other workers. Excludes "Payroll and Timekeeping Clerks" (43-3051). Illustrative examples: Mortgage Accounting Clerk, Bookkeeper, Accounts Receivable Clerk	Associates degree in accounting/finance with 2 years or more bookkeeping experience in manufacturing environment
Chemist	19-2031 Chemists Conduct qualitative and quantitative chemical analyses or experiments in laboratories for quality or process control or to develop new products or knowledge. Excludes "Geoscientists, Except Hydrologists and Geographers" (19-2042) and "Biochemists and Biophysicists" (19-1021). Illustrative examples: Industrial Chemist, Research and Development Chemist, Inorganic Chemist, Food Chemist	4-year degree in chemistry plus 2 years lab experience in manufacturing/quality control; 2 year associates degree plus relevant training and professional experience
Entry-level skilled or semi-skilled jobs		
Janitorial/ maintenance assistant	37-2011 Janitors and Cleaners, Except Maids and Housekeeping Cleaners Keep buildings in clean and orderly condition. Perform heavy cleaning duties, such as cleaning floors, shampooing rugs, washing walls and glass, and removing rubbish. Duties may include tending furnace and boiler, performing routine maintenance activities, notifying management of need for repairs, and cleaning snow or debris from sidewalk. Illustrative examples: School Custodian, Window Washer, Industrial Plant Custodian	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state licensing requirements

3.5.7 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Lignocellulosic derived bio-oils will directly compete with lignocellulosic ethanol for use and of similar biomass feedstocks (woody and herbaceous plant matter). In contrast, biodiesel as currently produced is dependent on a variety oils seeds and waste or byproduct fats and organic oils and is not a competitor for feedstocks with pyrolysis bio-oil production. Most of the constraints associated with the future development of pyrolysis-derived bio-oils are technology and product quality related. If those barriers can be overcome the technology has promise as an intermediate processing step to produce a transportable and energy dense crude oil feedstock for further refining as valuable byproducts such as biochar. This technology has a niche but unproven market in the consortium states for CHP applications with valuable byproducts at forest products industry locations.

Economic Constraints

This section discusses several key economic constraints on biofuels implementation; resource availability, capital and operating costs and markets.

Resource availability and cost

Whether reliant primarily on wood or agricultural biomass, fuel supply reliability and cost are crucial for the economic operation of a biofuels production facility. Table 3.56 summarizes total potential biomass supply availability from various sources for the Consortium states. The total resource potential is the first order of magnitude of a resource analysis that needs to be performed for a project site. Overall resource potential gives a preliminary look at the emphasis of a biofuels strategy that would be predominant in each of the Consortium states.

Table 3.5.6 Summary of biomass resource potential in Consortium states

	Total biomass resource potential (dry tons/year)				
State	**Crop residues**	**Forest biomass**	**Primary mill residues**	**Urban wood waste**	**Total**
Iowa	23,590,059	359,001	129,844	29,283	24,108,187
Montana	1,559,984	703,938	1,937,052	13,394	4,214,368
Nebraska	10,930,551	72,440	57,075	13,241	11,073,307
South Dakota	5,140,289	124,999	141,856	6,518	5,413,662
Utah	88,372	30,418	102,442	18,068	239,300
Wyoming	106,224	57,579	254,933	3,654	422,390
Total	**41,415,479**	**1,348,375**	**2,623,202**	**84,157**	**45,471,213**

Source: (Milbrandt, 2005)

For forest biomass, a key factor in the Consortium states is landownership. A significant proportion of the forest land ownership in Montana, South Dakota, Wyoming and Utah is part of the National Forest System. National Forest System land is managed under guidelines set forth in periodic land and resource management plans that set allowable annual cut levels, and the ability for federal agencies to plan and administer timber sales and forest management projects is limited by federal funding allocations that occur on an annual basis. To some extent, these administrative requirements have resulted in a shift of timber harvesting to private land. In Montana, close to 80 percent of the logging residue generation occurs on private land[31]. Due to variability in wood biomass availability from federal land, in many areas of the Consortium, close coordination and planning between project developers and federal land managers is required when assessing appropriate project scale and evaluating fuel supply economics, if federal land is anticipated to be a major source of fuel.

For agricultural biomass, key resource considerations for resource availability include maintenance of soil productivity (often due to soil erosion potential), cropping system, and landowner preference. Not all agricultural producers are interested in collection and sale of residues. These technical and sociological constraints need to be factored into any policy or project-level analysis of a biomass energy facility.

Key supplier groups include generators of urban, agricultural and forest biomass. Urban biomass suppliers include wood recycling companies, waste disposal companies, arborists and landscapers. Agricultural suppliers include producers and aggregators/marketers who work with producers directly to negotiate purchase terms and sometimes own and operate baling and other collection equipment. Forest biomass suppliers include private landowners, government agencies and the contractors that manage their land. The biomass supply system must be designed to continue to operate even if one component of the system breaks down. Therefore, maintaining an adequate network of suppliers to buffer impacts on the biomass supply due to changes in housing markets that affect construction residue availability, fluctuations in annual work by arborists and landscaping companies and fuels reduction and other forestry projects. In addition, fuel receiving, processing, storage and fuel reclaim systems will need to have contingency plans to permit operation in the event that any system component fails.

Biomass feedstock costs are a key determinant of economics. Three key factors contribute to the cost of biomass: collection costs, distance to source and current markets/competition for the resource. There needs to be a sufficient fuel quantity within an economic haul distance to minimize the costs and manage logistics associated with organizing truck deliveries and accommodate current and future demand for biomass feedstocks.

Truck is the predominant means for biomass delivery. Rail delivery terms, pricing and on-site loading and unloading requirements are often cost-prohibitive. An industry standard value used for analysis of biomass transportation costs is $0.12 per loaded ton-mile, with a maximum economical haul distance of 100 miles. Most biomass power facilities seek to acquire the vast majority of their resource from within 50 miles or closer to minimize transportation costs. Transportation costs for wood biomass add from $6 to $12 per ton for 50 and 100 mile distances, respectively.

Existing and proposed competition for biomass is also a key determinant of pricing, first due to the potential for increased transportation distances, and second due to other market and competitive impact such as ability to pay that can affect economic availability for biomass within a given supply shed. This is of particular concern for project financing due to concerns over supply security and cost. There are a variety of ways to mitigate this risk, but a detailed supply competitive analysis is increasingly a requirement for financing and risk mitigation for a biomass power or biofuels project.

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[31] Morgan, Todd. An Assessment of Forest-based Woody Biomass Supply and Use in Montana. Director, Forest Industry Research Bureau of Business and Economic Research at the University of Montana—Missoula. April 29, 2009

Capital and operating costs

Lignocellulosic Bio-Oil (LCBO) production facilities have been built at small scale to produce boiler fuels and liquid smoke (a food flavor additive). Dynamotive has built the first large commercial-scale facility to produce bio-oil. The Guelph Ontario facility uses eight reactors to process 73,000 dry tons of biomass a year – that equates to 9,125 tons per reactor which is equivalent to 1.5 MW output at a simple cycle gas turbine heat rate.

These values show that facility scale has a very significant impact on plant profitability. Feedstock costs are in addition to the non-feedstock production costs; this suggests that additional development is required to make this option cost-competitive with conventional diesel or other biofuels technologies.

Markets

The most near-term application of bio-oil is as a replacement for commercial/industrial heating oil. This has been done for a few facilities in the wood products industry as noted in early sections but that is primarily due to the fact that feedstock is the facilities waste product. However if the Ensyn/Tokol collaboration on their combined heat and power (CHP) project in Canada succeeds this may be the most viable and important market for the process. Conversion of bio-oils produced by pyrolysis to green diesel products through corefining with petroleum has a long way to go achieve commercial viability. Since there is little petroleum refining capacity in most Consortium states the likelihood of bio oil production and transport to distant refineries seems low, but there could be several small niche opportunities. There are several refineries, including ConocoPhillips and ExxonMobil in Billings, Montana, the Montana Refining Company in Great Falls, Montana, Frontier Refining in Cheyenne, Wyoming, Little America Refining in Evansville, Wyoming, Wyoming Refining in Newcastle, Wyoming and Sinclair in Sinclair, Wyoming. Similarly Utah has several refineries in the Salt Lake City area. This is not a comprehensive list in the region. Many of the refineries are smaller independent facilities, and many are not located in close proximity to forest resources and forest products industry, the byproducts of which represent a key opportunity for locating bio-oils facilities.

Social Constraints

Land use and landowner preferences are constraints that affect biofuels technology deployment. These need to be evaluated when considering feasibility of a bioenergy facility at a particular location, and when evaluating policies related to biomass or biofuels development on a state or regional level. However, use of forest products industry residues, a likely target feedstock and production option for pyrolysis oils, will not have significant social constraints. Direct harvest and utilization of trees or agricultural residues for conversion to bio-oils will have more significant issues related to landowner preferences and concerns related to soil erosion and land productivity.

Environmental Constraints

On February 21, 2011, the EPA finalized new emissions limits for both existing and new construction boilers and process heaters. The new proposed standards place particularly strict emissions limits on new boiler projects. This could hamper the implementation of new biomass projects due to high costs for annual emissions testing and pollutant control equipment. The implementation of these rules will likely also require a state-level regulatory rulemaking process. This may affect on-site energy generation options at biofuels facilities. One issue related to bio-oils is its acidity; it has a pH close to 2. As a result, it could result in corrosion of some piping materials and if the pH drops below 2 during storage and transport EPA could consider it a hazardous material (CFR Title 40 261.3). This could impact the methods and economics of bio-oil transportation and handling.

Political Constraints

The political constraints relevant to pyrolysis bio-oil development are not likely to be a major concern if the market is confined to CHP applications for the forest products industry.

Siting

Bio-oil production for CHP at existing forest products industry locations will have few siting issues. Siting at locations other than existing industrial facilities could raise issues within the community related to air and water quality, noise, traffic and overall issues related to sustainability and the environment. For a new facility, each of these issues need to be evaluated thoroughly as part of resource and environmental assessment efforts and a concise communications strategy needs to be developed in advance of public meetings related to the project.

Federal renewable fuels requirements

In 2008 the U.S. Congress passed renewable fuels legislation known as the Energy Independence Security Act (EISA) which requires the EPA to set renewable fuels target usage levels in the transportation sector. The targets and resulting policy incentives and mandates are known as RFS2. The RFS 2 does not dictate how renewable transportation fuels will be used as a fuel. It does dictate how much and when. It is up to the producers of transportation fuel to figure out how to get biofuels into the U.S. transportation fuels system. However, the EPA dictates what constitutes allowable transportation fuels for use in the U.S. There are significant opportunities for advanced biofuels nationwide that are promoted by the new RFS2 requirements, but the extent to which these requirements present opportunities for Consortium states depends on overcoming the technical barriers described in prior sections and the economics of producing and transporting crude bio-oils to refinery locations for processing.

3.5.8 FUNDING SOURCES

Numerous funding sources are available for biomass research and technology deployment including education and training infrastructure development, such as the U.S. DOE, USDA Rural Development, and USDA Forest Service Forest Products Laboratory. Solicitations are highly competitive and often require multiple submissions to succeed in obtaining funding.

The 2008 Farm Bill created the Biomass Crop Assistance Program (BCAP). BCAP has two provisions, one that establishes project areas and payments to encourage landowners to grow biomass, the Project Areas Program, and one that provides matching payments to eligible material owners for the sale and delivery of biomass to bioenergy plants know as CHST. CHST stands for Collection, Harvest, Storage and Transportation. The CHST program was suspended in Spring 2010 when funding and program rules became a concern after paying out $242 million dollars over an approximately 12 month period during the U.S. government fiscal years 2009/2010.

Chapter 4. Biomass

4.1 Background

Biomass represents a renewable energy resource that can create fuel, electricity and products from biological materials such as wood, waste, agricultural products, gas and alcohol fuels. While the Energy Information Administration notes that biomass makes up only about 3 percent of the U.S. energy supply, it has great potential for expansion. Consortium states have millions of acres of forest and agricultural land—the resources necessary to fuel biomass energy production.

As noted by a 2010 Montana Environmental Quality Council (EQC) study, biomass technologies offer a variety of benefits, including production of heat, electricity and transportation fuels. In addition, harvesting biomass can reduce wildfire risks, increase timber supplies, improve forest health, maintain forestry and agriculture jobs and promote forest and agriculture industries.

The EQC study also identified federal activities that support biomass development. A variety of legislation provided incentives for combined heat and power systems and biomass-derived fuels, perhaps the most significant was the federal Biomass Crop Assistance Program (BCAP), which was authorized by the 2008 Farm Bill. BCAP provides dollar-for-dollar financial assistance for biomass conversion facilities to create heat, power, biobased products and biofuels.

A number of states provide financial incentives for biomass development as well. According to the USDOE Database of State Incentives for Renewables and Efficiency, all Consortium states offer a variety of incentives for biomass development. These incentives range from tax credits to grants and loans.

The Edison Electric Institute (EEI) identified five primary biomass technology sectors ripe for development. They include:

1) combined heat and power – a process that extracts the top energy from biomass combustion to produce electricity and diverts the lower grade heat for heating buildings;
2) gasification – a process that uses heat, pressure and steam to convert materials directly into a gas;
3) hydrolysis – a process that uses water to split chemical bonds of substances using feedstocks;
4) biorefinery – the conversion of crops into liquid fuels, chemicals and new bio-based materials; and
5) co-firing – blending biomass with coal to fuel coal-fired power plants.

This report will evaluate the potential job impacts of five emerging biomass technologies that have potential for development in the Consortium states. They include:

1) methane capture/biogas;
2) cofiring;
3) solid fuel combustion;
4) gasification; and
5) pellet fuels.

Methane Capture/Biogas

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4.1.1 TECHNOLOGY DESCRIPTION

Biogas, a gaseous mixture containing 50 to 95 percent methane (CH_4) depending on the source, is generated from a variety of sources and can be captured and used for heat and power generation. Methane is commonly produced through anaerobic digestion of organic material. The major sources of organic material that are covered in this document include landfills, wastewater treatment facilities and livestock production. In the process of anaerobic digestion, bacteria in an oxygen deprived environment break down organic material into a mixture of gases, water, and a solid effluent. According to the most recent data from the EIA, the United States emitted 160.7 billion standard cubic feet (SCF) of methane in 2007[32]. Of this total, landfills accounted for 38.8 billion SCF, solid waste from animals for 14.9 billion SCF, and wastewater management for 6.1 billion SCF[33].

At many of these sources, biogas can be collected and used on site or transported to a central location, where it can be refined to pipeline-quality gas (comparable to natural gas, which is 95% methane) or combusted for electrical generation or heating. Biogas capture at many facilities can be an effective, affordable way to reduce greenhouse gas emissions by reducing methane emissions and displacing fossil fuels for energy production.

4.1.1.1 Landfill Gas

Biogas from anaerobic digestion occurs naturally inside landfills. After being placed in a landfill, waste such as paper, food scraps, and yard trimmings is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These CH_4-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent carbon dioxide (CO_2) and 50 percent CH_4 and some trace gases, by volume. Significant methane production typically begins one or two years after waste disposal in a landfill and continues for 10 to 60 years or longer.

Methane production from landfills is a function of several factors, including:

1) the total amount of waste in landfills, which is related to the total waste landfilled annually;
2) the characteristics of landfills receiving waste (i.e., composition of waste-in-place, size, climate);
3) the amount of CH_4 oxidized in landfills instead of being released into the atmosphere.

The estimated annual quantity of MSW generated was about 249 teragrams (Tg, or million metric tons) in 2008. Of this total, approximately 135 Tg were disposed of in landfills[34]. Between 1980 and 2008, waste

[32] EIA. "Emissions of Greenhouse Gases Report." http://www.eia.doe.gov/oiaf/1605/ggrpt/ Washington, DC: U.S. DOE, 2009.

[33] EPA. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2008." Washington D.C.: EPA, 2009.

[34] EPA. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2008." Washington D.C.: EPA, 2009.

generation and recycling rates both increased. The estimated quantity of CH_4 recovered and combusted from MSW landfills increased as well. In 2008, 5,666 Gigagrams (Gg, or thousand metric tons) of CH_4 was combusted[35]. To harvest this gas, landfill operators drill a series of wells into the landfill, collecting between 60% and 90% of the biogas. The gas is then pumped to a central processing facility where it can be flared, refined, or used for heat or electricity generation. Additionally, biogas can be captured during the composting process, adding additional value to the product.

4.1.1.2 Animal Waste Anaerobic Systems and Water Treatment Plants

The management of livestock manure can produce CH_4. Methane is produced by the anaerobic decomposition of manure. When livestock or poultry manure are stored or treated in systems that promote anaerobic conditions (e.g., as a liquid/slurry in lagoons, ponds, tanks, or pits), the decomposition of materials in the manure tends to produce CH4. When manure is handled as a solid (e.g., in stacks or drylots) or deposited on pasture, range, or paddock lands, it tends to decompose aerobically and produce little or no methane. Over a billion tons of animal manure is generated in the U.S. each year[36].

Ambient temperature, moisture, and manure storage or residency time affect the amount of CH_4 produced because they influence the growth of the bacteria responsible for methane formation. For non-liquid-based manure systems, moist conditions (which are a function of rainfall and humidity) can promote methane production. Manure composition, which varies by animal diet, growth rate, and type, including the animal's digestive system, also affects the amount of CH_4 produced. In general, the greater the energy contents of the feed, the greater the potential for CH_4 emissions. However, some higher energy feeds also are more digestible than lower quality forages, which can result in less overall waste excreted from the animal.

Wastewater treatment processes can produce methane. Wastewater from domestic and industrial sources is treated to remove soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants. Treatment may either occur on site, most commonly through septic systems or package plants, or off site at centralized treatment systems. Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nutrients. In the United States, approximately 20 percent of domestic wastewater is treated in septic systems or other on-site systems, while the rest is collected and treated centrally. There are approximately 1,000 large (treating 5 million gallons/year) municipal and industrial water treatment facilities in the U.S.[37].

Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for maintenance and growth. The resulting biomass (sludge) is removed from the effluent prior to discharge to the receiving stream. Microorganisms can biodegrade soluble organic material in wastewater under aerobic or anaerobic conditions, where the latter condition produces CH_4.

The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of the wastewater are the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Under the same conditions, wastewater with higher COD (or BOD) concentrations will

[35] EIA. "Renewable Energy Trends in Consumption and Electricity 2008." Washington DC: EIA, 2010.
[36] Cantrell, K.B, T. Ducey, K. S. Ro, and P. G. Hunt. "Livestock waste-to-energy generation opportunites." Bioresource Technology, 2008: 99:7941-7953.
[37] EESI. "Biogas Capture and Utilization: An Effective, Affordable Way to Reduce Greenhouse Gas Emissions and Meet Local Energy Needs." http://www.eesi.org/files/biogas_issuebrief_061609.pdf, 2009.

generally yield more CH_4than wastewater with lower COD (or BOD) concentrations. BOD represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes, while COD measures the total material available for chemical oxidation (both biodegradable and non-biodegradable). Because BOD is an aerobic parameter, it is preferable to use COD to estimate CH_4 production.

Water treatment plants and large farms use three types of digester systems to capture biogas depending on the level of solid.

- Covered Lagoon—A covered earthen lagoon passively collects biogas as it is produced from the liquid manure. Most appropriate for waste with a solids content of 0.5-3.0 percent.
- Complete Mix Digester—A heated tank made of reinforced concrete or steel with a gas-tight cover. The contents are mixed periodically with a motor-driven impeller or a pump. Appropriate for slurry manure with a solids content of 3-10 percent.
- Plug Flow Digester—A long, narrow heated tank, generally built below ground level and provided with a gas-tight cover. Only used for dairy manure with a solids content of 11-13 percent. In addition to manure, anaerobic digesters can be utilized to process other varieties of separated biomass.

While composting is also an option for much of this material, anaerobic digestion can serve as an alternative that reduces harmful emissions while capturing energy. Once biogas is captured from digesters, it is pumped into a central processing facility and refined, used for heat or electricity, or flared.

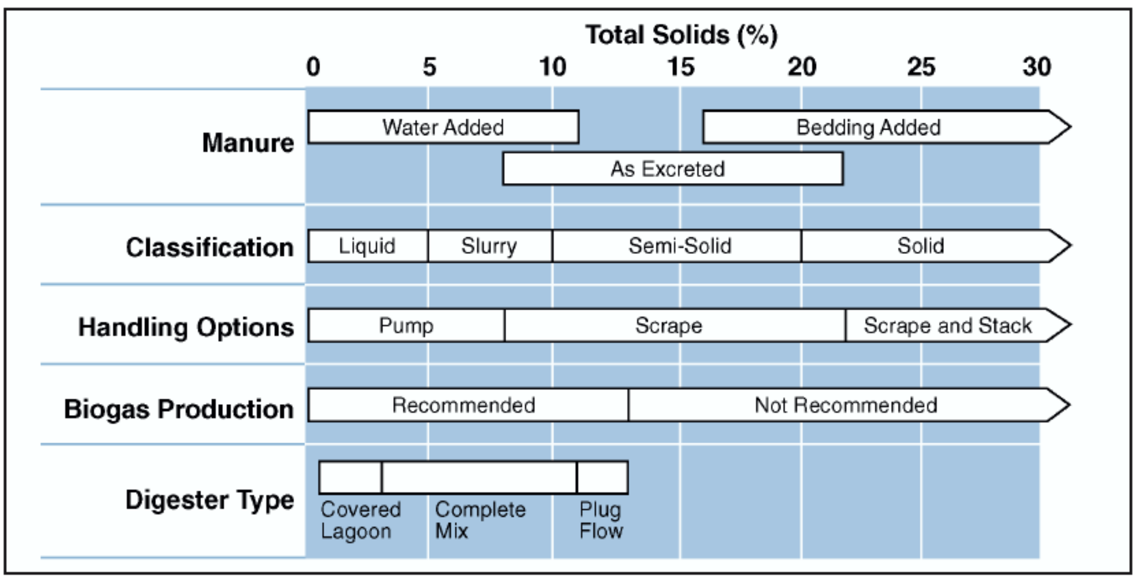

Figure 4.1.1 Methane generation and capture systems for water treatment and animal manure systems based on solids concentration

4.1.2 ENERGY AND ENVIRONMENTAL BENEFITS

Often CH_4 is captured and flared to reduce greenhouse gas emissions, but CH_4 is also a primary constituent of natural gas and an important energy source. As a result, efforts to utilize CH_4 emissions can provide significant energy, economic and environmental benefits. For biorefinery use, the scrubbed gas can be used to fuel engine generator sets and heating or drying operations. For natural gas pipeline injection, further CO_2 removal is performed to make 95%+ methane. The same procedures are used followed by compression to make compressed natural gas (CNG) or liquefied natural gas (LNG) for use in vehicles.

Greenhouse gases other than carbon dioxide (non-CO_2 gases) play an important role in efforts to address global climate change due to their high global warming potentials and the availability of cost-effective emission reduction opportunities. Non-CO_2 greenhouse gases are a significant contributor to climate change. Approximately 30% of the human-induced greenhouse effect can be attributed to the non-CO_2 greenhouse gases[38].

Methane is a greenhouse gas that remains in the atmosphere for approximately 9-15 years. Methane is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide (CO_2) over a 100-year period and is emitted from a variety of natural and human-influenced sources. Human-influenced sources include landfills, natural gas and petroleum systems, agricultural activities, coal mining, stationary and mobile combustion, wastewater treatment, and certain industrial process.

Nitrous oxide (N_2O) is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste. N_2O is a potent greenhouse gas (GHG). The global warming potential (GWP) of N_2O is 310 times that of CO_2 (IPCC, 1995). Major sources of N_2O are: agricultural soils (70.6%); mobile sources (14.7%); industrial sources (7.0%); manure management (4.1%); and stationary sources, including electricity, manufacturing and construction (3.7%)[39].

4.1.3 TECHNOLOGY PRODUCTION AND DEPLOYMENT

Methane collection technologies are mature technologies that can be found across the U.S. Landfill gas capture is the most common. As of December 2008, 485 projects to collect landfill gas existed in 43 states[40]. These projects supply 12 billion kWh of electricity per year and 255 billion cubic feet per day of biogas for commercial and residential space and water heating. According to the EPA Landfill Methane Outreach Program (LMOP), approximately 520 landfills are strong candidates for new landfill gas projects out of a total of 2,300 in the US.

As of February 2009, there were 125 manure digester systems operating in 26 states[41]. The EPA AgSTAR Program identified a total of 151 systems in May 2010[42]. The AgStar Program, which promotes agricultural biogas recovery programs, estimates that these systems could be technically feasible at an additional 6,000 swine and dairy operations nationwide. If all of these operations implement biogas capture, the EPA estimates they could generate up to 6.3 million megawatt-hours (MWh) per year of electricity while reducing annual methane emissions by 27.3 million metric tons of CO_2 equivalent ($MMTCO_2e$).

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[38] EPA. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2008." Washington D.C.: EPA, 2009.
[39] EPA. "U.S. Adipic Acid and Nitric Acid Emissions 1990-2020." Washington DC: EPA, 2001.
[40] EESI. "Biogas Capture and Utilization: An Effective, Affordable Way to Reduce Greenhouse Gas Emissions and Meet Local Energy Needs." <http://www.eesi.org/files/biogas_issuebrief_061609.pdf>, 2009
[41] EPA. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2008." Washington D.C.: EPA, 2009.
[42] EPA. "Anaerobic Digesters Continue to Grow in the U.S. Livestock Market." AgStar Program. http://www.epa.gov/agstar/resources.html, May 2010.

Most large wastewater treatment facilities already use anaerobic digestion as a step in the cleaning process. The biogas released from this process can be captured and used for electricity and heat generation. However, most facilities today simply flare the gas. Out of the roughly 1,000 large facilities currently in operation, only 106 are currently using biogas for heat or power generation[43]. Of these, 76 plants use the biogas for both heat and power, with a combined electric generating capacity of 220.1 MW, while the remaining 30 produce only heat or power.

4.1.4 POTENTIAL JOB IMPACTS

Natural Resource Harvesting Jobs

There is typically no net new job creation unless a facility is served by multiple waste generators, in which case a 2 MW power generation facility that obtains 50 percent of its biomass from off-site would employ one additional truck driver.

Manufacturing Jobs

There would be little or no additional job creation in the manufacturing of technology for methane capture at landfills, wastewater treatment or animal waste collection and treatment within Consortium states.

Construction Jobs

There would be limited short-term (12 to 18 month) construction jobs created associated with the installation of a methane capture facility. The construction impact would differ significantly depending upon scale. The average capacity of landfill gas power systems in the U.S. is approximately three MW based on total generation at the 485 projects in the U.S. identified by EESI and an average system capacity factor of 85 percent. The average size of WWTF power systems is also approximately three MW based on the 76 power-only systems with a total capacity of 220 MW[44]. For power systems in this size range, a construction and installation crew of approximately 6 full-time employees (depending on the project characteristics) for 12 to 18 months[45]. The crew is likely to consist of one mechanical engineer, one supervisor, one or two electricians (47-2111 Electricians) and plumbers and one or two heavy equipment operators.

The average electric capacity for farm-based anaerobic digesters that generate electricity is approximately 300 kW based on 151 total systems in 2010 with power generation of 323 million kilowatt-hours per year[46] and an assumed system capacity factor of 85 percent power generation. Many systems are smaller, in the 100 kilowatt range or less. A farm-based anaerobic digester system would require a small construction crew of approximately two to three persons would be sufficient, including one electrician with specialized expertise in on-site power systems, one plumber and one heavy equipment operator.

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[43] EESI. "Biogas Capture and Utilization: An Effective, Affordable Way to Reduce Greenhouse Gas Emissions and Meet Local Energy Needs." http://www.eesi.org/files/biogas_issuebrief_061609.pdf, 2009.
[44] Ibid.
[45] Goldstein, Rachel. "The Impact of Landfill Gas to Energy Projects on Jobs and Revenue." EPA LMOP Program, http://www.epa.gov/lmop/documents/pdfs/conf/8th/presentation-Goldstein.pdf, January 11, 2005.
[46] EPA. "Anaerobic Digesters Continue to Grow in the U.S. Livestock Market." AgStar Program. http://www.epa.gov/agstar/resources.html, May 2010.

Marketing Jobs

There are no new marketing positions that are likely to result from installation of methane capture at landfills, wastewater treatment facilities or livestock operations. For smaller landfill or animal waste operations, the U.S. EPA Landfill Methane Outreach Program (LMOP) can provide technical assistance related to power sales and other technical and economic barriers.

Maintenance Jobs

There is no net job creation with the possible exception of one on-site technician or maintenance staff member and, in the event that wastes are aggregated and trucked to a central location, potential addition of one or more truck driver (53-3032 Heavy and Tractor-Trailer Truck Drivers).

4.1.5 EDUCATION AND JOB SKILLS TRAINING

There are no educational or training requirements required for the manufacturing, construction, operation and maintenance of anaerobic digestion and methane capture that are not currently available in the workforce or easily available through technical colleges, vocational training or a combination thereof. The types of positions that will be required include electricians, truck drivers, small engine/generator repair and operations and plumbing and wastewater treatment personnel that are already present at most site locations. For farm-based anaerobic digesters, farm laborers typically possess the mechanical and plumbing skills required to operate and maintain engine-generator sets and wastewater treatment systems.

4.1.6 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

A methane capture and utilization project opportunity must pass some basic screening criteria based on facility size to have the potential to be technically and economically viable. A good candidate for landfill gas capture will be a landfill which contains a minimum of one million tons of waste, be currently accepting waste or have been closed for five years or less. Because landfill waste continues to emit methane for roughly 100 years, this should provide a reliable, long-term energy solution for local communities while avoiding harmful greenhouse gas emissions. The minimum size of a WWTF to be a potentially viable candidate for anaerobic digestion and biogas recovery is 5 million gallons per day (MGD) of waste influent flow rate; for each 4.5 MGD processed by a WWTF with anaerobic digestion, the biogas generated can support up to 100 kilowatts of electric generation capacity[47]. Farm-based anaerobic digestion systems are often significantly smaller than wastewater treatment or landfill applications. A facility generally needs at least 300 cows or 2,000 swine to break even on a methane capture and recovery project[48]. However, farm-based projects are often pursued with the intent to control odors and reduce the potential for water quality reduction in the area surrounding the facility, so the economic decision-making criteria may be different than larger landfill or WWTF projects. There is also some potential for aggregation of wastes from feedlots, poultry litter or dairy operations that may alleviate the size criterion.

Once the facility size hurdle is overcome, additional economic, environmental and other constraints may be encountered. These are described in the subsections that follow.

[47] EPA. "Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities." EPA Combined Heat and Power Partnership, http://www.epa.gov/chp/documents/wwtf_opportunities.pdf, 2007.
[48] EESI. "Biogas Capture and Utilization: An Effective, Affordable Way to Reduce Greenhouse Gas Emissions and Meet Local Energy Needs." http://www.eesi.org/files/biogas_issuebrief_061609.pdf, 2009.

Economic Constraints

Once a site with adequate biogas resources has been identified, biogas collection and recovery projects face a number of barriers. Among the most important of these are:

- Financing the up-front capital costs
- Barriers to interconnection with the electricity and gas grids from utilities and regulators
- Lack of a guaranteed price for heat and power
- State and local regulatory barriers

While financing the initial capital costs to install a landfill gas project are a barrier for development, the EPA estimates that the benefits of biogas capture for onsite use can outweigh the costs by as much as a factor of 10[49]. This makes biogas capture appealing not just from an emissions standpoint, but also from an economic one. Biogas from landfills can generate electricity at a cost as low as $0.055 per kWh[50]. The attractiveness of landfill biogas capture and use has led to successful growth in the industry and a major drop in methane emissions from landfills over 1990 levels.

Depending on the type of system installed, conventional animal waste storage facilities cost from $60 to over $400 per animal unit (one animal unit is equivalent to 1,000 pounds live animal weight, approximately the weight of one head of cattle). Digester costs can range from $200 to $550 per animal units. However, digesters also generate revenue from methane and reduce costs for fertilizer. Annual revenue from electricity sales and cost offsets range from $32 to $78 per animal unit, while fertilizer purchases avoided by using digested solids can generate from $41 to $60 per animal unit. This means that the use of anaerobic digesters is often equal to or better than simple storage from an economic standpoint. Although there is a size constraint (a facility generally needs at least 300 cows or 2,000 swine to break even), investment in anaerobic digestion can often have a payback period of 3 to 7 years[51].

While the cost of biogas capture from wastewater can vary widely depending on the technology used, the quantity of wastewater treated, and the current methane capture equipment in place, many plants have shown an ability to offset capital costs completely through income and savings from the generation of heat and electricity. According to the EPA, it is possible to produce electricity for as little as $0.038 per kWh assuming a 20-year capital repayment horizon.

Grid interconnection to an electricity provider, state and/or local regulations related to interconnection and power sales and the ability to negotiate a suitable off-take agreement for power from a small power producer are major barriers that can affect the deployment of methane capture and power generation.

Social Constraints

Collection and use of biogas is generally well-received by the public in large part because it is perceived as a beneficial use of a waste product and, in the case of livestock production, implementation can result in reduced facility odors. The economics must be clear-cut for a livestock producer to want to participate however, and operation requires significant buy-in by the management and staff to ensure that the facility can maintain and operate the anaerobic digester.

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[49] EPA. "Global Mitigation of Non-CO_2 Greenhouse Gases." EPA Office of Atmospheric Programs, http://www.epa.gov/climatechange/economics/downloads/GM_SectionIII_Waste.pdf, 2006.

[50] Kerr, Tom. "Landfill Gas-to-Energy Economics." EPA Climate Protection Division, http://apps3.eere.energy.gov/greenpower/conference/5gpmc00/tkerr.pdf.

[51] EESI. "Biogas Capture and Utilization: An Effective, Affordable Way to Reduce Greenhouse Gas Emissions and Meet Local Energy Needs." http://www.eesi.org/files/biogas_issuebrief_061609.pdf, 2009.

Environmental Constraints

If all of the landfill gas, agriculture projects and water treatment plants currently deemed feasible by the EPA were put in place, the U.S. could reduce its methane emissions by up to 102.3 $MMTCO_2e$. Anaerobic digestion virtually eliminates the release of harmful pollutants, including fecal coliform bacteria, into the water supply from feedlot operations. Capturing biogas from landfills or manure can significantly improve air quality in the surrounding community by reducing odor.

Transportation Constraints

There is no significant transportation constraint associated with deployment of methane capture technology.

Political Constraints

There are no political constraints associated with biogas utilization that pose barriers to technology deployment. However, the U.S. EPA recently finalized emission limits for both existing and new construction boilers and process heaters[52]. The new proposed standards place particularly strict emissions limits on new projects.

Boilers burning 10 percent or more biomass (and not coal or other solid fuels) are regulated under one of 10 biomass subcategories (five for new units, five for existing units)[53]. Biomass units are now subject to strict limits on particulate matter, carbon monoxide, dioxin/furan, and mercury.

Additionally, state and federal policies and regulations related to management of confined animal feeding operations (CAFOs) related to water quality and odor management can be an incentive for implementation of anaerobic digestion technology at livestock operations.

4.1.7 FUNDING SOURCES

Numerous funding sources are available for biomass research and technology deployment including education and training infrastructure development, such as the U.S. DOE, USDA Rural Development, and USDA Forest Service Forest Products Laboratory. Solicitations are highly competitive and often require multiple submissions to succeed in obtaining funding. The USDA Biomass Crop Assistance Program provides assistance to producers of biomass fuel for energy use.

[52] http://www.epa.gov/airquality/combustion
[53] Stoel Rives, LLP, Energy Law Alert: Boiler Hazardous Air Pollutant Emission Rules Released By EPA 2/24/2011

4.2 Co-firing

SME Information

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4.2.1 TECHNOLOGY DESCRIPTION

Co-firing is the simultaneous combustion of different fuels in the same boiler. Many coal- and oil-fired boilers at power stations have been retrofitted to permit multi-fuel flexibility. Biomass is a well-suited resource for co-firing with coal as an acid rain and greenhouse gas emission control strategy. Co-firing utilizing biomass has been successfully demonstrated in the full range of coal boiler types, including pulverized coal boilers, cyclones, stokers, and bubbling and circulating fluidized beds. The system described here is best suited to pulverized coal-fired boilers which represent the majority of the current fleet of utility boilers in the U.S.; however, there are also significant opportunities for co-firing with biomass in cyclones. Co-firing biomass in an existing pulverized coal boiler will generally require modifications or additions to fuel handling, storage and feed systems. An automated system capable of processing and storing sufficient biomass fuel in one shift for 24-hour use is needed to allow continuous co-firing while minimizing equipment operator expenses.

Typical biomass fuel receiving equipment will include truck scales and hydraulic tippers, however tippers are not required if deliveries are made with self-unloading vans. Biomass supplies may be unloaded and stored in bulk in the coal yard, then reclaimed for processing and combustion. New automated reclaiming equipment may be added, or existing front-end loaders may be detailed for use to manage and reclaim biomass fuel. Conveyors will be added to transport fuel to the processing facility, with magnetic separators to remove spikes, nails, and tramp metal from the feedstock. Since biomass is the “flexible” fuel at these facilities, a 5-day stockpile should be sufficient and will allow avoidance of problems with long-term storage of biomass such as mold development, decomposition, moisture pick-up, freezing, etc.

Fuel processing requirements are dictated by the expected fuel sources, with incoming feedstocks varying from green whole chips up to 5 cm (2 inches) in size (or even larger tree trimmings) to fine dry sawdust requiring no additional processing. In addition to woody residues and crops, biomass fuel sources could include alfalfa stems, switchgrass, rice hulls, rice straw, stone fruit pits, and other materials. For suspension firing in pulverized coal boilers, biomass fuel feedstocks should be reduced to 6.4 mm (0.25 inches) or smaller particle size, with moisture levels under 25% MCW (moisture content, wet basis) when firing in the range of 5% to 15% biomass on a heat input basis. Demonstrations have been conducted with feedstock moisture levels as high as 45%. New pretreatment processes (e.g. torrefaction and fast pyrolysis) may produce ready to fire fuels that will allow high percentage cofiring in the future but these technologies are in very limited or developmental use for now and are not covered in this report.

Co-firing is a fuel-substitution option for existing capacity, and is not a capacity expansion option. Equipment such as hoggers, hammer mills, spike rolls, and disc screens are required to properly size the feedstock. Other boiler types (cyclones, stokers, and fluidized beds) are better suited to handle larger fuel particle sizes. There must also be a biomass buffer storage and a fuel feed and metering system. Biomass is pneumatically conveyed from the storage silo and introduced into the boiler through existing injection ports, typically using the lowest level of burners. Introducing the biomass at or near the lowest level of burners helps to ensure complete burnout in the region of upper-level burners and the increased residence time in the boiler.

The system described here is designed for moderate percentage co-firing (greater than 5% on a heat input basis) and, for that reason, requires a separate feed system for biomass which acts in parallel with the coal feed systems. Existing coal or oil (start up) injection ports are modified with new burners to allow dedicated biomass injection during the co-firing mode of operation. For low percentage co-firing (less than 2% on a heat input basis), it is possible to use existing coal pulverizers to process the biomass if spare pulverizer capacity exists. If existing pulverizers are used, the biomass is processed and conveyed to the boiler with the coal supply and introduced into the boiler through the same injection ports as the coal (i.e., the biomass and coal are blended prior to injection into the boiler). Using existing pulverizers could reduce capital costs by allowing the avoided purchase of dedicated biomass processing and handling equipment, but the level of co-firing on a percentage basis will be limited by pulverizer performance, biomass type, and excess pulverizer capacity. The suitability of existing pulverizers to process biomass with coal will vary depending on pulverizer type and biomass type. Atritta mills (pulverizers which operate much like fine hammermills) have far more capability to process biomass fuels.

Drying equipment has been evaluated by many designers, and recommended by some. Dryers are not included here for three reasons: (1) the benefit-to-cost ratio is almost always low, (2) the industrial fuel sources that supply most co-firing operations provide a moderately dry fuel (between 28% and 6% MCW), and (3) biomass is only a modest percentage of the fuel fired.

4.2.2 ENERGY AND ENVIRONMENTAL BENEFITS

The current fleet of coal-fired electricity generators is producing over 50 percent of the nation's power supply. With the 1990 Clean Air Act Amendments (CAAA) requiring reductions in emissions of acid rain precursors such as sulfur dioxide (SO2) and nitrogen oxides (NOx) from utility power plants, co-firing biomass at existing coal-fired power plants is viewed as one of many possible compliance options. In addition, co-firing using biomass fuels from sustainably grown, dedicated energy crops is viewed as a possible option for reducing net emissions of CO_2. Coupled with the need of the industrial sector to dispose of biomass residues (generally clean wood byproducts or remnants), biomass co-firing offers the potential for solving multiple problems at potentially modest investment costs.

Unlike coal, most forms of biomass contain very small amounts of sulfur. Hence, substitution of biomass for coal can result in significant reductions in SO2 emissions. The amount of SO2 reduction depends on the percent of heat obtained from biomass and the sulfur content of the coal. Co- firing biomass with coal can allow power producers to earn SO2 emission allowances under Section 404(f) of the federal Clean Air Act Amendments of 1990 (CAAA). An allowance is earned for each ton of SO2 emissions reduced (1 allowance = 1 ton = 0.91 tonnes; 1 tonne = 1 metric ton). This section of the CAAA includes provisions for earning credits from SO2 emissions avoided through energy conservation measures (i.e., demand side management or DSM) and renewable energy. In addition to any allowances which the producer earned by not emitting SO2, two allowances can be given to the utility from an allowance reserve for every gigawatt-hour (106 kWh) produced by biomass in a co-fired boiler. These allowances may then be sold or traded to others who need them to remain in compliance with the CAAA. The value of an SO2 allowance has ranged from $135 in 1993 to a current value of about $80.

As with fossil fuels, a result of burning biomass is the emission of CO2. However, biomass *absorbs* about the same amount of carbon dioxide during its growing cycle as is emitted from a boiler when it is burned.

Hence, when biomass production is undertaken on a sustainable basis, net CO2 emissions on a complete fuel cycle basis (from growth to combustion) are considered to be nearly zero. Therefore, biomass co-firing may be one of the most practical strategic options for complying with restrictions on generation of greenhouse gases. Fossil CO2 reductions are currently being pursued voluntarily by utilities in the U.S. through the federal government's Climate Challenge program. These utilities may be able to receive early credit for their fossil CO2 emission reductions for future use in the event that legislation is passed which creates market value for CO2 reductions.

In addition to these emissions reductions and being a base load renewable power option, biomass co-firing has other possible benefits. The use of biomass to produce electricity in a dedicated feedstock supply system, where biomass is grown specifically for the purpose of providing a fuel feedstock, will provide new revenue sources to the U.S. agriculture industry by providing a new market for farm production. These benefits will result in substantial positive economic effects on rural America. Using urban wood residues as a fuel reduces landfill material and subsequently extends landfill life. For industries served by the utilities, rising costs of tipping fees, restrictions on landfill use, and potential liabilities associated with landfill use represent opportunities for power companies to assist industrial customers while obtaining low-cost biomass residues for use as alternative fuels. These residues can be mixed with more expensive biomass from energy crops to reduce the overall cost of biomass feedstocks. Finally, firing biomass in boilers with pollution control can reduce burning of wood residues in uncontrolled furnaces or in open fields, and hence provides another means of reducing air emissions.

Potential negative impacts associated with co-firing biomass fuels include: (1) the possibility for increased slagging and fouling on boiler surfaces when firing high-alkali herbaceous biomass fuels such as switchgrass, and (2) the potential for reduced fly ash marketability due to concerns that commingled biomass and coal ash will not meet existing ASTM fly ash standards for concrete admixtures, a valuable fly ash market. These two issues are the subject of continued research and investigation. Two factors indicate that biomass co-firing (using sources of biomass such as energy crops or residues from untreated wood) will have a negligible effect on the physical properties of coal fly ash. First, the mass of biomass relative to coal is small for co-firing applications, since biomass provides 15% or less of the heat input to the boiler. Second, combustion of most forms of biomass results in only half as much ash when compared to coal. Despite these factors, significant efforts will be required to ensure that commingled biomass and coal ash will meet ASTM standards for concrete admixture applications. In the immediate future (three to five years), the ASTM standards that preclude the use of non-coal ash will probably remain unchanged.

The power plants characterized here are pulverized coal plants that co-fire from 10% to 15% biomass on a heat input basis. The co-firing rate is not projected to exceed 15% due to biomass resource limitations and requirements to maintain unit efficiency. System capital and operating costs are assumed to be representative of plants which receive biomass via self-unloading vans and can utilize existing front- end loaders for receiving and pile management. The facilities are assumed to be located in a region where medium- to high-sulfur coal (0.8% by weight and greater) is used as a utility boiler fuel and where residue fuels may be plentiful. Areas with these characteristics include portions of the Northeast, Southeast, mid-Atlantic, and Midwest regions.

Emissions of gaseous effluents other than CO2 and SO2 are highly dependent on boiler operating conditions and design. However, NOx emissions for a co-fired boiler could be lower than those for a 100% coal-fired boiler due to the lower nitrogen content of biomass and the lower flame temperatures associated with combustion of high-moisture-content biomass feedstocks. In addition, reburn technologies using biomass could provide additional NOx reductions. Reburning involves a fuel-lean primary combustion stage, followed by the downstream injection of an additional fuel (natural gas, or micronized coal or biomass) in a fuel-rich secondary zone (the reburn zone) to reduce the NOx formed in the primary stage. Additional air is injected downstream of the fuel-rich zone to complete combustion. Further research and development in the area of NOx reduction, for both reburn and conventional co-firing arrangements, is required to better define the potential NOx reduction benefits associated with biomass co- firing. If the NOx reduction benefits using biomass are proven to be feasible for reducing the NOx emissions control costs at existing cyclone and pulverized coal boilers, the resulting cost savings could be several times the fuel savings for co-firing. The dollar value of NOx reduction will be site-specific, depending on the cost of the alternative NOx control action.

4.2.3 TECHNOLOGY DEVELOPMENT PROGRESS

Biomass cofiring at large, industrial-sized coal power plants is attractive in the United States and especially Europe, as it is the most economical way to make use of biomass resources and accrue GHG reduction benefits. Existing coal facilities can very easily accommodate up to 10% of their energy load using biomass with only a few changes to the existing infrastructure. Cofiring percentages greater than 10% will require more in depth alterations to the fuel handling system, burners, and emissions controls[54]. There are also several facilities in Europe that have been specifically designed to co-fire a variety of biomass fuels at levels greater than 50%.

Biomass co-firing is a retrofit application, primarily for coal-fired power plants. Biomass co-firing is applicable to most coal-fired boilers used for power generation. Retrofits to co-fire at 5% (by heat) or more for coal-fired cyclones, stokers, and fluidized bed boilers are potentially simpler and less expensive than for pulverized coal. However, pulverized coal boilers are the most widely used steam generating system for coal-fired power generation in the U.S., and they represent the majority of plants affected by CAAA provisions for reducing the emissions of SO2 and NOx from electric generating units.

Biomass co-firing with coal is currently practiced at a handful of utility- scale boilers (Northern States Power, Tacoma Public Utilities, New York State Electric and Gas, Tennessee Valley Authority). Co-firing has also been successfully demonstrated by GPU Genco, Madison Gas & Electric, Southern Company, and several others. Retrofits require commercially available fuel handling and boiler equipment. Optimized equipment for efficiently processing some biomass feedstocks (such as switchgrass and willow energy crops) to a size suitable for combustion in a pulverized coal boiler will require further development and demonstration. Engineering and design issues are well understood for most applications, but the optimum design for a given power plant will be site-specific and could vary depending on a number of key factors, including site layout, boiler type, biomass type and moisture content, level of co-firing, type of existing pulverizer, and pulverizer excess capacity. In general, capital costs for blended feed systems are low (about $150/biomass kW) and costs for separate feed systems are higher (about $600/biomass kW). The design shown in this technology characterization is a separate feed system. Separate feeding is needed for biomass heat contributions greater than 2% to 5% in a pulverized- coal boiler. At low co-firing levels in a pulverized-coal unit (<2%), or at mid-level (5% to 10%) in a cyclone, blended feed can be used especially if the biomass is dry and fine.

Two other issues needing additional research and development efforts are: (1) slagging and fouling on boiler surfaces caused by firing high alkali herbaceous biomass feedstocks such as switchgrass, and (2) the potential for reduced fly ash marketability due to concerns that commingled biomass and coal ash will not meet ASTM fly ash standards for concrete admixtures. Finally, due to high transportation costs, sufficiently inexpensive biomass residues and energy crops (relative to local coal prices) must exist within an 80 to 120 km (50 to 75 mile) radius to economically justify a co-firing operation. Improved resource acquisition methods, new pretreatment methods as well as pelletization and energy crop development are needed to foster the widespread adoption of biomass co-firing.

4.2.4 POTENTIAL JOB IMPACTS

Biomass cofiring will require 0.38 – 2.18 jobs per MW of installed capacity to grow and prepare the biomass fuel sources, transport it to the power plant facility, and receive and process the biomass once it reaches the facility. Comparatively, coal facilities require approximately 0.47 – 0.78 employees per MW

[54] IEA Bioenergy Annual Report 2007, www.ieabioenergy.com

of installed capacity for coal mining, transportation, and on-site fuel preparation[55]. The switch from an all-coal facility to a co-fired facility would result in (on average) job creation equivalent to 0.65 employees per MW of installed capacity. It was assumed that no jobs would be created with regards to maintenance and upkeep of the co-firing facility since the workers at the original coal facility could continue to provide these services with only minimal changes to the operational procedures.

The industries affected and overall employment impacts associated with biomass power development are discussed in more detail for the different stages of technology deployment in the following subsections.

Natural Resource Harvesting Jobs

The three broad categories of biomass resources that can be used for solid fuel boiler systems include wood biomass, agricultural crop residues and dedicated bioenergy crops.

The bulk of existing systems utilize wood biomass fuels from mill and forest residues. The bulk of sawmill residuals are currently utilized and will make up a small but steady proportion of the biomass supply for any new wood biomass power generation facility, generally from the redirection of supplies from an existing purchaser to the biomass power plant if the power facility can offer competitive pricing and purchase terms. This will not cause any net employment impacts. However, harvest of forest residues and increasing harvest of forest biomass from forest stand improvement activities will create a significant net employment gain both from positions in the field and at the power plant. Specific job descriptions for employment are described in the companion report to this that provides additional information on job skill requirements, education and training needs and current educational resources in Consortium states.

Harvesting forest residues that are generated as a byproduct of existing commercial timber harvesting operations (e.g., tree tops and branches) usually involves adding an industrial chipper, tractor trailer units and chip vans to an existing harvesting crew. This is the case for a whole-tree harvesting crew that fells trees and skids them whole to a landing site for further processing and transportation to the end user. This is typically the case for larger mechanized harvesting operations that increasingly make up a larger proportion of timber harvest volumes for large industrial users, especially for harvest of softwoods. Some harvesters cut and top the trees where they are cut in the forest, which makes collection of residuals more complicated. An additional grapple skidder can go back into the stand and collect this material, or specialized bundling or baling equipment can be used to collect and compress the residues for hauling to the landing, where they are then stored or loaded onto a truck. On average, approximately 60 percent of the forest residues can be removed from a site; the remainder is uncollectable because it is either part of the stump or is left on site due to collection inefficiencies or other site-specific conditions.

Additional sources of forest biomass include harvest of noncommercial trees, which include trees that are of noncommercial species, or trees that have defects or poor form, in conjunction with forest stand improvement or land clearing for development. This is often one of the least cost sources of biomass, as landowners and developers are often paying to have the material removed. Often, noncommercial trees are harvested in conjunction with commercial timber harvest and are piled and left on site or burned. In areas around existing biomass power facilities there is a market for at least a portion of this material. The job creation potential for these sources of material comes from increased heavy equipment operators (such as skidders, chippers, tractor-trailer drivers). However, some additional need for tree fallers or feller-buncher operators may be needed, as the new demand for biomass provides a market incentive for landowners to do forest stand improvement that was economically prohibitive without the presence of a market for low-grade or noncommercial timber.

[55] Sing, Virinder and Jeffrey Fehrs. The Work that Goes into Renewable Energy. November 2001. Renewable Energy Policy Project, Washington, D.C. www.repp.org.

Collection of agricultural residues such as corn stover and wheat straw typically entail baling the residual material and transporting it to a roadside location or another centralized location for storage and later use. The baling, storage and transport business is analogous to production of hay and silage crops.

Dedicated biomass energy crop systems within Consortium states would likely focus on dryland herbaceous energy crop systems due to water constraints. These can include native perennial grasses, switchgrass, miscanthus and sorghum varieties that are adapted to the climate and soils conditions in the Consortium states. Biomass energy crop species selection is a site-specific process; universities and commercial entities have long-term plant breeding and selection trials underway to help optimize crop production and yield in different areas of the country. More information on specific bioenergy crops that are potentially viable in Consortium states will be provided for the final report.

Dedicated tree crop cultivation in most of the Consortium states is likely to have limited applicability due to water consumption requirements for fast-growing woody trees that makes irrigation needed and can limit the economic opportunity for technology deployment.

Manufacturing/Building Jobs

There could be a small number of industrial equipment retail sales and warehouse positions for parts suppliers that could be created due to additional parts requirements for cofiring related processes at the plant.

Construction Jobs

Construction of equipment related to the cofiring project is likely to use specialized employees from utility internal engineering and maintenance staff augmented by consulting engineering or energy performance contractor staff resources. With the exception of some short-term plumbing, electrical, sheet metal and potentially construction labor, there will be a minimal new job impact from the construction phase of the project.

Marketing Jobs

The direct job impact for developing and attracting biomass power project developers and financing is minimal, and would be served by existing utility or electric power provider personnel.

Operations and Maintenance Jobs

There will be minimal new employment associated with biomass cofiring at the plant because the cofiring operations will, with limited exceptions, use existing facility personnel to perform fuel supply and plant maintenance functions.

4.3 Biomass Solid Fuel Combustion

SME Information

ANTARES Group Inc.

4.3.1 TECHNOLOGY DESCRIPTION

Direct combustion of solid fuel biomass in a boiler to generate steam for process and power use remains the most common way of converting biomass into a usable energy. Stoker grate and fluidized bed boilers combined with steam turbines represent the two most widely used biomass power and cogeneration technologies. They are both well-established mature technologies that continue to evolve and improve. Stoker grate boiler systems were the first modern boiler systems and originally designed for coal. In the 1940's designs emerged that were specific for wood. By using underfire air, the grate where the wood fuel was held could be cooled—allowing for more complete combustion of relatively high moisture content wood. Over the years stoker grate systems have evolved to encompass innovations such as water-cooled vibrating grates that greatly increase the efficiency of fuel wood distribution and completeness of burn. These modern stoker grate boilers are known as Stage 4 designs and include the following technologies[56]:

- Spreader stokers with pneumatic fuel distributors and further development of overfire air systems.
- Stokers with automatic ash discharge which included dumping grates, steam cleaned stationary water cooled grates, water cooled vibrating grates, and traveling grates.
- Superheaters for improved heat rate.
- Increased steaming pressures to improve the heat rate.
- Selective Non-catalytic Reduction (SNCR) systems to reduce NOx.

Stoker grate boiler systems tend to be the least expensive modern boiler design capable of producing steam heat and pressure profiles suitable for heat, power, and cogeneration applications. Their efficiencies are good and continue to improve.

Fluidized bed boilers represent the adaptation of chemical thermal reactor technology to fuel combustion. Fluidized bed boiler systems combust wood suspended in a bed of circulating air and inert particles, usually sand. There are two types of fluidized beds, Bubbling and Circulating. Bubbling beds tend to work best with fuels fed at consistent rates producing a consistent steam load[57]. Circulating bed designs operate with higher air velocities through the bed, 10 to 30 feet per second, which tends to increase ash and unburned fuel particles in the flue gas. This flue gas is re-circulated through the bed to complete the combustion. While a more complicated technology, circulating beds can use more highly variable fuels and can operate under more variable loads.

Both fluidized bed designs have improved fuel combustion because of longer fuel retention, better mixing with combustion air, and more uniformed temperature profiles in the boiler. This allows for more efficient operation at lower temperatures which reduces the production of NOx. In addition, improved overfire air designs and steam conditioning further increase the efficiencies of fluidized bed designs[58].

The use of direct combustion systems to produce both heat and power at the same time is known as cogeneration and greatly increases overall plant efficiency. Cogeneration is common at large

[56] Touplin, K. (1995). *Modern Wood Fired Boiler Designs - History and Technology Changes.* Worcester, MA: Riley Power Inc.

[57] Ibid.

[58] Ibid.

manufacturing facilities that require both thermal energy and electricity. For decades, large forest products facilities such as pulp and paper mills and plywood veneer plants have used cogeneration to provide some or nearly all of their energy requirements.

4.3.2 ENERGY AND ENVIRONMENTAL BENEFITS

Because of its relatively high moisture and oxygen content, green wood is typically around 50 percent water by weight; biomass tends to produce higher carbon dioxide (CO_2) emissions than fossil fuels per unit output. However, the carbon in biomass is part of a dynamic system where carbon cycles through several sinks (oceans, soil, and living organic matter). CO_2 from fossil fuels is geological carbon that has been stored for two million or more years in the earth's crust. The release of the CO_2 adds previously sequestered carbon into the carbon cycle where it continues to accumulate. The displacement of fossil fuels by biomass reduces the amounts of sequestered geological carbon being introduced into the system and for that reason bioenergy is treated as carbon neutral as long as the fuel is sustainably produced and used[59]. The renewable nature of biomass is its greatest energy benefit.

For biomass the other air emissions of primary concern are carbon monoxide, nitrogen oxides, volatile organic compounds, and particulates. For all these air emissions there are well-established emission levels and emission controls for biomass combustion facilities. CO_2 and water vapor are the predominant products of combustion.

The emissions that are given off during the combustion of biomass are compared to those of coal or natural gas in Table 4.3.1. The emissions data shows that when compared to another solid fuel, coal, biomass has some advantages. Biomass typically contains half the nitrogen content that coal does, and also has much lower levels of sulfur and heavy metals. However, when solid biomass is compared to natural gas emissions are higher[60].

Table 4.3.1 Emissions data for various kinds of fuels (no emissions controls)

Pollutant	Wood [lb/MMBtu]	Coal [lb/MMBtu]	Natural Gas [lb/MMBtu]
NO_x	0.220	0.510	0.0371
CO	0.600	0.025	0.0075
SO_2	0.025	0.890 (varies)	0.0028
VOC	0.017	0.003	0.0043
PM	0.570	0.460	0.0083
HCl	1.900E-02	6.100E-02	none
Hg	3.500E-06	16.00E-06	none
Mn	1.600E-03	1.200E-03	none

Source: (Washington State Department of Natural Resources)

To control emissions from biomass combustion, there are a variety of technologies available:

- There are several different ways to reduce nitrogen-related NO_x emissions.

[59] Washington State Department of Natural Resources. (n.d.). *Forest Biomass and Air Emissions Fact Sheet.* Retrieved July 20, 2010, from Washington State Department of Natural Resources: http://www.dnr.wa.gov/Publications/em_forest_biomass_and_air_emissions_factsheet_8.pdf

[60] Brown, R. C. (2003). *Biorenewable Resources: Engineering New Products from Agriculture.* Ames, Iowa: Iowa State Press.

- Staged combustion and fuel reburning
- Selective catalytic reduction (SCR), or a selective non-catalytic reduction (SNCR)

- Sulfur emissions are well below allowable limits and do not require any control systems.
- The formation of VOCs and CO is the result of incomplete combustion that is controlled by optimizing combustion.
- Heavy metals in biomass are found in the ash and are controlled by particulate control devices, such as cyclones, electrostatic precipitators (ESP), and bag houses.

Ash from combustion of clean biomass is benign and inert. Biomass ash can be safely landfilled or can be land applied as a fertilizer component. Its use in cement production has been demonstrated but the ASTM standard for use of fly ash in cement is currently specific to coal ash.

4.3.3 TECHNOLOGY DEVELOPMENT PROGRESS

Direct combustion technologies are mature technologies that are in use across the U.S. in numerous configurations and sizes. These systems continue to evolve and make step improvements in combustion efficiencies. The largest biomass power facilities operating in the U.S. are around 100 MW which require approximately 1.1 million green tons of wood a year. The largest biomass using facilities in the U.S. are pulp and paper mills. Large pulp mills can use in the neighborhood of 5 to 6 million green tons of wood a year. However, most of this biomass costs a third more than what is typically paid for fuel wood. There are several large proposed biomass power facilities under development in the U.S. and abroad. One of the largest biomass power facilities in the world went operational in 2010 in Finland with 385 MW of thermal energy and an additional 12 MW of electric power.

4.3.4 TECHNOLOGY PRODUCTION AND DEPLOYMENT

Across the U.S. there are 6,280 MW of installed biomass power capacity of all types, most of which is collocated at forest products manufacturing facilities. Nearly all of this capacity uses direct combustion technology. The largest concentration of biomass power generation facilities operating today in the U.S. are in California, although Maine, Michigan and Florida also are top states in terms of installed biomass capacity[61].

4.3.5 POTENTIAL JOB IMPACTS

Table 4.3.2 provides a summary of total job creation in full-time employees (FTEs) and job creation per unit of capacity for biomass combustion technology. The types and number of jobs do not differ between combustion technologies. The number of harvesting jobs increases with total biomass use in a fairly linear fashion. This analysis assumes that a forest harvesting crew of five (excluding truck drivers) can produce approximately 50,000 tons of wood fuel for a biomass plant per year, which is typical for a mechanized harvesting crew. There are however significant economies of scale in terms of staffing needs at the plant. A 5 megawatt electric (MWe) cogeneration facility may employ 14 at the facility, while a facility four times that size only employs 21 people.

[61] U.S. DOE. (2009). *Annual Energy Outlook.* Washington DC.

Table 4.3.2 Summary of job creation impacts for biomass combustion at various sizes

Job creation by category	Biomass Cogeneration Combustion	Biomass Cogeneration Combustion	Biomass Stand-alone Combustion
Average plant size	5MWe 15 MWt	20MWe 60 MWt	50MWe
Capacity units	MWe = Megawatts electric MWt = Megawatts thermal		
Annual biomass use (dry tons)	39,099	156,404	391,011
FTEs			
Harvesting Jobs	15	43	106
Plant O&M Jobs	14	21	29
Construction Jobs	50	75	150
FTEs per unit of capacity	(Per MWe)	(Per MWe)	(Per MWe)
Harvesting Jobs	3.00	2.15	5.30
Plant O&M Jobs	2.80	1.05	1.45
Construction Jobs	10.00	3.75	7.50

Separate sections below describe the job impacts for each of the major functions associated with biomass combustion (i.e., harvesting, manufacturing, construction, etc.) in more detail.

Natural Resource Harvesting Job Impacts

Wood is the predominant biomass fuel used for biomass power generation in the U.S. but virtually every type of biomass can be used for heat and electricity production. Straw, wood chips, wood pellets, treated and untreated wood wastes, agricultural waste, and biomass crops such as willow and switch grass have all been used in biomass combustion applications.

The most common source of wood fuel is the residues from primary wood processing mills such as saw mills. Mill residues are typically the least expensive fuel wood resource and easiest to collect. Most mill residuals are currently utilized and its contribution to the supply of a new facility depends upon the willingness of the new facility to pay competitive prices and offer desirable contract terms. If all the mill residues within a fuel supply shed are under contract additional fuel wood resources need to be identified.

Most other fuel wood resources are more expensive than mill residues because of the need for collection and processing. Typically these other fuel wood resources are left in the wood, burned, or placed in landfills. These resources include forest residues from commercial timber harvests, noncommercial tree harvestss from forest thinning and land clearing, and urban wood wastes. The collection and processing of these wood resources for fuel wood uses existing methods and technologies familiar to the current logging and refuses industries.

Agricultural residues can also be used as biomass fuel in properly designed combustion systems. Agricultural residues consist of the vegetative parts of commodity crops. The stems, leaves, cobs, and husk are left in the field after the harvest of the grain to act as ground cover and leach nutrients back into the soil. On many farms the amount of agricultural residue in the fields exceeds the need and a portion of the residues can be collected using standard farm equipment for use as fuel.

Dedicated biomass crop systems have been under development for some time. The cost and production risk of dedicated energy crops still limits their use, but research and government policy keep moving them closer to a viable alternative for biomass fuel production. Based on environmental information and land use data it is probable that herbaceous dedicated biomass energy crop systems are most probable in the Consortium states. Woody and herbaceous biomass cropping systems are being designed to use existing farm and forestry equipment and methods. These crops will most likely be grown on idle agricultural lands or pasture.

Except for mill residues, the use of biomass as a fuel will create new jobs collecting, processing, and transporting the biomass. Most of the jobs created will require the use of heavy equipment and all that entails. These jobs do required skilled operators, but not advanced education beyond high school.

Table 4.3.3 Summary of natural resource harvesting job creation for biomass combustion

Job creation by category	Responsibilities/skill set	Cogeneration 5MWe 15 MWt	Cogeneration 20MWe 60 MWt	Stand-alone 50MWe
Truck driver (53-3032 Heavy and Tractor-Trailer Truck Drivers)	Log and chip van deliveries	4	12	30
Logging and farm management (11-9011 Farmers, Ranchers, and Other Agricultural Managers)	Supervise multiple logging crews, act as fuel aggregator and negotiate with landowners	1	1	1
Heavy equipment mechanic (49-3042 Mobile Heavy Equipment Mechanics)	Repair and maintain logging equipment	1	2	4
Logging supervisor (45-1011 First-Line Supervisors of Farming and Forestry)	Supervise logging crew on job site	2	6	15
Logging equipment operator (45-4022 Logging Equipment Operators)	Operate logging equipment	7	22	56
	Total fuel procurement	**15**	**43**	**106**

There is typically little job difference between a cogeneration application and a stand-alone power plant. There can sometimes be job-sharing between staff at a cogeneration plant and an industrial or institutional facility that the cogeneration project supplies heat and power to, but these opportunities are limited and the estimates provided represent only the staff typically needed to operate and manage the cogeneration facility.

Manufacturing/Building Job Impacts

There are a limited number of combustion equipment manufacturers that sell and service equipment for the biomass power industry. These equipment manufacturers typically have regional engineering sales representatives. It is unlikely that a new manufacturing or fabrication manufacturing facility would be needed to serve the development of a biomass power industry in the Consortium states. However, as described in this report’s evaluation of job skills, descriptions, and education and training resources, parts and materials suppliers for maintenance and operation of field and plant equipment will produce some additional need for skilled mechanics, metal work, electrical/plumbing and retail sales and warehouse positions for parts suppliers.

Construction Job Impacts

Construction of a biomass power plant will require anywhere from 125 to as many as 400 construction workers and management staff depending on the size of the facility. Projected labor requirements for construction of a 50MW biomass power plant by Decker Energy in Georgia are anywhere from 300 to 400 people at peak periods, with a construction period lasting approximately two years[62]. Specific job

[62] Burchfield, Southeast Biomass: Project Development Incentives and Challenges, 2010

descriptions for employment are described in the companion report to this that provides additional information on job skill requirements, education and training needs and current educational resources in Consortium states.

Marketing Job Impacts

The direct job impact for developing and attracting biomass power project developers and financing is minimal, and would likely be served by existing economic development, industry leadership and private sector developers and members of the financial community. Additional marketing functions include power marketing, administration of government and market-based incentives for renewable energy resource use and feedstock procurement. These are all roles likely to be played by employees or consultants at the plant, and job impacts are included in that section.

Maintenance Job Impacts

A biomass power generation station operates twenty-four hours a day, seven days a week with little interruption except for scheduled maintenance one or two weeks a year and potential unscheduled interruptions on as limited a basis as possible. Plant staff members are needed at the fuel receiving, storage and handling facility to monitor incoming fuel shipments, move/maintain piles using front-end loaders and operate and maintain any automated stacking and fuel reclaim equipment and associated conveyance equipment. In the plant itself, boiler operators and maintenance staff are required three shifts a day with additional staff to cover for vacation and medical leave situations, along with general industrial equipment maintenance and janitorial staff. A plant engineer oversees plant operations while operational and maintenance supervisors manage plant crews. A plant technician with some laboratory training and experience is often needed to conduct fuel sampling and moisture testing/quality control. This can often be part of another maintenance staff member’s duties. Office labor positions include a plant manager, bookkeeper and fuel procurement manager. A business manager may also be present. The fuel procurement manager may be assisted by one or more field foresters who work with landowners and suppliers to ensure that the plant secures a reliable, cost-effective and sustainable fuel supply. Table 4.3.4 summarizes plant management and operational staff requirements for biomass combustion.

Table 4.3.4 Summary maintenance job creation for biomass combustion

Job creation by category	Responsibilities/skill set	Cogeneration 5MWe 15 MWt	Cogeneration 20MWe 60 MWt	Stand-alone 50MWe
Management				
Plant manager (11-3051 Industrial Production Managers)	Responsible for all personnel and plant decisions, including hiring, training, fuel contracts, maintenance contracts, equipment purchases, external communications, and scheduling	1	1	1
Environmental Manager	Responsible for environmental reporting, filings and oversight.	1	1	1
Business manager (11-3031 Financial Managers)	Support the general plant manager, manages personnel records, completes company payroll, manages human resources, and insurance.	1	1	1
Fuel procurement manager (11-3061 Purchasing Managers)	Purchasing and parts searching; managing inventory. This is likely a part-time position	0	1	1
Accounting/administrative (43-3031 Bookkeeping, Accounting, Auditing)	Receives visitors, answers phone, office administrative duties.	0	1	1
	Total management	**3**	**4**	**4**
Plant and fuel yard staff				
Plant engineer (17-2141 Mechanical Engineers)	General plant engineering, plant performance evaluation, maintenance planning, capital projects planning, reporting, etc.	0	1	1
Fuel procurement manager (11-3061 Purchasing Managers)	Manages wood purchases, deliveries, payment issues, and manages wood yard	0	0	1
Maintenance supervisor (51-1011 First-Line Supervisors)	5 total shifts to allow for coverage during vacations, etc. plus one overall maintenance planner	0	6	6
Boiler operator (51-8021 Stationary Engineers/ Boiler Operators)	5 total shifts to allow for coverage during vacations, etc.	5	5	10
Industrial equipment mechanic (49-9041 Industrial Machinery Mechanics)	Water treatment and instrument technicians, other mechanics.	0	0	2
Boilerhouse mechanic (47-2011 Boilermakers)	One shift, Monday - Friday, plus overtime as needed	2	2	2
Electrician (47-2111 Electricians)	One shift, Monday - Friday, plus overtime as needed	2	2	2
Front-end loader operator (53-7051 Industrial Truck and Tractor Operators)	5 total shifts as a baseline for a front-end loader fed fuel yard. More automated wood yard using stacker-reclaimers could reduce the number of employees needed.	5	5	5
	Total plant staff	**14**	**21**	**29**

4.3.6 EDUCATION AND JOB SKILL REQUIREMENTS

Educational requirements and job training needs for deployment of biomass power technologies are similar across this broad technology area because they have similar resource needs, supporting manufacturing/supply industries, construction processes, and operation and maintenance characteristics. The information in the following subsections describes 1) what kind of jobs would be needed to support technology deployment 2) educational requirements and job training/certification requirements, and 3) existing educational/institutional resources available to support these efforts within the Consortium states.

Natural Resource Harvesting Education and Job Skills

The bulk of biomass educational and training resources are associated with forestry because the predominant fuel resource for biomass power is wood. However, there is increasing interest in utilization of agricultural residues and dedicated energy crops as a fuel for power. A greater infrastructure development and job training effort may be needed to expand use of agricultural residues for fuel.

The bulk of the jobs for wood biomass suppliers are in the logging and transportation sectors. Each state has its own requirements and/or training/certification programs for logging operators and heavy truck/tractor trailer operators. Heavy equipment operators often require training for use of excavators, skid steers, feller-bunchers, skidders and other mechanized forestry equipment. It is helpful to have a commercial driver's license. Heavy equipment mechanics learn through a combination of vocational/technical training, apprenticeship and on-the job training. Training is offered through community colleges, technical colleges and equipment manufacturers.

Acting as a professional forester does require significant training and work experience. The Society of American Foresters offers the Certified Forester program that, while voluntary, gives credibility to foresters and may be required to be listed as a consulting forester by state forestry agencies. A four-year degree and a proven work track record are required, along with continuing education.

The bulk of the jobs for agricultural biomass suppliers will be in the farming and transportation sectors. Education and training opportunities overlap with those for the wood biomass supply chain. However, opportunities for agronomy, agribusiness management and specialized agricultural equipment and maintenance training are available. Several university-based research, cooperative extension and training programs are gearing up for development of an agricultural bioenergy industry, and these are often separate and unique to the agricultural community. Private/non-profit training programs exist that conduct training and certification for a variety of technician programs.

Management of businesses dedicated to the collection, processing and sales/distribution of agricultural biomass or bioenergy crop enterprise development would likely require at least a four-year degree plus significant production and business financial experience. Specialized knowledge in agronomy and agribusiness are recommended in today's complex, capital-intensive farm production environment due to the financial risks inherent in agriculture, especially for production of crop residues for bioenergy or dedicated energy crops. Some agronomy and agribusiness programs will have a biomass energy component, though it is not likely that many currently offer applied or practical training and educational programs specific to bioenergy. Other degree programs that may offer valuable experience include agricultural and biological engineering or mechanical engineering.

Agricultural equipment operation and maintenance for bioenergy requires specialized experience and knowledge of agricultural equipment such as tractors, harvesters, chipping/screening and grinding, planting, irrigation systems, herbicide and pesticide application equipment and others. These positions such as equipment operators and mechanics require apprenticeship and on-the-job training but increasingly require associates or other certificate programs available through community colleges or private technical training institutions.

Job Descriptions and Training Needs

Table 4.3.5 Natural Resource Management

Job category	BLS Job description (including Standard Occupational Classification Codes)	Minimum training requirements
Technical & managerial		
Logging and farm management	11-9013 Farmers, Ranchers, and Other Agricultural Managers Plan, direct, or coordinate the management or operation of farms, ranches, greenhouses, aquacultural operations, nurseries, timber tracts, or other agricultural establishments. May hire, train, and supervise farm workers or contract for services to carry out the day-to-day activities of the managed operation. May engage in or supervise planting, cultivating, harvesting, and financial and marketing activities.	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Skilled technician		
Heavy equipment mechanic	49-3042 Mobile Heavy Equipment Mechanics, Except Engines Diagnose, adjust, repair, or overhaul mobile mechanical, hydraulic, and pneumatic equipment, such as cranes, bulldozers, graders, and conveyors, used in construction, logging, and surface mining. Illustrative examples: Forklift Mechanic, Bulldozer Mechanic, Construction Equipment Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Logging supervisor	45-1011 First-Line Supervisors of Farming, Fishing, and Forestry Workers Directly supervise and coordinate the activities of agricultural, forestry, aquacultural, and related workers. Illustrative examples: Fish Hatchery Supervisor, Cranberry Bog Supervisor, Corral Boss	Applied associates degree and/or long-term apprenticeship/on-the-job training; Optional private sector/non-profit and/or state training and certification
Logging equipment operator	45-4022 Logging Equipment Operators Drive logging tractor or wheeled vehicle equipped with one or more accessories, such as bulldozer blade, frontal shear, grapple, logging arch, cable winches, hoisting rack, or crane boom, to fell tree; to skid, load, unload, or stack logs; or to pull stumps or clear brush. Illustrative examples: Grapple Skidder Operator, Lumber Stacker Operator, Logging Tractor Operator, Log Hauler	State-specific requirements for heavy equipment operators and optional private sector/non-profit and/or state training and certification
Agricultural equipment operator	45-2091 Agricultural Equipment Operators Drive and control farm equipment to till soil and to plant, cultivate, and harvest crops. May perform tasks, such as crop baling or hay bucking. May operate stationary equipment to perform post-harvest tasks, such as husking, shelling, threshing, and ginning. Illustrative examples: Tractor Operator, Hay Baler, Combine Operator	State-specific requirements for heavy equipment operators; on-the-job training

Job category	BLS Job description (including Standard Occupational Classification Codes)	Minimum training requirements
Entry-level skilled or semi-skilled		
Forestry technician	45-4011 Forest and Conservation Workers Under supervision, perform manual labor necessary to develop, maintain, or protect areas such as forests, forested areas, woodlands, wetlands, and rangelands through such activities as raising and transporting seedlings; combating insects, pests, and diseases harmful to plant life; and building structures to control water, erosion, and leaching of soil. Includes forester aides, seedling pullers, and tree planters. Illustrative examples: Wetlands Conservation Laborer, Reforestation Worker, Rangelands Conservation Laborer, Forestry Laborer	On-the-job training
Farm laborer	45-2092 Farm workers and Laborers, Crop, Nursery, and Greenhouse Manually plant, cultivate, and harvest vegetables, fruits, nuts, horticultural specialties, and field crops. Use hand tools, such as shovels, trowels, hoes, tampers, pruning hooks, shears, and knives. Duties may include tilling soil and applying fertilizers; transplanting, weeding, thinning, or pruning crops; applying pesticides; or cleaning, grading, sorting, packing, and loading harvested products. May construct trellises, repair fences and farm buildings, or participate in irrigation activities.	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	State-specific requirements for truck driving

Manufacturing Education and Job Skills

Manufacturing major components for a biomass power plant is likely to occur outside the region unless the specific equipment manufacturer is based within one of the Consortium states. It will require specific technical experience that is unlikely to be developed within the Consortium states for the development of individual projects. For this reason, this is unlikely to be a major new source of technical employment. As an example, Babcock & Wilcox is a major boiler manufacturer supplying the biomass industry, but its major base of operations is in Ohio. However, manufacture of specific parts and components during the manufacturing/fabrication or following plant construction could be a source of employment. Job types likely to be required include positions in welding, plumbing, electricians, sheet metal fabrication and related positions that can be met with the existing labor force. As an example from other similar analyses, the NYSERDA Biofuels Roadmap development effort identified a total of 26 jobs statewide in the materials and machinery sectors created from their economic impact analysis[63]. Job creation from this aspect of biomass technology deployment can be absorbed by the existing workforce.

Construction Education and Job Skills

Construction of a biomass power plant will require anywhere from 125 to 400 jobs at any given time during the construction period. Most of these positions can be filled using the existing construction workforce, and will include skill sets such as heavy equipment operation, electrical, plumbing, pipe-fitting, welding, metal fabrication, concrete pouring/finishing, truck driving, and various unskilled manual labor positions. It is likely that a limited number of the positions could include mid-level construction and engineering management positions. Some of these will be met using contract staff, but some will be hired from the local work force. It is unlikely that individual projects would require a dedicated workforce strategy for this job sector.

Marketing Education and Job Skills

Marketing job functions can be broken down into several broad categories; 1) Technology marketing – or the recruiting of project development and financial capital resources; 2) Power sales – including the negotiation of power purchase agreements, certification of power as renewable energy resources, and administration of renewable energy credits and other incentives; and 3) Feedstock procurement – recruiting farmers, forest landowners and coordination of biomass supply procurement effort. These are not likely to be major areas of job growth, but they will require specific educational and job skills.

Maintenance Education and Job Skills

Operation and maintenance of the facility is the next largest contributor to overall employment impacts for a biomass power facility. Operations and maintenance staff usually makes up one-quarter to one-half of total employment at a typical plant. The skill sets mirror those for operation and maintenance of industrial and utility-scale solid-fuel boiler systems.

[63] New York State Energy Research and Development Authority. www.nyserda.org

Table 4.3.6 Plant Operations and Maintenance

Job categories by skill level	BLS Job description	Minimum training requirements
Technical & managerial		
Plant manager	11-3051 Industrial Production Managers Plan, direct, or coordinate the work activities and resources necessary for manufacturing products in accordance with cost, quality, and quantity specifications. Illustrative examples: Production Control Manager, Plant Manager, Manufacturing Director	4-year accredited degree program in engineering, technical and/or finance/business with >10 years experience relevant production management experience
Plant engineer	17-2141 Mechanical Engineers Perform engineering duties in planning and designing tools, engines, machines, and other mechanically functioning equipment. Oversee installation, operation, maintenance, and repair of equipment such as centralized heat, gas, water, and steam systems. Illustrative examples: Engine Designer, Tool and Die Engineer, Heating and Cooling Systems Engineer, Combustion Engineer	4-year accredited engineering program (mechanical most likely) + minimum 5 to 10 years in relevant production environment
Fuel procurement manager	11-3061 Purchasing Managers Plan, direct, or coordinate the activities of buyers, purchasing officers, and related workers involved in purchasing materials, products, and services. Includes wholesale or retail trade merchandising managers and procurement managers. Illustrative examples: Purchasing Director, Procurement Manager, Contracting Manager	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Business manager	11-3031 Financial Managers Plan, direct, or coordinate accounting, investing, banking, insurance, securities, and other financial activities of a branch, office, or department of an establishment. Illustrative examples: Financial Director, Comptroller	4-year degree in business and finance or equivalent professional experience with experience in manufacturing
Skilled technician		
Maintenance supervisor	51-1011 First-Line Supervisors of Production and Operating Workers Directly supervise and coordinate the activities of production and operating workers, such as inspectors, precision workers, machine setters and operators, assemblers, fabricators, and plant and system operators. Excludes team or work leaders. Illustrative examples: Printing Worker Supervisor, Machinist Supervisor, Assembly Line Supervisor	Applied associates degree and/or long-term apprenticeship/on-the-job training plus5 years or more experience in power production or utility environment
Boiler operator	51-8021 Stationary Engineers and Boiler Operators Operate or maintain stationary engines, boilers, or other mechanical equipment to provide utilities for buildings or industrial processes. Operate equipment, such as steam engines, generators, motors, turbines, and steam boilers. Illustrative examples: Boiler Room Operator, Boiler Engineer, Heating, Ventilation, and Air Conditioning (HVAC) Mechanic Boiler Operator	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state boiler operator certification
Industrial equipment mechanic	49-9041 Industrial Machinery Mechanics Repair, install, adjust, or maintain industrial production and processing machinery or refinery and pipeline distribution systems. Excludes "Millwrights" (49-9044), "Mobile Heavy Equipment Mechanics, Except Engines" (49-3042), and "Maintenance Workers, Machinery" (49-9043). Illustrative examples: Hydroelectric Machinery Mechanic, Foundry Equipment Mechanic, Boilerhouse Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training

Job categories by skill level	BLS Job description	Minimum training requirements
Boilermaker	47-2011 Boilermakers Construct, assemble, maintain, and repair stationary steam boilers and boiler house auxiliaries. Align structures or plate sections to assemble boiler frame tanks or vats, following blueprints. Work involves use of hand and power tools, plumb bobs, levels, wedges, dogs, or turnbuckles. Assist in testing assembled vessels. Direct cleaning of boilers and boiler furnaces. Inspect and repair boiler fittings, such as safety valves, regulators, automatic-control mechanisms, water columns, and auxiliary machines. Illustrative examples: Boiler Tester, Boiler Mechanic, Boiler Installer	Applied associates degree and/or long-term apprenticeship/on-the-job training
Accounting/administrative	43-3031 Bookkeeping, Accounting, and Auditing Clerks Compute, classify, and record numerical data to keep financial records complete. Perform any combination of routine calculating, posting, and verifying duties to obtain primary financial data for use in maintaining accounting records. May also check the accuracy of figures, calculations, and postings pertaining to business transactions recorded by other workers. Excludes "Payroll and Timekeeping Clerks" (43-3051). Illustrative examples: Mortgage Accounting Clerk, Bookkeeper, Accounts Receivable Clerk	Associates degree in accounting/finance with 2 years or more bookkeeping experience in manufacturing environment
Chemist	19-2031 Chemists Conduct qualitative and quantitative chemical analyses or experiments in laboratories for quality or process control or to develop new products or knowledge. Excludes "Geoscientists, Except Hydrologists and Geographers" (19-2042) and "Biochemists and Biophysicists" (19-1021). Illustrative examples: Industrial Chemist, Research and Development Chemist, Inorganic Chemist, Food Chemist	4-year degree in chemistry plus 2 years lab experience in manufacturing/quality control; 2 year associates degree plus relevant training and professional experience
Entry-level skilled or semi-skilled jobs		
Janitorial/ maintenance assistant	37-2011 Janitors and Cleaners, Except Maids and Housekeeping Cleaners Keep buildings in clean and orderly condition. Perform heavy cleaning duties, such as cleaning floors, shampooing rugs, washing walls and glass, and removing rubbish. Duties may include tending furnace and boiler, performing routine maintenance activities, notifying management of need for repairs, and cleaning snow or debris from sidewalk. Illustrative examples: School Custodian, Window Washer, Industrial Plant Custodian	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state licensing requirements

4.3.7 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Economic Constraints

This section summarizes key resource, capital and operating cost, siting and market constraints that biomass power technologies operate under. The extent to which each of these constraints affects the viability of a biomass power project is project-specific, but this section brackets key constraints based on project scale and location.

Resource availability

Whether reliant primarily on wood or agricultural biomass, fuel supply reliability is crucial for the economic operation of a biomass power plant. Table 4.3.7 summarizes total potential biomass fuel supply availability from various sources for the Consortium states. The total resource potential is the first order of magnitude of a resource analysis that needs to be performed for a project site. Overall resource potential gives a preliminary look at the emphasis of a biomass power or biofuels strategy that would be predominant in each of the Consortium states. Design considerations for a biomass power plant typically dictate that a system would run on either wood or agricultural residues/herbaceous crops due to handling and combustion characteristics, or one predominant fuel source with the other making up a smaller (10 to 20 percent or less) component of the fuel supply.

Table 4.3.7 Summary of total biomass resource potential in Consortium states (dry tons/year)

State	Total biomass resource potential (dry tons/year)					
	Crop residues	Manure	Forest biomass	Primary mill residues	Urban wood waste	Total
Iowa	23,590,059	141,940	359,001	129,844	29,283	24,250,126
Montana	1,559,984	3,628	703,938	1,937,052	13,394	4,217,995
Nebraska	10,930,551	102,372	72,440	57,075	13,241	11,175,679
South Dakota	5,140,289	35,694	124,999	141,856	6,518	5,449,356
Utah	88,372	9,860	30,418	102,442	18,068	249,161
Wyoming	106,224	2,181	57,579	254,933	3,654	424,570
Total	**41,415,479**	**295,674**	**1,348,375**	**2,623,202**	**84,157**	**45,766,887**

Source: (Milbrandt, 2005)[64]

For forest biomass, a key factor in the Consortium states is landownership. A significant proportion of the forest landownership in Montana, South Dakota, Wyoming and Utah is part of the National Forest System managed by the U.S. Department of Agriculture. National Forest System land is managed under guidelines set forth in periodic land and resource management plans that set allowable annual cut levels, and the ability for federal agencies to plan and administer timber sales and forest management projects is limited by federal funding allocations that occur on an annual basis. To some extent, these administrative requirements have resulted in a shift of timber harvesting to private land. In Montana, close to 80 percent of the logging residue generation occurs on private land[65]. Due to variability in wood biomass availability from federal land, in many areas of the Consortium, close coordination and planning between project developers and federal land managers is required when assessing appropriate project scale and evaluating fuel supply economics, if federal land is anticipated to be a major source of fuel.

For agricultural biomass, key resource considerations for resource availability include maintenance of soil productivity (often due to soil erosion potential), cropping system, and landowner preference. Not all agricultural producers are interested in collection and sale of residues. These technical and sociological constraints need to be factored into any policy or project-level analysis of a biomass energy facility.

Key supplier groups include generators of urban, agricultural and forest biomass. Urban biomass suppliers include wood recycling companies, waste disposal companies, arborists and landscapers. Agricultural suppliers include producers and aggregators/marketers who work with producers directly to negotiate purchase terms and sometimes own and operate baling and other collection equipment. Forest

[64] Milbrandt, A. A Geographic Perspective on the Current Biomass Resource Availability in the United States. *Technical Report*, NREL/TP-560-39181 December 2005. National Renewable Energy Laboratory, Golden, CO
[65] Morgan, Todd. An Assessment of Forest-based Woody Biomass Supply and Use in Montana. Director, Forest Industry Research Bureau of Business and Economic Research The University of Montana – Missoula. April 29 2009.

biomass suppliers include private landowners, government agencies and the contractors that manage their land. The biomass supply system must be designed to continue to operate even if one component of the system breaks down. Therefore, maintaining an adequate network of suppliers is necessary to buffer impacts on the biomass supply. These impacts may be due to changes in housing markets that affect construction residue availability, fluctuations in annual work by arborists and landscaping companies and variable levels of fuels reduction and other forestry projects. In addition, fuel receiving, processing, storage and fuel reclaim systems will need to have contingency plans to permit operation in the event that any system component fails.

Wood fuel cost is a key determinant of economics. Three key factors contribute to the cost of biomass: distance to source, wood quality/fuel processing requirements and current markets/competition for the resource.

Truck is the predominant means for biomass delivery. Rail delivery terms, pricing and on-site loading and unloading requirements are often cost-prohibitive. A 10MW biomass power plant may only receive 10 to 15 truckloads per day. However a larger 100MW facility can expect to receive ten times that amount of traffic, which can significantly affect local traffic patterns. An industry standard value used for analysis of biomass transportation costs is $0.12 per loaded ton-mile, with a maximum economical haul distance of 100 miles. Most biomass power facilities seek to acquire the vast majority of their resource from within 50 miles or closer to minimize transportation costs. Transportation costs for wood fuel range from $6 to $12 per ton for 50 and 100 mile distances, respectively.

Fuel quality affects biomass costs at the burner tip in a number of ways. First, transportation costs on a ton-mile basis are incurred regardless of the moisture content or quality of the fuel wood, so there is a significant incentive to reduce fuel moisture content. As-harvested wood moisture content ranges from 45 to 50 percent (measured as a percentage of wet weight); while agricultural residue moisture content is significantly lower (10 to 20 percent).

Additional biomass handling and processing requirements can also add to biomass fuel costs. Many biomass power plant fuel specifications dictate that materials coming into the plant be chipped to dimensions of 3 inches or smaller (in some cases 1.5 inches or smaller) and be relatively free of contaminants. At the plant, biomass frequently needs to be run through a system of screens, magnets and wood grinders to ensure appropriate fuel quality and remove metals and other contaminants that could damage the facility's equipment or cause unwanted air emissions. This extra processing adds additional cost to the price of the biomass. These additional costs must also be considered when evaluating project economics[66].

Fuel moisture also impacts system performance. Combustion systems operate more efficiently with a lower moisture content fuel. Some gasification systems require moisture content to be controlled below 35 to 40 percent to optimize output.

Existing and proposed competition for wood fuel is a key determinant of pricing, first due to the potential for increased transportation distances, and second due to other market and competitive impact such as ability to pay that can affect economic availability for biomass within a given supply shed. This is of particular concern for project financing due to concerns over supply security and cost. There are a variety of ways to mitigate this risk, but a detailed supply competitive analysis is increasingly a requirement for financing and risk mitigation for a biomass power or biofuels project.

[66] Jackson, Samuel W. Wood2Energy: A State of the Science and Technology Report. University of Tennessee. May, 2010. www.wood2energy.org

Siting requirements

Biomass power generation facilities occupy a footprint ranging from approximately 15 acres for a 5 to 10MW power plant up to approximately 130 acres for a 100MW power plant. The total plant footprint depends on the site configuration and degree of automation for fuel receiving, storage, processing and handling. The site needs to be accessible via tractor-trailers carrying a full load (typically 80,000 to 84,000 lb maximum but this varies by state) and have adequate on-site space to accommodate peak delivery volumes. The turning lane (if present) may require improvements to permit adequate space to allow trucks to slow down upon entrance and accelerate upon leaving the facility, and accommodate turning lane traffic. A traffic analysis is typically conducted as part of plant engineering and planning processes.

The biomass power facility will need access to propane or natural gas lines for space heating and startup purposes, access to adequate transmission capacity adjacent to the site, and will typically require construction of a substation and related interconnection equipment. Locating adjacent to water supplies either from surface water or groundwater for cooling is typically needed unless and air-cooled system is used, which is uncommon. Wastewater treatment requirements are not large, but a complete absence thereof could be considered a difficulty if septic systems cannot be used in a specific location.

Social Constraints

Land use and landowner preferences are constraints that affect biomass power and biofuels technology deployment. These need to be evaluated when considering feasibility of a bioenergy facility at a particular location, and when evaluating the reasonableness of policies related to biomass or biofuels development on a state or regional level.

Forest and agricultural landowner preferences are crucial in determining their willingness to provide forest or agricultural biomass to a biomass energy facility. For forest landowners, federal planning and administrative requirements were discussed in prior sections. Perhaps more important is the forest land owner management objective. If a forested area has historically been a forest-based economy that relies on timber production, there will likely not be as significant an issue. If however, an area focuses on recreational values such as hunting, fishing, and tourism (even on large ranch properties that emphasize hunting leases as a portion of their income); there will be a more conservative approach to increasing mechanized forestry on properties in the area. Agricultural producers are often concerned with ensuring that any additional harvest activities on their land—or leased land—retain ownership of residual materials or potential carbon credits associated with production and use. Some valuation of nutrient removals on agricultural land may be part of negotiations for procurement of agricultural residues. Research at Iowa State University's Bioeconomy Institute led by John Tyndall has attempted to characterize how these attitudes and concerns will affect the growth of the biofuels industry in Iowa (Tyndall, 2007).

Environmental Constraints

The U.S. EPA recently finalized emission limits for both existing and new construction boilers and process heaters[67]. The new proposed standards place particularly strict emissions limits on new projects.

Boilers burning 10 percent or more biomass (and not coal or other solid fuels) are regulated under one of 10 biomass subcategories (five for new units, five for existing units)[68]. Biomass units are now subject to strict limits on particulate matter, carbon monoxide, dioxin/furan, and mercury. This could prevent the implementation of new biomass projects due to high costs for annual emissions testing and additional pollutant control equipment.

Political Constraints

[67] http://www.epa.gov/airquality/combustion

[68] Stoel Rives, LLP, Energy Law Alert: Boiler Hazardous Air Pollutant Emission Rules Released By EPA 2/24/2011

Significant community outreach and communication efforts are required for public acceptance of a biomass energy project. The acceptance issues encountered by biomass project developers are similar to those for other energy project developers but also have several unique concerns:

- Air emissions (perception of biomass as an incinerator rather than an energy facility, particulates, breathing health concerns, concerns about potential carcinogens);
- Water use and effluent discharge (In water constrained areas the use of water is always a major concern as is any effluent discharge);
- Truck traffic (safety, road conditions, traffic congestion);
- Noise;
- Odor;
- Aesthetics of facility;
- Environmental (forest sustainability, water quality, aesthetics of forest/woodlands, wildlife, land use change);
- Definition of "clean" biomass and inclusion of urban wood waste as part of fuel supply; and
- Carbon neutrality of biomass.

Siting a bioenergy project within a residential area can be difficult because of the need to meet the concerns of a large number of stakeholders. Noise, odor, and facility aesthetics are all really associated with impacts of property values and probably associated with zoning issues in residential areas. Most biomass energy facilities are located outside of residential areas or have a significant land buffer between the facility and residential areas.

Each of these issues need to be evaluated thoroughly as part of resource and environmental assessment efforts and a concise communications strategy needs to be developed in advance of public meetings related to the project. This is the case regardless of whether the facility is located in a residential or a rural area. Input on facility siting can come from local groups but also can come from state or national organizations that are seeking to promote or slow down deployment of biomass energy technologies.

4.3.8 FUNDING SOURCES

Numerous funding sources are available for biomass research and technology deployment including education and training infrastructure development, such as the U.S. DOE, USDA Rural Development, and USDA Forest Service Forest Products Laboratory. Solicitations are highly competitive and often require multiple submissions to succeed in obtaining funding. The USDA Biomass Crop Assistance Program provides assistance to producers of biomass fuel for energy use.

4.4 Biomass Gasification – Based Power Generation

SME Information

ANTARES Group Inc.

4.4.1 TECHNOLOGY DESCRIPTION

There are numerous biomass gasification-based power generation and CHP (combined heat and power) technology offerings being tendered at varying levels of commercial readiness throughout the world. A key driver in modern biomass gasification research is to develop systems that can take advantage of high efficiency energy cycles. Gasification technologies have been somewhat successfully deployed for coal by integrating coal-gasification with gas turbines and there is hope that the same can be accomplished using biomass fuels. Fuel cells, combustion turbines and reciprocating engines have the potential to operate at excellent efficiencies relative to boiler/steam turbines, even in the smaller systems—which can be very appropriate for biomass-fueled plants. Efficiencies for a 5 MWe, simple-cycle gas turbine generator are in the high 20 percent range (thermal input/electric output) and approach 40 percent for the Mercury recuperated gas turbine offered by Solar Turbines. Similar efficiencies are possible for reciprocating engines. With equipment to recover heat from engine exhaust or equipment cooling streams, cogeneration (or combined heat and power) system efficiencies can approach 80 percent in applications that have a use for process steam or hot water. Fuel cells using natural gas have expected efficiencies in the 40 to 60 percent range. Although there are a lot of governing variables, boiler-based cogeneration systems can have far lower efficiencies but offer other advantages with regards to reliability.

As new and emerging technologies are the focus of this report, biomass-gasification based combined heat and power systems will be the focus. These technologies are undergoing substantial development and demonstration throughout Europe and recent press coverage suggests that they may start appearing in North America. These systems are an evolution of commercial, close-coupled gasification systems that have been available for boiler applications for several decades.

Most biomass gasifiers (the key component to advanced biopower cycles) can generally be divided into two major categories; fixed- and fluidized-bed systems. Table 4.4.1 provides a technical comparison of fixed and fluid bed gasification technologies. In reviewing the table it is important to consider that both technical (shown) and economic design criteria must be considered in selecting a technology.

Fixed bed systems are commercially dominant, but tend to be limited to smaller district heating and cogeneration projects. Fluidized bed gasifiers represent an alternate option especially for larger scales, and both bubbling and circulating fluidized bed gasifiers have been used commercially in larger utility scale projects to generate electricity using the wood gas in a boiler to raise steam.

Table 4.4.1 Gasifier characteristics by type

	Fixed Bed Types			Fluidized Beds	
	Updraft	Downdraft	Side-Draft	Bubbling	Circulating
Sensitivity to:					
fuel specification	moderate	specific	moderate	flexible	flexible
fuel size	very good	good	good	fair	fair
moisture content	very good	fair	good	good	good
Ash content	poor	poor	poor	very good	very good
Reaction temperature	1000 °C	1000 °C	900 °C	850 °C	850 °C
Fuel mixing	poor	poor	poor	very good	excellent
Gas exit temperature	250 °C	800 °C	900 °C	800 °C	850 °C
Tar in gas	very high	very low	very high	moderate	low
Dust in gas	good	moderate	high	very high	very high
Turndown ration	good	fair	good	very good	good
Scale-up potential	good	poor	poor	good	very good
Start-up facility	poor	poor	poor	good	good
Control facility	fair	fair	fair	very good	very good
Carbon conversion	very good	very good	poor	fair	very good
Thermal efficiency	excellent	very good	good	good	very good
LHV of gas	poor	poor	poor	poor	fair

Source: Combustion and Gasification in Fluidized Beds, Prabir Basu

Key factors in using biomass derived gas in high efficiency systems include its cleanliness and its energy density (Btu/scf). These characteristics depend on a variety of factors including the following:

- The chemical composition of the feedstock;
- Whether air, oxygen, steam or some combination of these is used in the process;
- Gasification temperatures and particle residence times; and
- The type and amount of gas cleaning that takes place prior to end-use.

With respect to the latter, the gas leaving a gasifier contains several types of contaminants that can be deleterious to downstream power generation equipment, ash handling and emissions. These can include some corrosive agents such as hydrogen sulfide or contaminants such as tars, particulate matter and alkalis. The development of technologies to clean up syngas from biomass gasification is the major focus of resarch. Until cost effective gas clean up technology is developed and demonstrated, the potential of biomass gasifiers to produce large quanities of gas suitable for use in equipment or processes designed for high quality gaseous fuels (such as gas turbines, chemical synthesis or direct injection into natural gas pipelines) will be limited. Current gas clean up technologies are listed in Table 4.4.2.

Table 4.4.2 Syngas cleanup options

	Constituent			
Technology	***Tars***	***Particulate***	***Chlorine***	***Alkali***
Wet Scrubber	●	●	●	●
Catalyst	●			
Ceramic Filter	○	●		○
Fiber Filter		●		○
ESP	●	●		○
Cyclone	○	●		○

Key

Direct Removal ●

Indirect/Partial ○

Capital cost and performance estimates for emerging biomass power generation technologies are somewhat speculative as the most interesting technologies are still undergoing demonstration and do not reflect commercial project developments costs. That said, considerable effort has been undertaken by a number of organizations worldwide to estimate key system performance parameters. Technology performance data is also available from a few demonstration projects. Table 4.4.3 summarizes the size and cost for two potential biomass gasification power plant configurations.

Table 4.4.3 Typical gasifier electricity plant size and costs

			Typical Costs	
Technology	**Efficiency (%) LHV**	**Typical Size**	**Capital Costs [$/kW]**	**Product Cost [$/kWh]**
Gasification + turbine [IGCC][69]	30 – 40	10 – 30 MW_e	$2,500-$5,500	$0.11-$0.13/kWh
Gasification + engine	25 – 30	0.2 – 2 MW_e	$3,000-$4,000	$0.11/kWh

Source: (IEA, 2007)

With the exception of fuel costs, biomass energy plants are generally more expensive to build and operate than natural gas-fired plants. The additional of a gasifier, fuel handling equipment and possibly additional pollution controls may make a biomass gasification-based CHP plant almost twice as much to build as similarly sized natural gas unit. For this reason, the technology will perform best, when it can be fueled using very low cost biomass resources and where a very efficient energy cycle can be integrated into the host facility.

4.4.2 ENERGY AND ENVIRONMENTAL BENEFITS

Because of its relatively high moisture and oxygen content (green wood is typically around 50% water by weight) biomass tends to produce higher carbon dioxide (CO_2) emissions than fossil fuels per unit output. However, the carbon in biomass is part of a dynamic system where carbon cycles through several sinks (oceans, soil, and living organic matter). CO_2 from fossil fuels is geological carbon that has been stored for millions of years in the earth's crust. The release of the CO_2 adds previously sequestered carbon into the carbon cycle where it continues to accumulate. The displacement of fossil fuels by biomass reduces the amounts of sequestered geological carbon being introduced into the system and for that reason bioenergy is treated as carbon neutral as long as the fuel is sustainably produced and used[70]. The renewable nature of biomass is its greatest energy benefit.

Other gaseous emissions from biomass gasification-based systems are highly dependent on the gas cleanup and emissions reductions technologies employed. For example, selective non-catalytic reduction (SNCR) can be used to reduce NO_x emissions by 30% to 50%.

Given the variability in designs and the relatively early stage of development, precise emissions estimates are difficult to acquire. However, Table 4.4.4 shows approximate emissions rates for engine-based biomass gasification CHP system. These rates are based on information collected from vendors, published data and a proprietary an in-house database.

Table 4.4.4 Biomass Gasification Engine-based CHP System

		Engine based CHP System
Emissions	NO_X (lb/MMBtu)	0.303 – 0.625
	SO_2 (lb/MMBtu)	0.0
	CO (lb/MMBtu)	1.27 – 1.50
	VOC (lb/MMBtu)	0.0
	Total PM (lb/MMBtu)	<0.03

4.4.3 TECHNOLOGY DEVELOPMENT PROGRESS

Biomass gasifiers coupled with gas-fired boilers have been offered on a commercial basis for some time. However, coupling gasifiers with high efficiency prime movers (such as gas turbines or gas engines) remains in the pre-commercial or demonstration phase. Additionally, the most significant work taking place on these technologies is occurring in Europe and Asia. In these locations, there is keen interest in developing these technologies to meet existing government renewable energy and carbon reduction mandates. More than a half dozen biomass gasification-based CHP projects have been undertaken in the last decade. In the United States, the Department of Energy did support some gasification pilot projects in the late 90's, but none of them resulted in a commercial offering. These included:

- Hawaii Commercial and Sugar Company in Paia, Maui, Hawaii
- McNeil Power Generating Station in Burlington, Vermont
- Minnesota Valley Alfalfa Produces in Granite Falls, Minnesota

[70] Washington State Department of Natural Resources. (n.d.). *Forest Biomass and Air Emissions Fact Sheet.* Retrieved July 20, 2010, from Washington State Department of Natural Resources: http://www.dnr.wa.gov/Publications/em_forest_biomass_and_air_emissions_factsheet_8.pdf

However, if one is to judge by the European experience, it is reasonable to expect at least a few, commercial scale, advanced biomass CHP projects in North America over the next 10 years. It is also possible, depending on market and policy drivers, that systems developed strictly for commercial purposes will begin to appear later in this time horizon.

4.4.4 TECHNOLOGY PRODUCTION AND DEPLOYMENT

Initial deployment of biomass gasification technology will occur at either locations where fuel is available or where the thermal/electric efficiency benefits of the technology can be fully be realized. Based on the European deployment history to date, it is expected that most of the early, engine- or turbine-based systems will be small (below 10 MWe). As the technology proves itself, cogeneration or combine cycle applications at larger biomass facilities will be developed. Facilities with capacities greater than 20MWe may become more common and eventually, larger greenfield sites for the production of power using combined cycle technology or pipeline grade gas will be built. The size of these larger facilities will be primarily dictated by the availability of inexpensive feedstock and units with capacities in the range of 50-100MWe could be possible. However, these latter cases are likely to be more than a decade away.

Operating and maintaining a gasification-based biomass power plant will be substantially similar to the requirements for operating and maintaining a direct-combustion system. The facility will still use solid biomass fuels, necessitating bulk fuel procurement, handling and receiving systems.

It is more difficult to predict construction labor requirements, but based on its experience, Construction of such systems is expected to be similar to traditional solid fuel power plant requirements.

Because of these similarities with traditional biomass-fueled plants, we have assumed that job creation for a direct combustion biomass energy plant and a gasification-based energy plant are the same (Table 4.4.5).

Table 4.4.5 Summary of job creation for biomass power at various sizes

Job creation by category	**Biomass Cogeneration Gasification**	**Biomass Cogeneration Gasification**
Average plant size	5MWe 15 MWt	20MWe 60 MWt
Capacity units	MWe = Megawatts electric MWt = Megawatts thermal	
Annual biomass use (dry tons)	39,099	156,404
FTEs		
Harvesting Jobs	15	43
Plant O&M Jobs	14	21
Construction Jobs	50	75
FTEs per unit of capacity	(Per MWe)	(Per MWe)
Harvesting Jobs	3.00	2.15
Plant O&M Jobs	2.80	1.05
Construction Jobs	10.00	3.75

Natural Resource Harvesting Jobs

Wood is the predominant biomass fuel used for biomass power generation in the U.S. but virtually every type of biomass can be used for heat and electricity production. Straw, wood chips, wood pellets, treated and untreated wood wastes, agricultural waste, and biomass crops such as willow and switch grass have all been used in biomass combustion applications.

The most common source of wood fuel is the residues from primary wood processing mills such as saw mills. Mill residues are typically the least expensive fuel wood resource and easiest to collect. Most mill residuals are currently utilized and its contribution to the supply of a new facility depends upon the willingness of the new facility to pay competitive prices and offer desirable contract terms. If all the mill residues within a fuel supply shed are under contract additional fuel wood resources need to be identified.

Most other fuel wood resources are more expensive than mill residues because of the need for collection and processing. Typically these other fuel wood resources are left in the woods, burned, or placed in landfills. These resources include forest residues from commercial timber harvests, noncommercial tree harvests from forest thinning and land clearing, and urban wood waste. The collection and processing of these wood resources for fuel wood uses existing methods and technologies familiar to the current logging and refuses industries.

Agricultural residues can also be used as biomass fuel in properly designed combustion systems. Agricultural residues consist of the vegetative parts of commodity crops. The stems, leaves, cobs, and husk are left in the field after the harvest of the grain to act as ground cover and leach nutrients back into the soil. On many farms the amount of agricultural residue in the fields exceeds the need and a portion of the residues can be collected using standard farm equipment for use as fuel.

Dedicated biomass crop systems have been under development for some time. The cost and production risk of dedicated energy crops still limits their use, but research and government policy keep moving them closer to a viable alternative for biomass fuel production. Based on environmental information and land use data it is probable that herbaceous dedicated biomass energy crop systems are most probable in the Consortium states. Woody and herbaceous biomass cropping systems are being designed to use existing farm and forestry equipment and methods. These crops will most likely be grown on idle agricultural lands or pasture.

Except for mill residues, the use of biomass as a fuel will create new jobs collecting, processing, and transporting the biomass. Most of the jobs created will require the use of heavy equipment and all that entails. These jobs do required skilled operators, but not advanced education beyond high school.

There is typically little job difference between a cogeneration application and a stand-alone power plant. There can sometimes be job-sharing between staff at a cogeneration plant and an industrial or institutional facility that the cogeneration project supplies heat and power to, but these opportunities are limited and the estimates provided represent only the staff typically needed to operate and manage the cogeneration facility.

Table 4.4.6 Summary of natural resource harvesting job creation for biomass power

Job creation by category	Responsibilities/skill set	Cogeneration 5MWe 15 MWt	Cogeneration 20MWe 60 MWt
Truck driver (53-3032 Heavy and Tractor-Trailer Truck Drivers)	Log and chip van deliveries	4	12
Logging and farm management (11-9011 Farmers, Ranchers, and Other Agricultural Managers)	Supervise multiple logging crews, act as fuel aggregator and negotiate with landowners	1	1
Heavy equipment mechanic (49-3042 Mobile Heavy Equipment Mechanics)	Repair and maintain logging equipment	1	2
Logging supervisor (45-1011 First-Line Supervisors of Farming and Forestry)	Supervise logging crew on job site	2	6
Logging equipment operator (45-4022 Logging Equipment Operators)	Operate logging equipment	7	22
	Total fuel procurement	**15**	**43**

Manufacturing/Building Jobs

There are a limited number of gasification equipment manufacturers that sell and service equipment. These equipment manufacturers typically have regional engineering sales representatives. It is unlikely that a new manufacturing or fabrication manufacturing facility would be needed to serve the development of a biomass power industry in the coalition states. However, as described later in this report, mechanics, metal work, electrical/plumbing and retail sales and warehouse positions for parts suppliers.

Construction Jobs

Construction of a biomass gasification plant will require anywhere from 125 to as many as 400 construction workers and management staff depending on the size of the facility. Projected labor requirements for construction of a 50MW biomass power plant by Decker Energy in Georgia are anywhere from 300 to 400 people at peak periods, with a construction period lasting approximately two years[71]. Specific job descriptions for employment are described in the companion report to this that provides additional information on job skill requirements, education and training needs and current educational resources in Consortium states.

Marketing Jobs

The direct job impact for developing and attracting biomass gasifier project developers and financing is minimal, and would likely be served by existing economic development, industry leadership and private sector developers and members of the financial community. Additional marketing functions include power marketing, administration of government and market-based incentives for renewable energy resource use and feedstock procurement. These are all roles likely to be played by employees or consultants at the plant, and job impacts are included in that section.

Maintenance Jobs

A biomass power generation station operates twenty-four hours a day, seven days a week with little interruption except for scheduled maintenance one or two weeks a year and potential unscheduled interruptions on as limited a basis as possible. Plant staff members are needed at the fuel receiving, storage and handling facility to monitor incoming fuel shipments, move/maintain piles using front-end

[71] Burchfield, Southeast Biomass: Project Development Incentives and Challenges, 2010

loaders and operate and maintain any automated stacking and fuel reclaim equipment and associated conveyance equipment. In the plant itself, boiler operators and maintenance staff are required three shifts a day with additional staff to cover for vacation and medical leave situations, along with general industrial equipment maintenance and janitorial staff. A plant engineer oversees plant operations while operational and maintenance supervisors manage plant crews. A plant technician with some laboratory training and experience is often needed to conduct fuel sampling and moisture testing/quality control. This can often be part of another maintenance staff member's duties. Office labor positions include a plant manager, bookkeeper and fuel procurement manager. A business manager may also be present. The fuel procurement manager may be assisted by one or more field foresters who work with landowners and suppliers to ensure that the plant secures a reliable, cost-effective and sustainable fuel supply.

Table 4.4.7 on page 122 summarizes plant management and operational staff requirements for biomass combustion.

Table 4.4.7 Summary of maintenance job creation for biomass power

Job creation by category	Responsibilities/skill set	Cogeneration 5MWe 15 MWt	Cogeneration 20MWe 60 MWt
Management/G&A			
Plant manager (11-3051 Industrial Production Managers)	Responsible for all personnel and plant decisions, including hiring, training, fuel contracts, maintenance contracts, equipment purchases, external communications, and scheduling	1	1
Environmental Manager	Responsible for environmental reporting, filings and oversight.	1	1
Business manager (11-3031 Financial Managers)	Support the general plant manager, manages personnel records, completes company payroll, manages human resources, and insurance.	1	1
Fuel procurement manager (11-3061 Purchasing Managers)	Purchasing and parts searching; managing inventory. This is likely a part-time position	0	1
Accounting/administrative (43-3031 Bookkeeping, Accounting, Auditing)	Receives visitors, answers phone, office administrative duties.	0	1
	Total management/G&A	**3**	**4**
Plant and fuel yard staff			
Plant engineer (17-2141 Mechanical Engineers)	General plant engineering, plant performance evaluation, maintenance planning, capital projects planning, reporting, etc.	0	1
Fuel procurement manager (11-3061 Purchasing Managers)	Manages wood purchases, deliveries, payment issues, and manages wood yard	0	0
Maintenance supervisor (51-1011 First-Line Supervisors)	5 total shifts to allow for coverage during vacations, etc. plus one overall maintenance planner	0	6
Boiler operator (51-8021 Stationary Engineers/ Boiler Operators)	5 total shifts to allow for coverage during vacations, etc.	5	5
Industrial equipment mechanic (49-9041 Industrial Machinery Mechanics)	Water treatment and instrument technicians, other mechanics.	0	0
Boilerhouse mechanic (47-2011 Boilermakers)	One shift, Monday - Friday, plus overtime as needed	2	2
Electrician (47-2111 Electricians)	One shift, Monday - Friday, plus overtime as needed	2	2
Front-end loader operator (53-7051 Industrial Truck and Tractor Operators)	5 total shifts as a baseline for a front-end loader fed fuel yard. More automated wood yard using stacker-reclaimers could reduce the number of workers needed.	5	5
	Total plant staff	**14**	**21**

4.4.5 EDUCATION AND JOB SKILLS TRAINING

Educational requirements and job training needs for deployment of biomass power technologies are similar across this broad technology area because they have similar resource needs, supporting manufacturing/supply industries, construction processes, and operation and maintenance characteristics. The information in the following subsections describes 1) what kind of jobs would be needed to support technology deployment 2) educational requirements and job training/certification requirements, and 3) existing educational/institutional resources available to support these efforts within the Consortium states.

Natural Resource Harvesting Education and Job Skills

The bulk of biomass educational and training resources are associated with forestry because the predominant fuel resource for biomass power is wood. However, there is increasing interest in utilization of agricultural residues and dedicated energy crops as a fuel for power. A greater infrastructure development and job training effort may be needed to expand use of agricultural residues for fuel.

The bulk of the jobs for wood biomass suppliers are in the logging and transportation sectors. Each state has its own requirements and/or training/certification programs for logging operators and heavy truck/tractor trailer operators. Heavy equipment operators often require training for use of excavators, skid steers, feller-bunchers, skidders and other mechanized forestry equipment. It is helpful to have a commercial driver's license. Heavy equipment mechanics learn through a combination of vocational/technical training, apprenticeship and on-the job training. Training is offered through community colleges, technical colleges and equipment manufacturers.

Acting as a professional forester does require significant training and work experience. The Society of American Foresters offers the Certified Forester program that, while voluntary, gives credibility to foresters and may be required to be listed as a consulting forester by state forestry agencies. A four-year degree and a proven work track record are required, along with continuing education.

The bulk of the jobs for agricultural biomass suppliers will be in the farming and transportation sectors. Education and training opportunities overlap with those for the wood biomass supply chain. However, opportunities for agronomy, agribusiness management and specialized agricultural equipment and maintenance training are available. Several university-based research, cooperative extension and training programs are gearing up for development of an agricultural bioenergy industry, and these are often separate and unique to the agricultural community. Private/non-profit training programs exist that conduct training and certification for a variety of technician programs.

Management of businesses dedicated to the collection, processing and sales/distribution of agricultural biomass or bioenergy crop enterprise development would likely require at least a four-year degree plus significant production and business financial experience. Specialized knowledge in agronomy and agribusiness are recommended in today's complex, capital intensive farm production environment due to the financial risks inherent in agriculture, especially for production of crop residues for bioenergy or dedicated energy crops. Some agronomy and agribusiness programs will have a biomass energy component, though it is not likely that many currently offer applied or practical training and educational programs specific to bioenergy. Other degree programs that may offer valuable experience include agricultural and biological engineering or mechanical engineering.

Agricultural equipment operation and maintenance for bioenergy requires specialized experience and knowledge of agricultural equipment such as tractors, harvesters, chipping/screening and grinding, planting, irrigation systems, herbicide and pesticide application equipment and others. These positions such as equipment operators and mechanics require apprenticeship and on-the-job training but increasingly require associates or other certificate programs available through community colleges or private technical training institutions.

Table 4.4.8 Natural Resource Management Job Descriptions

Job category	BLS Job description and Standard Occupational Classification Codes	Minimum training requirements
Technical & managerial		
Logging and farm management	11-9013 Farmers, Ranchers, and Other Agricultural Managers Plan, direct, or coordinate the management or operation of farms, ranches, greenhouses, aquacultural operations, nurseries, timber tracts, or other agricultural establishments. May hire, train, and supervise farm workers or contract for services to carry out the day-to-day activities of the managed operation. May engage in or supervise planting, cultivating, harvesting, and financial and marketing activities.	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Skilled technician		
Heavy equipment mechanic	49-3042 Mobile Heavy Equipment Mechanics, Except Engines Diagnose, adjust, repair, or overhaul mobile mechanical, hydraulic, and pneumatic equipment, such as cranes, bulldozers, graders, and conveyors, used in construction, logging, and surface mining. Illustrative examples: Forklift Mechanic, Bulldozer Mechanic, Construction Equipment Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Logging supervisor	45-1011 First-Line Supervisors of Farming, Fishing, and Forestry Workers Directly supervise and coordinate the activities of agricultural, forestry, aquacultural, and related workers. Illustrative examples: Fish Hatchery Supervisor, Cranberry Bog Supervisor, Corral Boss	Applied associates degree and/or long-term apprenticeship/on-the-job training; Optional private sector/non-profit and/or state training and certification
Logging equipment operator	45-4022 Logging Equipment Operators Drive logging tractor or wheeled vehicle equipped with one or more accessories, such as bulldozer blade, frontal shear, grapple, logging arch, cable winches, hoisting rack, or crane boom, to fell tree; to skid, load, unload, or stack logs; or to pull stumps or clear brush. Illustrative examples: Grapple Skidder Operator, Lumber Stacker Operator, Logging Tractor Operator, Log Hauler	State-specific requirements for heavy equipment operators and optional private sector/non-profit and/or state training and certification
Agricultural equipment operator	45-2091 Agricultural Equipment Operators Drive and control farm equipment to till soil and to plant, cultivate, and harvest crops. May perform tasks, such as crop baling or hay bucking. May operate stationary equipment to perform post-harvest tasks, such as husking, shelling, threshing, and ginning. Illustrative examples: Tractor Operator, Hay Baler, Combine Operator	State-specific requirements for heavy equipment operators; on-the-job training
Entry-level skilled or semi-skilled		
Forestry technician	45-4011 Forest and Conservation Workers Under supervision, perform manual labor necessary to develop, maintain, or protect areas such as forests, forested areas, woodlands, wetlands, and rangelands through such activities as raising and transporting seedlings; combating insects, pests, and diseases harmful to plant life; and building structures to control water, erosion, and leaching of soil. Includes forester aides, seedling pullers, and tree planters. Illustrative examples: Wetlands Conservation Laborer, Reforestation Worker, Rangelands Conservation Laborer, Forestry Laborer	On-the-job training

Job category	BLS Job description and Standard Occupational Classification Codes	Minimum training requirements
Farm laborer	45-2092 Farm workers and Laborers, Crop, Nursery, and Greenhouse Manually plant, cultivate, and harvest vegetables, fruits, nuts, horticultural specialties, and field crops. Use hand tools, such as shovels, trowels, hoes, tampers, pruning hooks, shears, and knives. Duties may include tilling soil and applying fertilizers; transplanting, weeding, thinning, or pruning crops; applying pesticides; or cleaning, grading, sorting, packing, and loading harvested products. May construct trellises, repair fences and farm buildings, or participate in irrigation activities.	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	State-specific requirements for truck driving

Manufacturing Education and Job Skills

Manufacturing major components for a biomass power plant is likely to occur outside the region unless the specific equipment manufacturer is based within one of the Consortium states. It will require specific technical experience that is unlikely to be developed within the Consortium states for the development of individual projects. For this reason, this is unlikely to be a major new source of technical employment. As an example, Babcock & Wilcox is a major boiler manufacturer supplying the biomass industry, but its major base of operations is in Ohio. However, manufacture of specific parts and components during the manufacturing/fabrication or following plant construction could be a source of employment. Job types likely to be required include positions in welding, plumbing, electricians, sheet metal fabrication and related positions that can be met with the existing labor force. As an example from other similar analyses, the NYSERDA Biofuels Roadmap development effort identified a total of 26 jobs statewide in the materials and machinery sectors created from their economic impact analysis[72]. Job creation from this aspect of biomass technology deployment can be absorbed by the existing workforce.

Construction Education and Job Skills

Most construction positions can be filled using the existing construction workforce, and will include skill sets such as heavy equipment operation, electrical, plumbing, pipe-fitting, welding, metal fabrication, concrete pouring/finishing, truck driving, and various unskilled manual labor positions. It is likely that a limited number of the positions could include mid-level construction and engineering management positions. Some of these will be met using contract staff, but some will be hired from the local work force. It is unlikely that individual projects would require a dedicated workforce strategy.

[72] New York State Energy Research and Development Authority. www.nyserda.org

Marketing Education and Job Skills

Marketing job functions can be broken down into several broad categories; 1) Technology marketing – or the recruiting of project development and financial capital resources; 2) Power sales – including the negotiation of power purchase agreements, certification of power as renewable energy resources, and administration of renewable energy credits and other incentives; and 3) Feedstock procurement – recruiting farmers, forest landowners and coordination of biomass supply procurement effort. These are not likely to be major areas of job growth, but they will require specific educational and job skills.

Maintenance Education and Job Skills

Operation and maintenance of the facility is the next largest contributor to overall employment impacts for a biomass power facility. Operations and maintenance staff usually makes up one-quarter to one-half of the total employment at a typical plant. The skill sets mirror those for operation and maintenance of industrial and utility-scale solid-fuel boiler systems.

Table 4.4.9 Plant Operations and Maintenance

Job categories by skill level	BLS Job description and Standard Occupational Classification Code	Minimum training requirements
Technical & managerial		
Plant manager	11-3051 Industrial Production Managers Plan, direct, or coordinate the work activities and resources necessary for manufacturing products in accordance with cost, quality, and quantity specifications. Illustrative examples: Production Control Manager, Plant Manager, Manufacturing Director	4-year accredited degree program in engineering, technical and/or finance/business with >10 years experience relevant production management experience
Plant engineer	17-2141 Mechanical Engineers Perform engineering duties in planning and designing tools, engines, machines, and other mechanically functioning equipment. Oversee installation, operation, maintenance, and repair of equipment such as centralized heat, gas, water, and steam systems. Illustrative examples: Engine Designer, Tool and Die Engineer, Heating and Cooling Systems Engineer, Combustion Engineer	4-year accredited engineering program (mechanical most likely) + minimum 5 to 10 years in relevant production environment
Fuel procurement manager	11-3061 Purchasing Managers Plan, direct, or coordinate the activities of buyers, purchasing officers, and related workers involved in purchasing materials, products, and services. Includes wholesale or retail trade merchandising managers and procurement managers. Illustrative examples: Purchasing Director, Procurement Manager, Contracting Manager	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Business manager	11-3031 Financial Managers Plan, direct, or coordinate accounting, investing, banking, insurance, securities, and other financial activities of a branch, office, or department of an establishment. Illustrative examples: Financial Director, Comptroller	4-year degree in business and finance or equivalent professional experience with experience in manufacturing
Skilled technician		
Maintenance supervisor	51-1011 First-Line Supervisors of Production and Operating Workers Directly supervise and coordinate the activities of production and operating workers, such as inspectors, precision workers, machine setters and operators, assemblers, fabricators, and plant and system operators. Excludes team or work leaders. Illustrative examples: Printing Worker Supervisor, Machinist Supervisor, Assembly Line Supervisor	Applied associates degree and/or long-term apprenticeship/on-the-job training plus5 years or more experience in power production or utility environment

Job categories by skill level	BLS Job description and Standard Occupational Classification Code	Minimum training requirements
Boiler operator	51-8021 Stationary Engineers and Boiler Operators Operate or maintain stationary engines, boilers, or other mechanical equipment to provide utilities for buildings or industrial processes. Operate equipment, such as steam engines, generators, motors, turbines, and steam boilers. Illustrative examples: Boiler Room Operator, Boiler Engineer, Heating, Ventilation, and Air Conditioning (HVAC) Mechanic Boiler Operator	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state boiler operator certification
Industrial equipment mechanic	49-9041 Industrial Machinery Mechanics Repair, install, adjust, or maintain industrial production and processing machinery or refinery and pipeline distribution systems. Excludes "Millwrights" (49-9044), "Mobile Heavy Equipment Mechanics, Except Engines" (49-3042), and "Maintenance Workers, Machinery" (49-9043). Illustrative examples: Hydroelectric Machinery Mechanic, Foundry Equipment Mechanic, Boilerhouse Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Boilerhouse mechanic	47-2011 Boilermakers Construct, assemble, maintain, and repair stationary steam boilers and boiler house auxiliaries. Align structures or plate sections to assemble boiler frame tanks or vats, following blueprints. Work involves use of hand and power tools, plumb bobs, levels, wedges, dogs, or turnbuckles. Assist in testing assembled vessels. Direct cleaning of boilers and boiler furnaces. Inspect and repair boiler fittings, such as safety valves, regulators, automatic-control mechanisms, water columns, and auxiliary machines. Illustrative examples: Boiler Tester, Boiler Mechanic, Boiler Installer	Applied associates degree and/or long-term apprenticeship/on-the-job training
Accounting/administrative	43-3031 Bookkeeping, Accounting, and Auditing Clerks Compute, classify, and record numerical data to keep financial records complete. Perform any combination of routine calculating, posting, and verifying duties to obtain primary financial data for use in maintaining accounting records. May also check the accuracy of figures, calculations, and postings pertaining to business transactions recorded by other workers. Excludes "Payroll and Timekeeping Clerks" (43-3051). Illustrative examples: Mortgage Accounting Clerk, Bookkeeper, Accounts Receivable Clerk	Associates degree in accounting/finance with 2 years or more bookkeeping experience in manufacturing environment
Chemist	19-2031 Chemists Conduct qualitative and quantitative chemical analyses or experiments in laboratories for quality or process control or to develop new products or knowledge. Excludes "Geoscientists, Except Hydrologists and Geographers" (19-2042) and "Biochemists and Biophysicists" (19-1021). Illustrative examples: Industrial Chemist, Research and Development Chemist, Inorganic Chemist, Food Chemist	4-year degree in chemistry plus 2 years lab experience in manufacturing/quality control; 2 year associates degree plus relevant training and professional experience
Entry-level skilled or semi-skilled jobs		
Janitorial/maintenance assistant	37-2011 Janitors and Cleaners, Except Maids and Housekeeping Cleaners Keep buildings in clean and orderly condition. Perform heavy cleaning duties, such as cleaning floors, shampooing rugs, washing walls and glass, and removing rubbish. Duties may include tending furnace and boiler, performing routine maintenance activities, notifying management of need for repairs, and cleaning snow or debris from sidewalk. Illustrative examples: School Custodian, Window Washer, Industrial Plant Custodian	On-the-job training

Job categories by skill level	BLS Job description and Standard Occupational Classification Code	Minimum training requirements
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state licensing requirements

4.4.6 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Economic Constraints

This section summarizes key resource, capital and operating cost, siting and market constraints that biomass power technologies operate under. The extent to which each of these constraints affects the viability of a biomass power project is project-specific, but this section brackets key constraints based on project scale and location.

Resource Availability.

Whether reliant primarily on wood or agricultural biomass, fuel supply reliability is crucial for the economic operation of a biomass power plant. The total resource potential is the first order of magnitude of a resource analysis that needs to be performed for a project site. Overall resource potential gives a preliminary look at the emphasis of a biomass power or biofuels strategy that would be predominant in each of the Consortium states. Design considerations for a biomass power plant typically dictate that a system would run on either wood or agricultural residues/herbaceous crops due to handling and combustion characteristics, or one predominant fuel source with the other making up a smaller (10 to 20 percent or less) component of the fuel supply.

Table 4.4.10 Summary of biomass resource potential in Consortium states (dry tons/year)

	Total biomass resource potential (dry tons/year)					
State	**Crop residues**	**Manure**	**Forest biomass**	**Primary mill residues**	**Urban wood waste**	**Total**
Iowa	23,590,059	141,940	359,001	129,844	29,283	24,250,126
Montana	1,559,984	3,628	703,938	1,937,052	13,394	4,217,995
Nebraska	10,930,551	102,372	72,440	57,075	13,241	11,175,679
South Dakota	5,140,289	35,694	124,999	141,856	6,518	5,449,356
Utah	88,372	9,860	30,418	102,442	18,068	249,161
Wyoming	106,224	2,181	57,579	254,933	3,654	424,570
Total	**41,415,479**	**295,674**	**1,348,375**	**2,623,202**	**84,157**	**45,766,887**

Source: (Milbrandt, 2005)[73]

For forest biomass, a key factor in the Consortium states is landownership. A significant proportion of the forest landownership in Montana, South Dakota, Wyoming and Utah is part of the National Forest System. National Forest land is managed under guidelines set forth in periodic land and resource management plans that set allowable annual cut levels, and the ability for federal agencies to plan and administer timber sales and forest management projects is limited by federal funding allocations that occur on an annual basis. To some extent, these administrative requirements have resulted in a shift of timber harvesting to private land. In Montana, close to 80 percent of the logging residue generation

[73] Milbrandt, A. A Geographic Perspective on the Current Biomass Resource Availability in the United States. *Technical Report,* NREL/TP-560-39181 December 2005. National Renewable Energy Laboratory, Golden, CO

occurs on private land[74]. Due to variability in wood biomass availability from federal land, in many areas of the Consortium, close coordination and planning between project developers and federal land managers is required when assessing appropriate project scale and evaluating fuel supply economics, if federal land is anticipated to be a major source of fuel.

For agricultural biomass, key resource considerations for resource availability include maintenance of soil productivity (often due to soil erosion potential), cropping system, and landowner preference. Not all agricultural producers are interested in collection and sale of residues. These technical and sociological constraints need to be factored into any policy or project-level analysis of a biomass energy facility.

Key supplier groups include generators of urban, agricultural and forest biomass. Urban biomass suppliers include wood recycling companies, waste disposal companies, arborists and landscapers. Agricultural suppliers include producers and aggregators/marketers who work with producers directly to negotiate purchase terms and sometimes own and operate baling and other collection equipment. Forest biomass suppliers include private landowners, government agencies and the contractors that manage their land. The biomass supply system must be designed to continue to operate even if one component of the system breaks down. Therefore, maintaining an adequate network of suppliers is necessary to buffer impacts on the biomass supply. These impacts may be due to changes in housing markets that affect construction residue availability, fluctuations in annual work by arborists and landscaping companies, and variable levels of fuels reduction and other forestry projects. In addition, fuel receiving, processing, storage and fuel reclaim systems will need to have contingency plans to permit operation in the event that any system component fails.

Wood fuel cost is a key determinant of economics. Three key factors contribute to the cost of biomass: distance to source, wood quality/fuel processing requirements and current markets/competition for the resource.

Truck is the predominant means for biomass delivery. Rail delivery terms, pricing and on-site loading and unloading requirements are often cost-prohibitive. A 10MW biomass power plant may only receive 10 to 15 truckloads per day. However a larger 100MW facility can expect to receive ten times that amount of traffic, which can significantly affect local traffic patterns. An industry standard value used for analysis of biomass transportation costs is $0.12 per loaded ton-mile, with a maximum economical haul distance of 100 miles. Most biomass power facilities seek to acquire the vast majority of their resource from within 50 miles or closer to minimize transportation costs. Transportation costs for wood fuel range from $6 to $12 per ton for 50 and 100-mile distances, respectively.

Fuel quality affects biomass costs at the burner tip in a number of ways. First, transportation costs on a ton-mile basis are incurred regardless of the moisture content or quality of the fuel wood, so there is a significant incentive to reduce fuel moisture content. As-harvested wood moisture content ranges from 45 to 50 percent (measured as a percentage of wet weight), while agricultural residue moisture content is significantly lower (10 to 20 percent).

Additional biomass handling and processing requirements can also add to biomass fuel costs. Many biomass power plant fuel specifications dictate that materials coming into the plant be chipped to dimensions of 3 inches or smaller (in some cases 1.5 inches or smaller) and be relatively free of contaminants. At the plant, biomass frequently needs to be run through a system of screens, magnets and wood grinders to ensure appropriate fuel quality and remove metals and other contaminants that could damage the facility's equipment or cause unwanted air emissions. This extra processing adds additional

[74] Morgan, Todd. An Assessment of Forest-based Woody Biomass Supply and Use in Montana. Director, Forest Industry Research Bureau of Business and Economic Research The University of Montana – Missoula. April 29 2009.

cost to the price of the biomass. These additional costs must also be considered when evaluating project economics[75].

Fuel moisture also impacts system performance. Combustion systems operate more efficiently with a lower moisture content fuel. Some gasification systems require moisture content to be controlled below 35 to 40 percent to optimize output.

Existing and proposed competition for wood fuel is a key determinant of pricing, first due to the potential for increased transportation distances, and second due to other market and competitive impact such as ability to pay that can affect economic availability for biomass within a given supply shed. This is of particular concern for project financing due to concerns over supply security and cost. There are a variety of ways to mitigate this risk, but a detailed supply competitive analysis is increasingly a requirement for financing and risk mitigation for a biomass power or biofuels project.

Siting requirements. Biomass power generation facilities occupy a footprint ranging from approximately 15 acres for a 5 to 10MW power plant up to approximately 130 acres for a 100MW power plant. The total plant footprint depends on the site configuration and degree of automation for fuel receiving, storage, processing and handling. The site needs to be accessible via tractor trailers carrying a full load (typically 80,000 to 84,000 lb maximum but this varies by state) and have adequate on-site space to accommodate peak delivery volumes. The turning lane (if present) may require improvements to permit adequate space to allow trucks to slow down upon entrance and accelerate upon leaving the facility, and accommodate turning lane traffic. A traffic analysis is typically conducted as part of plant engineering and planning processes.

The biomass power facility will need access to propane or natural gas lines for space heating and startup purposes, access to adequate transmission capacity adjacent to the site, and will typically require construction of a substation and related interconnection equipment. Locating adjacent to water supplies either from surface water or groundwater for cooling is typically needed unless an air-cooled system is used—which is uncommon. Wastewater treatment requirements are not large, but a complete absence thereof could be considered a difficulty if septic systems cannot be used in a specific location.

Social Constraints

Land use and landowner preferences are constraints that affect biomass power and biofuels technology deployment. These need to be evaluated when considering feasibility of a bioenergy facility at a particular location, and when evaluating the reasonableness of policies related to biomass or biofuels development on a state or regional level.

Forest and agricultural landowner preferences are crucial in determining their willingness to provide forest or agricultural biomass to a biomass energy facility. For forest landowners, federal planning and administrative requirements were discussed in prior sections. Perhaps more important is the forest landowner management objective. If a forested area has historically been a forest-based economy that relies on timber production, there will likely not be as significant an issue. If however, an area focuses on recreational values such as hunting, fishing, and tourism (even on large ranch properties that emphasize hunting leases as a portion of their income), there will be a more conservative approach to increasing mechanized forestry on properties in the area. Agricultural producers are often concerned with ensuring that any additional harvest activities on their land, and in the case of leased farm land, there is some question regarding ownership of the residual materials and any potential carbon credits that could be associated with the residue production and use. Some valuation of nutrient removals on agricultural land may be part of negotiations for procurement of agricultural residues. Research at Iowa State University's

[75] Jackson, Samuel W. Wood2Energy: A State of the Science and Technology Report. University of Tennessee. May, 2010. www.wood2energy.org

Bioeconomy Institute led by John Tyndall has attempted to characterize how these attitudes and concerns will affect the growth of the biofuels industry in Iowa[76].

Environmental Constraints

The U.S. EPA recently finalized emission limits for both existing and new construction boilers and process heaters[77]. The new proposed standards place particularly strict emissions limits on new projects.

Boilers burning 10 percent or more biomass (and not coal or other solid fuels) are regulated under one of 10 biomass subcategories (five for new units, five for existing units)[78]. Biomass units are now subject to strict limits on particulate matter, carbon monoxide, dioxin/furan, and mercury. This could prevent the implementation of new biomass projects due to high costs for annual emissions testing and additional pollutant control equipment.

Political Constraints

Significant community outreach and communication efforts are required for public acceptance of a biomass energy project. The acceptance issues encountered by biomass project developers are similar to those for other energy project developers but also have several unique concerns:

- Air emissions (perception of biomass as an incinerator rather than an energy facility, particulates, breathing health concerns, concerns about potential carcinogens);
- Water use and effluent discharge (In water constrained areas the use of water is always a major concern as is any effluent discharge);
- Truck traffic (safety, road conditions, traffic congestion);
- Noise;
- Odor;
- Aesthetics of facility;
- Environmental (forest sustainability, water quality, aesthetics of forest/woodlands, wildlife, land use change);
- Definition of "clean" biomass and inclusion of urban wood waste as part of fuel supply; and
- Carbon neutrality of biomass.

Siting a bioenergy project within a residential area can be difficult because of the need to meet the concerns of a large number of stakeholders. Noise, odor, and facility aesthetics are all really associated with impacts of property values and probably associated with zoning issues in residential areas. Most biomass energy facilities are located outside of residential areas or have a significant land buffer between the facility and residential areas.

Each of these issues need to be evaluated thoroughly as part of resource and environmental assessment efforts and a concise communications strategy needs to be developed in advance of public meetings related to the project. This is the case regardless of whether the facility is located in a residential or a rural area. Input on facility siting can come from local groups but also can come from state or national organizations that are seeking to promote or slow down deployment of biomass energy technologies.

4.4.7 FUNDING SOURCES

Numerous funding sources are available for biomass research and technology deployment including education and training infrastructure development, such as the U.S. DOE, USDA Rural Development, and

[76] Tyndall, John. Rapid Assessment of Woody Biomass Capabilities in Three Regions of the U.S. Midwest. Iowa State University, Department of Natural Resource Ecology and Management. 2007.
[77] http://www.epa.gov/airquality/combustion
[78] Stoel Rives, LLP, Energy Law Alert: Boiler Hazardous Air Pollutant Emission Rules Released By EPA 2/24/2011

USDA Forest Service Forest Products Laboratory. Solicitations are highly competitive and often require multiple submissions to succeed in obtaining funding. The USDA Biomass Crop Assistance Program provides assistance to producers of biomass fuel for energy use.

4.5 Pellet Fuels

SME Information

ANTARES Group Inc.

4.5.1 BACKGROUND

Wood pellet technology is a mature technology as is the production of wood briquettes and fire logs. The production of wood pellets requires the use of dry wood (10% moisture content) that has been reduced to fine “saw dust” particles. The wood is either forced through an extruder or a die at pressure of 45,000 psi. The friction and pressure creates 200° F heat which cause the lignin component of the wood to melt and bind the wood particles together without the need for any other binding or adhesive material.

Currently, there are around 80 wood pellet mills in the U.S. producing primarily premium grade wood pellets for use in U.S. residential and commercial markets, and for the European industrial market. While the U.S. residential and commercial wood pellet markets have been relatively flat for the past several years the demand from Europe is quite strong. Several large pellet mills in the eastern U.S. either have long-term contracts to supply European companies or are owned by European companies.

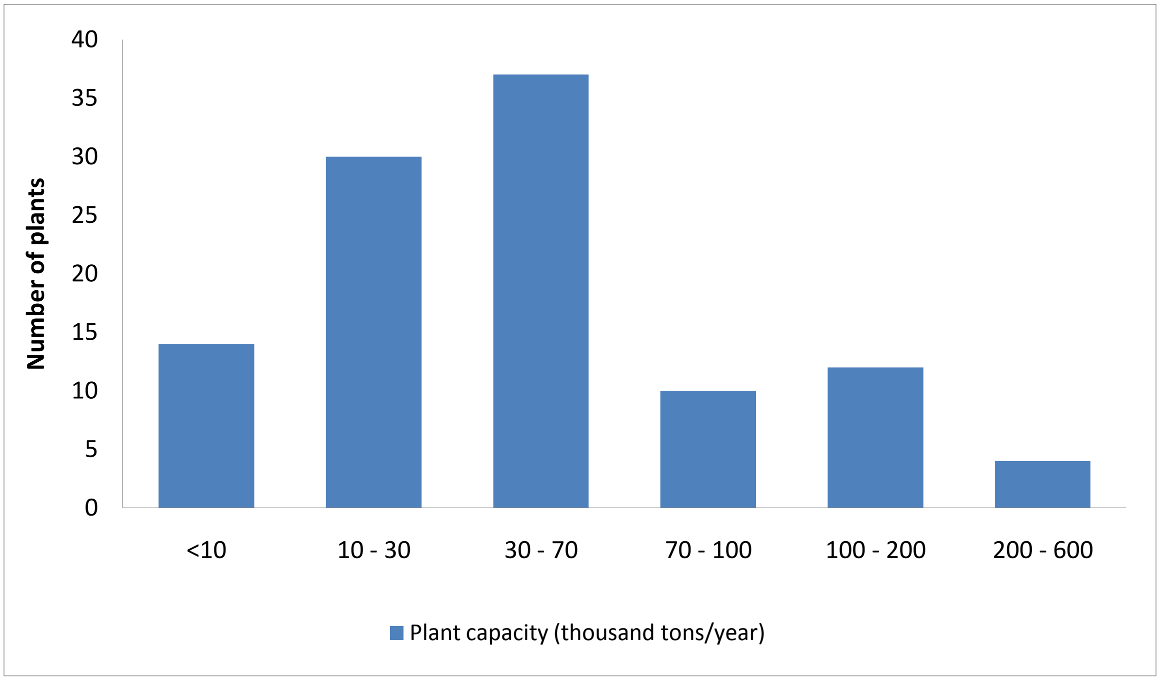
- New England Wood Pellets produces 200,000 tons of wood pellets and announced a contract to supply Europe
- Green Circle produces 500,000 tons of pellets a year and is owned by a Swedish Company
- CKS Pellets produces 100,000 tons of pellets a year and was recently purchased by a German/Belgium Company
- Georgia BioMass is partially owned by a German company and when construction is complete in late 2010 it will produce 1,000,000 tons of wood pellets a year

In North America, pellet mills range in capacity from very small units producing 1 ton per hour to large industrial facilities producing 500,000 tons per year with future facilities to have production capabilities of a million tons of pellets. There are economies of scale of operation for pellet systems that are dependent on the availability and cost of feedstocks and the end market for wood pellets. The largest number of pellet facilities in 2008 has capacities in the 30,000 to 70,000 ton per year range.

Pellet fuel production in 2008 in the U.S. was approximately 1.8 million tons, approximately 66 percent of total capacity[79]. Total North American pellet production capacity was 4.2 million tons per year in 2008. Recently, several pellet operations supplying the domestic market have closed and many others have curtailed operations due to increasing feedstock costs and limited market growth in pellet appliances.

[79] Spelter, H., & Toth, D. (2009). *North America's Wood Pellet Sector.* Madison, WI: U.S. Department of Agriculture Forest Service Forest Products Laboratory.

Figure 4.5.1 Size distribution of pellet mills in North America (U.S. and Canada) in 2009



4.5.2 TECHNOLOGY DESCRIPTION

While pellet technology is mature, production of pellets from herbaceous material such as switch grass, wheat straw, and corn stover is emerging. The pellet production method is essentially identical to that for wood pellets except that sometimes steam or water is added to help melt or liquefy the lignin as it is extruded or passes through the die. In the U.S. there are currently no pellet facilities making fuel pellets from herbaceous materials, but there is a market for alfalfa pellets for use as animal feed and organic nitrogen fertilizer.

Biomass pellets from wood and herbaceous materials need to be kept dry. Direct contact with water causes the pellets to lose cohesion and break down into small particles. The use of biochar or torrefied wood to make pellets produces a pellet that is resistant to moisture. Biochar/torrefied wood uses a pyrolysis process to produce a char. This char has proven to be environmentally stable and water resistant. Promoters of these technologies claim that pellets from these materials are energy dense, water resistant, can be stored for a long period of time and are more cost efficient to transport.

4.5.3 ENERGY AND ENVIRONMENTAL BENEFITS

Residential wood pellet heating systems have the highest combustion efficiencies for small wood fueled systems. Wood pellet heating units/stoves are lower in particular matter emissions than wood stoves and other chunk wood heating systems, and produce less ash byproducts. The ash byproducts are inert and can be disposed of in residential waste collection systems or land applied (wood and wood pellet ash has some benefits as an additive to compost and as a land amendment for acid soils).

Like the residential systems, commercial sized wood pellet boilers for thermal heat are more efficient that than typical small wood fired heat systems. Net boiler efficiency of pellet systems averages approximately 83 percent (A.B. Curtis, 2004) compared to 70% for convential small wood boiler systems.

Most of the increase in combustion efficiency of residential and small commercial pellet systems over other wood combustion systems comes from the fuel characteristics of the fuel pellets over wood chips, hog fuel, and firewood. Pellets are extremely low in moisture content, are a consistent size, have greater surface area, and are homogenous. These fuel characteristics allow for use in more sophisticated furnace/boiler designs than is feasible using more variable wood fuels. However, the efficiencies observed for pellet furnaces and boilers come with the expense of an energy intense production process for pellets.

Pellet production requires size reduction and drying of the wood along with the production of the pellet and packaging. These processes account for 58% of the energy in a wood pellet and are four times higher than the energy to produce fuel wood from mill residues and eight times higher than the energy to produce fuel wood chips or hog fuel[80]. Wood pellets have 1.6 times more energy content than green wood. However, it should be noted that wood pellets are easier to transport and store than bulk forms of other types of wood fuels.

Table 4.5.1 shows several types of biomass fuels with their respective densities and volumetric energy contents compared with those of coal. Wood pellets have a density comparable to that of coal and are generally recognized to consistently have the highest energy density per unit of volume and mass of available biomass fuels.

Table 4.5.1 Energy data for various fuels (wet-based)

Fuel	**Density**		**Volumetric Energy Content**		**Energy per unit Mass**	
	[kg/m^3]	**[lb/ft^3]**	**[GJ/m^3]**	**[Thousand Btu/ft^3]**	**[GJ/kg]**	**[MMBtu/ton]**
Coal	600-900	37.5-51.2	11-33	295-349	0.018-0.037	6.82-7.87
Hardwood	280-480	17.5-30.0	5.3-9.1	142-244	0.019	8.11-8.13
Softwood	200-340	12.5-21.2	4.0-6.8	107-182	0.020	8.56-8.58
Baled Straw	160-300	10.0-18.7	2.6-4.9	69-131	0.016	6.90-7.01
Agricultural Residues	50-200	3.1-12.5	0.8-3.6	21-96	0.016-0.018	6.77-7.68
Wood Chips	550	34.3	5.8	155	0.011	4.52
Wood Pellets	600	37.5	9.0	241	0.015	6.43

Sources: (Brown, 2003[81]) & (Mitchell, 2007[82])

Pellet mills that use rotary drum dryers or similar technology do often result in some particulate matter, nitrogen oxide, carbon monoxide and VOC emissions, and this can be an issue for permitting and public acceptance of a new processing facility. A small facility producing from 20,000 to 40,000 tons of pellet fuel per year is typically a minor emissions source in the eyes of state air quality regulators, but this is highly dependent on the state and location of the proposed facility. Any proposed facility will likely require an air shed analysis to determine facility compliance with ambient air quality standards. There is little or no wastewater from the pelletizing process.

[80] Craven, J., & Bi, X. (2008). Life Cycle Analysis of the Canadian Wood Pellet. *BioEnergy Conference.* University of British Columbia: Department of Chemical and Biological Engineering.

[81] Brown, R. C. (2003). *Biorenewable Resources: Engineering New Products from Agriculture.* Ames, Iowa: Iowa State Press.

[82] Mitchell, P. (2007). Torrified Biomass: A Foresiting Study into the Business Case for Pellets from Torrified Biomass as a New Solid Fuel. *All Energy*

4.5.4 TECHNOLOGY DEVELOPMENT PROGRESS

Wood pellet fuel manufacturing is a proven, commercially viable technology with over 100 operational facilities in North America. Pellet plants cover a wide range of sizes, from small pellet mills that produce 20,000 tons or less of pellet fuels per year to very large industrial projects that produce 500,000 tons of pellet fuels per year.

Fuel pellet production from herbaceous materials has been proven at the demonstration scale (Me Energy in Missouri), but due to ash content these fuel pellets will have difficulty finding markets. Pelletizing of biochar/torrefied wood has been proven on a pilot scale and shows promise if the cost of biochar/torrefication can be made economically viable.

Table 4.5.2 provides estimated capital costs for three pellet fuel facility sizes. There are economies of scale for capital investment in pellet production.

Table 4.5.2 Estimated capital costs for three pellet processing facility sizes

Production (tons/hour)	Production (tons/year)	Capital costs ($)	Capital costs ($)	Capital costs ($/production unit)
3	22,338	$3,921,977	$3,921,977	176
10	74,460	$11,108,052	$11,108,052	149
13	100,000	$14,918,146	$13,624,889	136

Note: Currency converted from Canadian dollars to U.S. currency assuming $0.9438 U.S. $ per Canadian $ and adjusted from 2005 costs to 2010 values assuming 3 percent inflation.

However, feedstock makes up approximately 53 percent of the total production costs of pellet fuel[83], which makes it extremely important as a determinant of pellet production costs. Table 4.5.3 provides estimates of pellet production costs based on a published cost breakdown of pellet production costs[84].

Table 4.5.3 Estimated production costs for three pellet processing facility sizes

Feedstock cost ($/dry ton)	Pellet production cost ($/ton)
$40	$166
$45	$187
$50	$208
$55	$228
$60	$249

Published market values for bagged pellet fuels range from approximately $180 to $250 per ton[85], so it is crucial to have a firm handle on feedstock costs and markets for a successful venture.

[83] Processco. (2007). Wood Pellet Production Cost Analysis. Montreal, Canada.

[84] Ibid.

[85] woodpellets.com. (n.d.). *Making Wood Pellets for Pellet Stoves and Inserts*. Retrieved July 26, 2010, from http://www.hearth.com/visit/nepellet/source/55_dryer.html

4.5.5 TECHNOLOGY PRODUCTION AND DEPLOYMENT

Pellet mills producing pellets for the domestic residential/commercial market and the European market will continue to use clean bark free wood to meet quality specifications. Pellet mills producing product for the domestic markets will continue to struggle as long as residential pellet stove sales lag and there are no large-scale commercial or utility use of wood pellets in the U.S.

Pellet mills selling large bulk quantities of wood pellets into the European market will continue to do well. These facilities tend to be large pellet mills with access to ship transport through barge and rail, and have the ability to ship pellets in bulk. As long as European buyers have incentives to produce biomass power these large pellet mills with access to European bound shipping will continue to thrive.

Pellets from herbaceous materials, while technically possible, will not develop due to the ash characteristics of the feedstock.

Pellets from biochar/torrefaction have higher energy density than wood pellets and are resistant to water. These are desirable, but the biochar technology is still in the demonstration phase. If biochar/torrefied wood can be produced economically pellets from these materials will enter the fuel market. Initial deployment will be on a small scale similar to the size of small wood pellet mills, but could grow rapidly if the biochar/torrefication technology is scalable and there is interest in use from utility sized facilities.

4.5.6 POTENTIAL JOB IMPACTS

Total employment in the North American pellet sector in 2008 was approximately 2300 at 111 mills, or an average of 21 employees per facility. Larger mills tend to be more automated, requiring fewer employees per unit of production. In many cases, larger mills (200 to 600 thousand tonnes per year) serving the bulk fuel market for export to Europe have fully automated conveyance and storage systems. By contrast, smaller operations in the 70 thousand tonnes per year or smaller range are more likely to produce bagged pellets and may use manual labor to set up bags to be filled as they are produced.

A larger than average facility was chosen for analysis because new pellet facilities are using forest biomass as a feedstock, requiring larger facilities.

Table 4.5.4 Summary of employment impacts of biomass pellet manufacturing

Job creation by category	Pellet manufacturing 100,000 tons/year
Annual biomass use (dry tons)	121,000
FTEs	
Harvesting Jobs	36
Plant O&M Jobs	24
Construction Jobs	50
FTEs per unit of capacity	
Harvesting Jobs	0.36
Plant O&M Jobs	0.24
Construction Jobs	0.50

Natural Resource Harvesting Jobs

Wood is the predominant biomass source used for pellet manufacturing in the U.S. but virtually every type of biomass can be used. Straw, mill residues, wood chips, treated and untreated wood wastes, agricultural waste, and biomass crops such as willow and switch grass have all been used to make pellets.

The most common source of wood is the residues from primary wood processing mills such as saw mills. Mill residues are typically the least expensive fuel wood resource and easiest to collect. Most mill residuals are currently utilized and its contribution to supply of a new facility depends upon the willingness of the new facility to pay competitive prices and offer desirable contract terms. If all the mill residues within a supply shed are under contract additional wood resources need to be identified.

Most other wood resources are more expensive than mill residues because of the need for collection and processing. Typically these other wood resources are left in the wood, burned, or placed in landfills. These resources include forest residues from commercial timber harvest, noncommercial tree harvest from forest thinning and land clearing, and urban wood waste. The collection and processing of these wood resources for pellets uses methods familiar to the current logging and refuses industries.

Except for mill residues, the use of biomass as a fuel will create new jobs collecting, processing, and transporting the biomass. Most of the jobs created will require the use of heavy equipment and all that entails. These jobs do required skilled operators, but not advanced education beyond high school.

Table 4.5.5 summarizes job creation for a 100,000 ton per year pellet facility.

Table 4.5.5 Summary of natural resource harvesting job creation for pellet manufacturing

Job creation by occupational code	Responsibilities/skill set	Jobs
Truck driver (53-3032 Heavy and Tractor-Trailer Truck Drivers)	Log and chip van deliveries	10
Logging and farm management (11-9013 Farmers, Ranchers, and Other Agricultural Managers)	Supervise multiple logging crews, act as fuel aggregator negotiate with landowners	1
Heavy equipment mechanic (49-3042 Mobile Heavy Equipment Mechanics)	Repair and maintain logging equipment	5
Logging supervisor (45-1011 First-Line Supervisors of Farming and Forestry)	Supervise logging crew	5
Logging equipment operator (45-4022 Logging Equipment Operators)	Operate logging equipment	15
	Total fuel procurement	**36**

Manufacturing/Building Jobs

There are a limited number of pellet mill equipment manufacturers that sell and service equipment for the pellet manufacturing industry. These equipment manufacturers typically have regional engineering sales representatives. It is unlikely that a new manufacturing or fabrication manufacturing facility would be needed to serve the development of a pellet fuel industry in the Consortium states.

Construction Jobs

Approximately 50 to 100 people will be employed during construction of a mid-size pellet mill for approximately 12 to 18 months. Most of these will be with existing construction firms.

Marketing Jobs

There is a minimal job impact associated with marketing pellet fuel technology. The market for potential developers includes a mix of local entrepreneurs with substantive forest products industry management expertise who are evaluating diversification options and national project developers who may require some education and outreach to see localized opportunities.

Maintenance Jobs

Operations and maintenance for a pellet operation can range from approximately 12 staff for a small (less than 30,000 ton per year) facility to approximately 45 for a large facility such as Green Circle's 550,000 ton per year highly automated Florida facility[86].

Table 4.5.6 Summary of Maintenance Job Creation for 100,000 ton Pellet Manufacturing

Job creation by category	Responsibilities/skill set	Jobs
Management/G&A		
Plant manager (11-3051 Industrial Production Managers)	Responsible for all personnel and plant decisions, including hiring, training, fuel contracts, maintenance contracts, equipment purchases, external communications, and scheduling	1
Business manager (11-3031 Financial Managers)	Support the general plant manager, manages personnel records, completes payroll, manages human resources, and insurance.	1
Accounting/administrative (43-3031 Bookkeeping, Accounting, Auditing)	Receives visitors, answers phone, office administrative duties including bookkeeping assistance	1
	Total management/G&A	**3**
Plant and fuel yard staff		
Plant engineer (17-2141 Mechanical Engineers)	General plant engineering, plant performance evaluation, maintenance planning, capital projects planning, reporting, etc.	1
Fuel procurement manager (11-3061 Purchasing Managers)	Manages wood purchases, deliveries, payment issues, and manages wood yard	1
Maintenance supervisor (51-1011 First-Line Supervisors)	5 total shifts to allow for coverage during vacations, etc.	5
Boiler operator (51-8021 Stationary Engineers)	5 total shifts to allow for coverage during vacations, etc.	5
Industrial equipment mechanic (49-9041 Industrial Mechanics)	Water treatment and instrument technicians, other mechanics.	5
Boilerhouse mechanic (47-2011 Boilermakers)	One shift, Monday - Friday, plus overtime as needed	1
Electrician (47-2111 Electricians)	One shift, Monday - Friday, plus overtime as needed	2
Front-end loader operator (53-7051 Industrial Truck and Tractor Operators)	5 total shifts as a baseline for a front-end loader fed fuel yard. More automated yard using stacker-reclaimers could reduce	5
	Total plant staff	**25**

4.5.7 EDUCATION AND JOB SKILLS TRAINING

Educational requirements and job training needs for deployment of pellet manufacturing are similar to those in the forest products industry. The information in the following subsections describes 1) what kind of jobs would be needed to support technology deployment 2) educational requirements and job training/certification requirements, and 3) existing educational/institutional resources available to support

[86] Kotrba, R. (2007, November). *Closing the Energy Circle.* Retrieved from Biomass Magazine: http://www.biomassmagazine.com/article.jsp?article_id=1331&q=&page=3

these efforts within the Consortium states. Table 4.5.7 provides job descriptions by skill level and training /educational requirements.

Natural Resource Harvesting Education and Job Skills

The bulk of biomass educational and training resources are associated with forestry because the predominant fuel resource for biomass pellet manufacturing is wood. The bulk of the jobs for wood biomass suppliers are in the logging and transportation sectors. Each state has its own requirements and/or training/certification programs for logging operators and heavy truck/tractor trailer operators. Heavy equipment operators often require training for use of excavators, skid steers, feller-bunchers, skidders and other mechanized forestry equipment. It is helpful to have a commercial driver's license. Heavy equipment mechanics learn through a combination of vocational/technical training, apprenticeship and on-the job training. Training is offered through community colleges, technical colleges and equipment manufacturers.

Acting as a professional forester does require significant training and work experience. The Society of American Foresters offers the Certified Forester program that, while voluntary, gives credibility to foresters and may be required to be listed as a consulting forester by state forestry agencies. A four-year degree and a proven work track record are required, along with continuing education.

Table 4.5.7 Natural Resource Management Job Descriptions

Job category	BLS Job description and Standard Occupational Classification Code	Minimum training requirements
Technical & managerial		
Logging and farm management	11-9013 Farmers, Ranchers, and Other Agricultural Managers Plan, direct, or coordinate the management or operation of farms, ranches, greenhouses, aquacultural operations, nurseries, timber tracts, or other agricultural establishments. May hire, train, and supervise farm workers or contract for services to carry out the day-to-day activities of the managed operation. May engage in or supervise planting, cultivating, harvesting, and financial and marketing activities.	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Skilled technician		
Heavy equipment mechanic	49-3042 Mobile Heavy Equipment Mechanics, Except Engines Diagnose, adjust, repair, or overhaul mobile mechanical, hydraulic, and pneumatic equipment, such as cranes, bulldozers, graders, and conveyors, used in construction, logging, and surface mining. Illustrative examples: Forklift Mechanic, Bulldozer Mechanic, Construction Equipment Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Logging supervisor	45-1011 First-Line Supervisors of Farming, Fishing, and Forestry Workers Directly supervise and coordinate the activities of agricultural, forestry, aquacultural, and related workers. Illustrative examples: Fish Hatchery Supervisor, Cranberry Bog Supervisor, Corral Boss	Applied associates degree and/or long-term apprenticeship/on-the-job training; Optional private sector/non-profit and/or state training and certification

Job category	BLS Job description and Standard Occupational Classification Code	Minimum training requirements
Logging equipment operator	45-4022 Logging Equipment Operators Drive logging tractor or wheeled vehicle equipped with one or more accessories, such as bulldozer blade, frontal shear, grapple, logging arch, cable winches, hoisting rack, or crane boom, to fell tree; to skid, load, unload, or stack logs; or to pull stumps or clear brush. Illustrative examples: Grapple Skidder Operator, Lumber Stacker Operator, Logging Tractor Operator, Log Hauler	State-specific requirements for heavy equipment operators and optional private sector/non-profit and/or state training and certification
Entry-level skilled or semi-skilled		
Forestry technician	45-4011 Forest and Conservation Workers Under supervision, perform manual labor necessary to develop, maintain, or protect areas such as forests, forested areas, woodlands, wetlands, and rangelands through such activities as raising and transporting seedlings; combating insects, pests, and diseases harmful to plant life; and building structures to control water, erosion, and leaching of soil. Includes forester aides, seedling pullers, and tree planters. Illustrative examples: Wetlands Conservation Laborer, Reforestation Worker, Rangelands Conservation Laborer, Forestry Laborer	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	State-specific requirements for truck driving

Manufacturing Education and Job Skills

Manufacturing major components for a pellet manufacturing plant is likely to occur outside the region unless the specific equipment manufacturer is based within one of the Consortium states. It will require specific technical experience that is unlikely to be developed within the Consortium states for the development of individual projects. For this reason, this is unlikely to be a major new source of technical employment. However, manufacture of specific parts and components during manufacturing/fabrication or following plant construction could be a source of employment. Job types likely to be required include positions in welding, plumbing, electricians, sheet metal fabrication and related positions that can be met with the existing labor force.

Construction Education and Job Skills

Construction of a mid-size pellet manufacturing plant will require anywhere from 50 to 100 jobs at any given time during the construction period. Most of these positions can be filled using the existing construction workforce, and will include skill sets such as heavy equipment operation, electrical, plumbing, pipe-fitting, welding, metal fabrication, concrete pouring/finishing, truck driving, and various unskilled manual labor positions. A limited number of the positions could include mid-level construction and engineering positions. Some of these will be met using contract staff, but some will be hired from the local work force. Pellet technology deployment will not require a dedicated workforce strategy.

Marketing Education and Job Skills

Marketing job functions can be broken down into several broad categories; 1) Technology marketing – or the recruiting of project development and financial capital resources; 2) Power sales – including the negotiation of power purchase agreements, certification of power as renewable energy resources, and administration of renewable energy credits and other incentives; and 3) Feedstock procurement – recruiting farmers, forest landowners and coordination of biomass supply procurement effort. These are not likely to be major areas of job growth, but they will require specific educational and job skills.

Maintenance Education and Job Skills

Operation and maintenance of the facility is the next largest contributor to overall employment impacts for a biomass power facility. Typical employment at the plant is one half to one quarter of the total employment impact of a pellet manufacturing facility depending on facility size.

Table 4.5.8 Plant Operations and Maintenance Job Descriptions

Job categories by skill level	BLS Job description and Standard Occupational Classification Code	Minimum training requirements
Technical & managerial		
Plant manager	11-3051 Industrial Production Managers Plan, direct, or coordinate the work activities and resources necessary for manufacturing products in accordance with cost, quality, and quantity specifications. Illustrative examples: Production Control Manager, Plant Manager, Manufacturing Director	4-year accredited degree program in engineering, technical and/or finance/business with >10 years experience relevant production management experience
Plant engineer	17-2141 Mechanical Engineers Perform engineering duties in planning and designing tools, engines, machines, and other mechanically functioning equipment. Oversee installation, operation, maintenance, and repair of equipment such as centralized heat, gas, water, and steam systems. Illustrative examples: Engine Designer, Tool and Die Engineer, Heating and Cooling Systems Engineer, Combustion Engineer	4-year accredited engineering program (mechanical most likely) + minimum 5 to 10 years in relevant production environment
Fuel procurement manager	11-3061 Purchasing Managers Plan, direct, or coordinate the activities of buyers, purchasing officers, and related workers involved in purchasing materials, products, and services. Includes wholesale or retail trade merchandising managers and procurement managers. Illustrative examples: Purchasing Director, Procurement Manager, Contracting Manager	Forestry, agronomy or related 4-year degree + finance and 5 to 10 years experience in production environment
Business manager	11-3031 Financial Managers Plan, direct, or coordinate accounting, investing, banking, insurance, securities, and other financial activities of a branch, office, or department of an establishment. Illustrative examples: Financial Director, Comptroller	4-year degree in business and finance or equivalent professional experience with experience in manufacturing
Skilled technician		
Maintenance supervisor	51-1011 First-Line Supervisors of Production and Operating Workers Directly supervise and coordinate the activities of production and operating workers, such as inspectors, precision workers, machine setters and operators, assemblers, fabricators, and plant and system operators. Excludes team or work leaders. Illustrative examples: Printing Worker Supervisor, Machinist Supervisor, Assembly Line Supervisor	Applied associates degree and/or long-term apprenticeship/on-the-job training plus5 years or more experience in power production or utility environment
Boiler operator	51-8021 Stationary Engineers and Boiler Operators Operate or maintain stationary engines, boilers, or other mechanical equipment to provide utilities for buildings or industrial processes. Operate equipment, such as steam engines, generators, motors, turbines, and steam boilers. Illustrative examples: Boiler Room Operator, Boiler Engineer, Heating, Ventilation, and Air Conditioning (HVAC) Mechanic Boiler Operator	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state boiler operator certification

Job categories by skill level	BLS Job description and Standard Occupational Classification Code	Minimum training requirements
Industrial equipment mechanic	49-9041 Industrial Machinery Mechanics Repair, install, adjust, or maintain industrial production and processing machinery or refinery and pipeline distribution systems. Excludes "Millwrights" (49-9044), "Mobile Heavy Equipment Mechanics, Except Engines" (49-3042), and "Maintenance Workers, Machinery" (49-9043). Illustrative examples: Hydroelectric Machinery Mechanic, Foundry Equipment Mechanic, Boilerhouse Mechanic	Applied associates degree and/or long-term apprenticeship/on-the-job training
Boilerhouse mechanic	47-2011 Boilermakers Construct, assemble, maintain, and repair stationary steam boilers and boiler house auxiliaries. Align structures or plate sections to assemble boiler frame tanks or vats, following blueprints. Work involves use of hand and power tools, plumb bobs, levels, wedges, dogs, or turnbuckles. Assist in testing assembled vessels. Direct cleaning of boilers and boiler furnaces. Inspect and repair boiler fittings, such as safety valves, regulators, automatic-control mechanisms, water columns, and auxiliary machines. Illustrative examples: Boiler Tester, Boiler Mechanic, Boiler Installer	Applied associates degree and/or long-term apprenticeship/on-the-job training
Accounting and administrative	43-3031 Bookkeeping, Accounting, and Auditing Clerks Compute, classify, and record numerical data to keep financial records complete. Perform any combination of routine calculating, posting, and verifying duties to obtain primary financial data for use in maintaining accounting records. May also check the accuracy of figures, calculations, and postings pertaining to business transactions recorded by other workers. Excludes "Payroll and Timekeeping Clerks" (43-3051). Illustrative examples: Mortgage Accounting Clerk, Bookkeeper, Accounts Receivable Clerk	Associates degree in accounting/finance with 2 years or more bookkeeping experience in manufacturing environment
Chemist	19-2031 Chemists Conduct qualitative and quantitative chemical analyses or experiments in laboratories for quality or process control or to develop new products or knowledge. Excludes "Geoscientists, Except Hydrologists and Geographers" (19-2042) and "Biochemists and Biophysicists" (19-1021). Illustrative examples: Industrial Chemist, Research and Development Chemist, Inorganic Chemist, Food Chemist	4-year degree in chemistry plus 2 years lab experience in manufacturing/quality control; 2 year associates degree plus relevant training and professional experience
Entry-level skilled or semi-skilled jobs		
Janitorial/maintenance assistant	37-2011 Janitors and Cleaners, Except Maids and Housekeeping Cleaners Keep buildings in clean and orderly condition. Perform heavy cleaning duties, such as cleaning floors, shampooing rugs, washing walls and glass, and removing rubbish. Duties may include tending furnace and boiler, performing routine maintenance activities, notifying management of need for repairs, and cleaning snow or debris from sidewalk. Illustrative examples: School Custodian, Window Washer, Industrial Plant Custodian	On-the-job training
Truck driver	53-3032 Heavy and Tractor-Trailer Truck Drivers Drive a tractor-trailer combination or a truck with a capacity of at least 26,000 pounds Gross Vehicle Weight (GVW). May be required to unload truck. Requires commercial drivers' license. Illustrative examples: Cement Truck Driver, Moving Van Driver, Auto Carrier Driver	Applied associates degree and/or long-term apprenticeship/on-the-job training; relevant state licensing requirements

4.5.8 POTENTIAL CONSTAINTS/OBSTACLES TO DEPLOYMENT

Economic Constraints

This section summarizes key resource, capital and operating cost, siting and market constraints that pellet manufacturing facilities operate under.

Resource Availability

Fuel supply reliability is crucial for the economic operation of a pellet manufacturing facility. New pellet manufacturing facilities are likely to utilize pulp wood quality forest biomass and clean sawdust and chips from mill residuals. Pulp wood quality trees are required because the logs need to be debarked to meet ash standards for pellet production.

For forest biomass, a key factor in the Consortium states is landownership. A significant proportion of the forest landownership in Montana, South Dakota, Wyoming and Utah is part of the National Forest System managed by the U.S. Department of Agriculture. National Forest System land is managed under guidelines set forth in periodic land and resource management plans that set allowable annual cut levels, and the ability for federal agencies to plan and administer timber sales and forest management projects is limited by federal funding allocations that occur on an annual basis. To some extent, these administrative requirements have resulted in a shift of timber harvesting to private land. In Montana, close to 80 percent of timber harvest occurs on private land[87]. Due to variability in wood biomass availability from federal land, in many areas of the Consortium, close coordination and planning between project developers and federal land managers is required when assessing appropriate project scale and evaluating fuel supply economics, if federal land is anticipated to be a major source of fuel.

Wood fuel cost is a key determinant of economics. Three key factors contribute to the cost of biomass: distance to source, wood quality/fuel processing requirements and current markets/competition for the resource.

Truck is the predominant means for biomass delivery. Rail delivery terms, pricing and on-site loading and unloading requirements are often cost-prohibitive. A 100,000-ton per year pellet manufacturing plant may only receive 25 to 30 truckloads per day. However a larger 250,000-ton per year facility can expect to receive 75 to 90 truckloads per day, which can significantly affect local traffic patterns. An industry standard value used for analysis of biomass transportation costs is $0.12 per loaded ton-mile, with a maximum economical haul distance of 100 miles. Most wood products facilities seek to acquire the vast majority of their resource from within 50 miles or closer to minimize transportation costs. Transportation costs for wood fuel range from $6 to $12 per ton for 50 and 100-mile distances, respectively.

Existing and proposed competition for wood fuel is a key determinant of pricing, first due to the potential for increased transportation distances, and second due to other market and competitive impact such as ability to pay that can affect economic availability for biomass within a given supply shed. This is of particular concern for project financing due to concerns over supply security and cost. There are a variety of ways to mitigate this risk, but a detailed supply competitive analysis is increasingly a requirement for financing and risk mitigation for a biomass power or biofuels project.

<u>Siting requirements</u>. Biomass pellet manufacturing facilities occupy a footprint ranging from approximately 5 to 10 acres for small facility to as many as approximately 225 acres for Green Circle, reportedly the largest pellet manufacturing facility in the world. The total plant footprint depends on the site configuration and degree of automation for fuel receiving, storage, processing and handling. The site needs to be accessible via tractor-trailers carrying a full load (typically 80,000 to 84,000 lb maximum but this varies by state) and have adequate on-site space to accommodate peak delivery volumes. The turning

[87] Morgan, T. (2009). *An Assessment of Forest-based Woody Biomass Supply and Use in Montana.* Missoula, MT: Montana Department of Natural Resources and Conservation.

lane (if present) may require improvements to permit adequate space to allow trucks to slow down upon entrance and accelerate upon leaving the facility, and accommodate turning lane traffic. A traffic analysis is typically conducted as part of plant engineering and planning processes.

The facility will need access to propane or natural gas lines for space heating and dryer startup. Locating adjacent to water supplies either from surface water or groundwater for cooling is typically needed for limited process and staff needs. Wastewater treatment requirements are not large, but a complete absence thereof could be considered a difficulty if septic systems cannot be used in a specific location.

Social Constraints

Land use and landowner preferences are major constraints affecting availability of biomass supply for pellet manufacturing and other bioenergy technologies. These need to be evaluated when considering feasibility of a bioenergy facility at a particular location, and when evaluating the reasonableness of policies related to biomass or biofuels development on a state or regional level.

Forest land owner preferences are crucial in determining their willingness to provide forest biomass to a biomass energy facility. For forest landowners, federal planning and administrative requirements were discussed in prior sections. Perhaps more important is the forest landowner management objective. If a forested area has historically been a forest-based economy that relies on timber production, there will likely not be as significant an issue. If land use emphasizes recreational values such as hunting, fishing, and tourism (even on large ranch properties that emphasize hunting leases as a portion of their income), there will be a more conservative approach to increasing mechanized forestry.

Environmental Constraints

The U.S. EPA recently finalized emission limits for both existing and new construction boilers and process heaters[88]. The new proposed standards place particularly strict emissions limits on new projects. Boilers burning 10 percent or more biomass (and not coal or other solid fuels) are regulated under one of 10 biomass subcategories (five for new units, five for existing units)[89]. Biomass units are now subject to strict limits on particulate matter, carbon monoxide, dioxin/furan, and mercury. This could prevent the implementation of new biomass projects due to high costs for annual emissions testing and additional pollutant control equipment.

Political Constraints

Significant community outreach and communication efforts are required for public acceptance of a biomass energy project. The acceptance issues encountered by biomass project developers are similar to those for other energy project developers but also have several unique concerns:

- Air emissions (perception of biomass as an incinerator rather than an energy facility, particulates, breathing health concerns, concerns about potential carcinogens);
- Water use and effluent discharge (In water constrained areas the use of water is always a major concern as is any effluent discharge);
- Truck traffic (safety, road conditions, traffic congestion);
- Noise;
- Odor;
- Aesthetics of facility;
- Environmental (forest sustainability, water quality, aesthetics of forest/woodlands, wildlife, land use change);
- Definition of "clean" biomass and inclusion of urban wood waste as part of fuel supply; and

[88] http://www.epa.gov/airquality/combustion

[89] Stoel Rives, LLP, Energy Law Alert: Boiler Hazardous Air Pollutant Emission Rules Released By EPA 2/24/2011

- Carbon neutrality of biomass.

Siting a bioenergy project within a residential area can be difficult because of the need to meet the concerns of a large number of stakeholders. Noise, odor, and facility aesthetics are all really associated with impacts of property values and probably associated with zoning issues in residential areas. Most biomass energy facilities are located outside of residential areas or have a significant land buffer between the facility and residential areas.

Each of these issues need to be evaluated thoroughly as part of resource and environmental assessment efforts and a concise communications strategy needs to be developed in advance of public meetings related to the project. This is the case regardless of whether the facility is located in a residential or a rural area. Input on facility siting can come from local groups but also can come from state or national organizations that are seeking to promote or slow down deployment of biomass energy technologies.

4.5.9 FUNDING SOURCES

Numerous funding sources are available for biomass research and technology deployment including education and training infrastructure development, such as the U.S. DOE, USDA Rural Development, and USDA Forest Service Forest Products Laboratory. Solicitations are highly competitive and often require multiple submissions to succeed in obtaining funding. The USDA Biomass Crop Assistance Program provides assistance to producers of biomass fuel for energy use.

Chapter 5. Smart Grid and Transmission

SME Information

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5.1 TECHNOLOGY DESCRIPTION

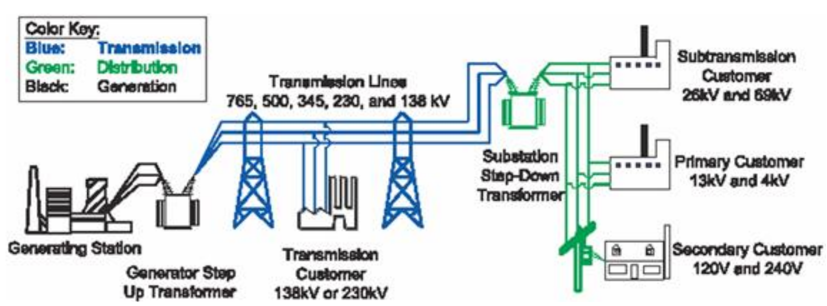
The US Energy Information Administration estimates that the nation's demand for electricity will increase at least 30 percent in the next 25 years[90]. Serving that demand will require conservation, continued development of renewable sources of electricity such as wind, solar and geothermal generation and continued reliance on traditional sources of generation such as coal, natural gas and hydroelectricity. Technological developments are expected to make these traditional generation sources cleaner and more efficient.

Technological advancements in electricity generation will be marginalized, however, without significant efficiency upgrades to the nation's electrical grid. The U.S. DOE, Office of Electricity Delivery and Energy Reliability (OE) is working to "lead national efforts to modernize the electric grid; enhance security and reliability of the energy infrastructure; and facilitate recovery from disruptions to energy supply." One key element of OE's strategy for modernizing the electric grid is to take advantage of the potential for information technology to change the operational and control strategies it uses to help keep electricity affordable by improving the cost-effectiveness of grid infrastructure investments and increasing the reliability of electricity supply and delivery to customers. OE has played a leading role in identifying this opportunity, which has come to be known generically as the "smart grid."

In order to comprehend the smart grid, it is important to understand the kinds of assets involved in a smart grid and how they are functionally engaged to provide cost efficiencies. This sets the context for why a smart grid is likely to be deployed and what assets it is likely to contain that can be leveraged for additional benefits.

Electricity has historically been generated at central station power plants and distributed to customers, as shown in Figure 5.1. The voltage is stepped-up from large central generating stations for transmission through 10,287 transmission stations, stepped-down for utility distribution in 2,178 distribution substations (DOE/OE 2006), may be further stepped-down at points along the utility distribution lines (feeders), and again at pad- and pole-mounted transformers to provide low-voltage service to one or several customers.

Figure 5.1. Today's Electricity Delivery System (Source: DOE/FEMP [2009])



[90] US Energy Information Administration, Annual Energy Outlook 2011 with Projections to 2035

The delivery of electricity typically utilizes a supervisory control and data acquisition system (SCADA) that provides monitoring and control from generation through the step-down substation to detect the need for an increase/reduction in generating resources, and to respond to system instabilities. There are several limitations to SCADA systems.

- Limited bandwidths and relatively slow data transmission rates often require several seconds or more to respond to an alarm or system change.
- There is often limited or no visibility in the distribution network below the substation.

The coming evolution in the delivery of electricity is the smart grid, which is the application of information technology that enables more visibility and control of both the existing grid infrastructure and new grid assets, such as customer demand response and distributed energy resources consisting of small generators and electricity storage devices.

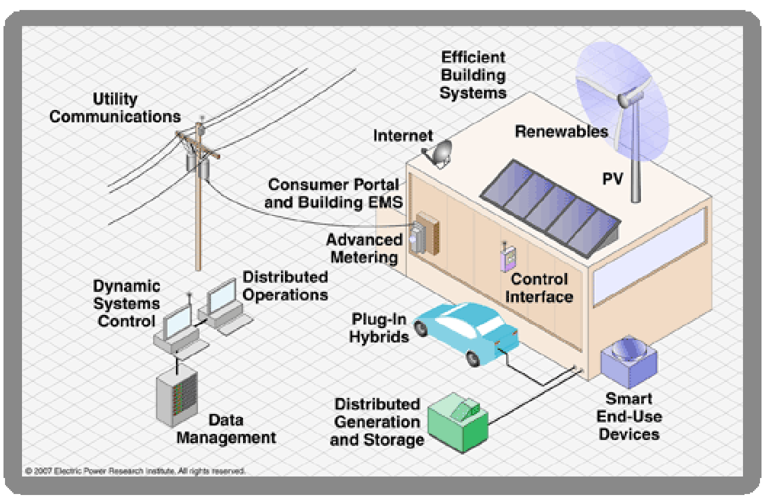
The smart grid's much higher fidelity control is provided through high-speed, two-way communication, sensing, and real-time coordination of all assets down to the customer meter and the end-use devices. Thus the smart grid is not characterized by a single technology or a device, but instead is a vision for a distributed, internet-like system that will:

- provide better control of existing grid infrastructure assets;
- provide additional functionality and benefits from existing assets;
- integrate new (often small, widely distributed) assets into the existing operational paradigm;
- engage these new assets to provide entirely new benefits to the grid.

The next immediate developments in SCADA technology for utilities are to increase bandwidth and begin to measure and control assets below the substation level, at which time the system will begin to become part of a distributed control system—and a key part of the smart grid[91].

This vision is perhaps best understood by examining the following image.

Figure 5.2 Smart Grid Network (Source: Electric Power Research Institute)



[91] Boyer SA. 2007. "Collecting Data from Distant Facilities." *InTech.* http://www.isa.org

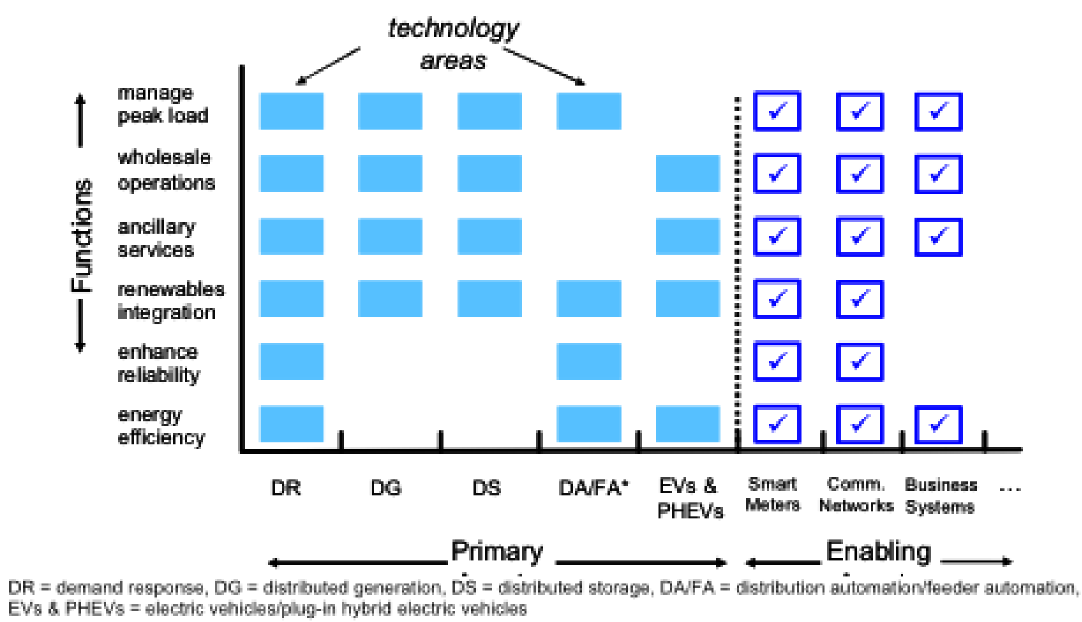
Beyond describing the smart grid as a vision, it is helpful to describe what the smart grid ***consists of*** in terms of:

- the **assets** that would be purchased; and
- the **functions** for which they would be used, and from which benefits are derived.

This is illustrated in the matrix in Figure 5.3, with a number of key assets on the horizontal axis and broadly defined categories of major functions on the vertical axis. This illustration of the current and emerging vision for the smart grid is not intended to be definitive or comprehensive, but rather will evolve over time.

Assets are divided into primary and enabling assets. *Primary assets* are the smart grid's "prime movers," i.e., non-traditional assets that are actively controlled to effect change in the grid's operating conditions.

Figure 5.3 Defining the "smart grid" in terms of assets and functions



Enabling assets are the sensing, software, and information infrastructure required to coordinate the operation of the primary assets to respond to grid conditions. Although more accurately portrayed as a separate third dimension, enabling assets are shown here on the same axis for clarity.

Functions are grid operational strategies that use smart grid assets to derive cost, reliability, and efficiency or renewable energy benefits. The intersection of an asset and a function, denoted as a technology area, is the set of policies, engagement strategies, incentive mechanisms, control strategies, software applications, and capabilities of the primary and enabling assets required to accomplish a given function.

Primary Assets

The *primary assets* in Figure 5.3, broadly considered key to the smart grid, are:

1) Demand response (DR) – communications and controls for end-use devices and systems to reduce (or, in special cases, increase) their demand for electricity at certain times.
2) Distributed generation (DG) – small engine or turbine generator sets, wind turbines, and solar electric systems connected at the distribution level.
3) Distributed storage (DS) – batteries, flywheels, super-conducting magnetic storage, and other electric and thermal storage technologies connected at the distribution level.
4) Distribution/feeder automation (DA/FA) – distribution and feeder automation expand SCADA communications in substations and into the feeders with remotely actuated switches for reconfiguring the network, advanced protective relays with dynamic and zonal control capabilities, dynamic capacitor bank controllers, and condition-based transformer-management systems (to name a few).
5) Transmission wide-area visualization and control – transmission control systems that rapidly sense and respond to disturbances.
6) Electric and plug-in electric hybrid vehicles (EVs/PHEVs) – the batteries in EVs represent both a new type of load that must be managed and an opportunity for them to discharge as energy storage resources to support the grid.

Demand response is intentionally defined as an asset, to differentiate the ***investment*** required for installing its control and communications capabilities from its ***use*** to achieve one or more functions. Although the term *demand response* is often used to represent both the asset and its use for the peak load management function, this is more precisely the technology area represented by the intersection of the demand response asset and the peak load-management function. This distinction between demand response as an asset and the functions it can provide is helpful because demand response, like many other smart grid assets, can provide a number of other functional benefits ranging from ancillary services to reliability. Along with distributed generation and storage, demand response can play a key role in providing the additional ancillary services and reliability required for effectively integrating renewables. Additionally, there is potential for the control signals that support demand response to be used for conducting end-use system diagnostics and improving feedback to consumers to obtain energy efficiency.

The notion of ***active control in response to grid conditions*** is the foundation of the notion of a smart grid. Most energy efficiency investments are *passive* in that they require no control at all (better insulation or air conditioner efficiency, for example). Some forms of *active* energy efficiency are control-based (e.g., thermostat setbacks, clothes dryer humidity controls) but are not designed to be responsive to grid conditions. Hence, energy efficiency investments, while critical to obtaining efficiency and carbon savings, are not smart grid assets in this framework. However, this report does consider obtaining efficiency benefits as a functional objective for the use of smart grid assets.

Similarly, renewables themselves are not generally envisioned as a controllable smart grid asset. The carbon-free energy they supply is critical to achieving the nation's carbon-management goals, however. One of the functions of a smart grid is the ability to manage the assets under its control to help integrate renewables, such as mitigating the need for additional costly ancillary services to manage their intermittency, and reducing costs for improved voltage control schemes and short-circuit protection.

Enabling Assets

Investments in a number of *enabling assets* are also necessary to support the use of the primary assets for smart grid applications, hence the function of a smart grid. Among these cross-cutting technologies are:

1) wide-area communications networks, servers, gateways, etc.;

2) smart meters–beyond what many consider as basic advanced metering infrastructure (AMI) technology, a more fully smart meter could also support shorter metering intervals approaching 5 minutes or less to support provision of ancillary services and distribution capacity management (rather than the hourly interval generally considered adequate for peak load management at the bulk power systems level);
3) full two-way communications including to a home-area network to communicate to smart thermostats and appliances;
4) instantaneously read voltage, current, and power factor to support distribution state estimation and optimized system volt-VAR control;
5) offer remote connect/disconnect functionality for reliability and customer service applications;
6) local-area home, commercial building, and industrial energy management and control systems (EMCS) and networks;
7) consumer information interfaces and decision support tools; and
8) utility back-office systems, including billing systems.

Other key technical ingredients of the smart grid that are similarly cross-cutting, but are typically embedded in assets are:

1) cyber-security technologies for secure communications for all levels of operation
2) an interoperability framework, and associated standards and protocols that focus on communications between the various SCADA control domains inherent in the smart grid: including the Independent System Operator/Regional Transmission Organization utility, customer, and aggregator.

Functions: Operational Objectives

Functions are the benefits or applications to which smart grid assets are engaged to improve cost effectiveness, reliability, and energy efficiency of the power system. These can be summarized in broad categories corresponding to the benefits derived:

- managing peak load capacity for generation, transmission, and distribution
- reducing costs for wholesale operations
- providing enhanced reliability/adequate reliability at less cost
- providing ancillary services
- reducing the operational costs of integrating renewables
- leveraging the network for energy efficiency and carbon savings.

Managing peak load capacity includes displacing the need for new generation, localizing this function to displace the need for new transmission, further localizing it to manage capacity to offset the need for new and upgraded distribution substations and feeders, and managing transformer loading to extend their lifetimes. About 40% of grid infrastructure costs are for generation capacity, which must be adequate to serve peak load demand while maintaining adequate reserves for forced outages and contingencies. In light of growing demand for generation worldwide, environmental constraints on new coal generation, the imposition of renewable generation portfolios by states, rising costs for steel, concrete, and other materials, and costs for new generation capacity to meet load growth are expected to grow substantially. Another 40% of infrastructure costs are for distribution systems, so the opportunity to manage peak load demand at the substation level is an important opportunity. Peak load management from demand response, distributed storage, and optimization of distribution delivery voltages and power factors can all serve to defer investment in generation, transmission, and distribution systems. The value stream from this is derived in terms of the avoided carrying costs for investment in new capacity.

Reducing costs for wholesale operations involves lowering the demand for generation when marginal production costs are greater than revenues from retail sales, similarly minimizing purchases or maximize production when wholesale prices are high, and reducing transmission loads when and where congestion costs are high. This can be accomplished by utilizing demand response, distributed storage, and distribution voltage controls to reduce net demand.

A smart grid can enhance reliability in two fundamental ways. It can prevent and limit blackouts with transmission wide-area control and visualization tools that enhance situational awareness and rapidly reconfigure the transmission grid to prevent or limit a blackout. At the distribution level, where the vast bulk of outages occur in terms of aggregate customer-minutes without power, outages are typically caused by events such as vehicle accidents, wind and ice storms, and animals shorting out transformers, rather than systemic failures. To remedy these outages, distribution and feeder automation assets can be used to rapidly isolate faults and then reconfigure distribution feeders through remotely actuated switches. This shortens the recovery time for nearly all customers from an hour or more to a matter of seconds. In its ultimate form, this is a stand-alone microgrid fully capable of supplying its own power and managing its local distribution.

Beyond power production, many ancillary services are provided by power plants to keep the grid in a stable and reliable condition. These include the following:

- *Regulation* is supplied on a minute-by-minute basis to control the supply/demand balance by continually throttling variable-output power plants.
- *Ramping and load following* are similarly required to manage the grid when the rate of load change is high, such as the morning and late evening.
- *Spinning and non-spinning reserve* capacity is required to manage the sudden, forced-outage loss of power plants scheduled to generate electricity on a given day.
- *Reactive power* needs to be supplied by power plants to correct phase shifts between current and voltage due to system load variance.

The highest cost resources in power markets that quantify such services are those for short-term regulation. Today, we turn power plants up and down continually to provide regulation, which wastes fuel and increases wear and tear on the plants. Ancillary services could be supplied by dispatching the smart grid's demand response, distributed generation, and storage assets to provide regulation and load following services, and using them in standby mode (when not otherwise engaged) to provide spinning reserves. While valuable in today's grid operations, the need for ancillary services is projected to increase as large amounts of renewable generation penetrates the grid, due to the intermittency of output from wind and solar generators.

5.2 TECHNOLOGY DEPLOYMENT

Approximately 70 utilities in the US have filed some form of advanced metering infrastructure (AMI) plan as a precursor to smart grid deployment[92].

Consortium states Montana and Wyoming are participating in the five-year Pacific Northwest Smart Grid Demonstration Project with the Battelle Laboratories, Bonneville Power Administration and a number of Northwest and Rocky Mountain region utilities, including Montana's NorthWestern Energy and Flathead Electric Cooperative and Wyoming's Lower Valley Energy. The project will demonstrate smart grid technologies across five states (Idaho, Montana, Oregon, Washington and Wyoming) and will involve more than 60,000 metered customers.

The project aims to implement distributed communication and a control and incentive system. Homeowners will be provided a combination of devices (smart meters), software and advanced analytical

[92] The U.S. Smart Grid Revolution: KEMA's Perspectives for Job Creation," January 13, 2009

tools to give them more information about their energy use and expenses. Data will then be collected to provide information about energy consumers' behavior while using these new technologies[93].

NorthWestern Energy's largest customer base is in Montana, but its involvement in smart grid technology could eventually be expanded to its customers in Consortium states South Dakota and Nebraska as well.

5.3 POTENTIAL JOB IMPACTS

According to a study conducted by KEMA on behalf of the GridWise Alliance—a consortium of industry smart grid stakeholders—the development of a national smart grid will create about 280,000 new direct jobs and an additional 140,000 industry supplier jobs.

Implementing smart grid will require a wide range of skills and education. Table 5.1 describes the jobs required for implementation. Many of these jobs will likely be filled by a mix of existing utility employees and outside consultants.

Table 5.1 Smart Grid Jobs

Smart Grid Position	**During Implementation**
Reclosers	X
Breakers	X
Sensors	XX
Communications Installation Management	XX
IT Software Upgrades, Replacement and New Applications	X
CIS	X
AMI	X
MDM	X
WAM	X
Net Metering Applications	X
OMS	X
DMS/SCADA	X
Demand Response	X
Asset Management	X
Customer Service (call centers, account managers)	XX
Functional Specialists	
Special Metering	XX
Outage Management	XX
Net Metering (solar, wind, other DG)	XX
Prepaid Services	XX
Demand Response	XX
Special Billing	XX
Vehicle to Grid	XX
Theft Prevention	XX
Field Technical Support	XX
Distribution Automation	XX
System Planners & Engineers	XX
Asset Management	XX
Power Quality	XX
Project Office Leadership	
Project Manager	X
Executive Assistant	X
Lead Consultant	X
Program Support	
Scheduler(s)	X
Budget Analyst	X
Contacts Administrator	XX
Resource Manager	X
Communications Manager	X
Change Management Lead	X
Legal Support	X
Quality Assurance	

[93] Battelle Laboratories, 2010

Vendor Management	X
Test and Verification Supervisor	X
Performance Analysis	X
Planning	
Requirements Development Manager	X
Business Case Manager	X
Telecom/Communications	X
IT Interface (software, DB)	X
Grid Upgrades (e.g., Dist. Auto.)	X
Regulatory support for rate planning	X
Marketing and Outreach planning	X
Financial Support	
Rate Design Implementation	X
Marketing Implementation	X
Public Relations	X
Revenue Cycle Services	X
Implementation Operations & Support	
Supply Chain and Inventory Management	XX
Logistics	XX
Meter Receipt Testing	XX
Meter Disposal	XX
Meter Installation (incl. field testing)	XX
Grid Component Installation Management	X
Transformers	X

KEMA estimated that national implementation of smart grid with participation from all utilities would create over 117,000 jobs to supply equipment. Assuming manufacturing efficiencies over time, and accounting for equipment upgrades and failures more than 90,000 positions on an on-going basis would be needed. Table 5.2 demonstrates the initial and on-going smart grid equipment supply jobs that would be created by national smart grid deployment.

Table 5.2 Jobs Needed to Support Smart Grid by Direct Suppliers

	Supply Chain Impact	
	Deployment	**Ongoing**
In Home Devices	49,300	
AMI Meters	5,100	6,500
Communications Equipment	38,700	52,200
Distribution Automation Hardware	18,800	24,100
MDM Hardware	1,300	1,700
Back Office Hardware	4,500	6,100
Total Jobs	117,700	90,600

The Pacific Northwest Smart Grid Demonstration Project is expected to create 1,500 jobs in the five participating states. 500 of those jobs will be located in Washington with the remaining 1,000 divided among Idaho, Montana, Oregon and Wyoming.

5.4 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

The primary factors that could limit deployment of smart grid are capital spending constraints, workforce reductions and supply chain barriers[94]. Customers receiving smart meters and other technological benefits would realize savings almost immediately. However, the broader installation of smart grid systems would take significant time, potentially moving cost benefits for utilities into the distant future and decreasing momentum for full deployment.

[94] The U.S. Smart Grid Revolution: KEMA's Perspectives for Job Creation," January 13, 2009

Chapter 6. Solar Energy: Nanostructured Solar Cells (Photovoltaics)

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Solar energy can be used for a variety of energy technologies, from producing steam for industrial processes, heating fluids and producing electricity. This report evaluates developments in photovoltaic cells, devices made of semiconductor material that converts sunlight into electricity. Photovoltaic technology is rapidly improving and developing.

6.1 TECHNOLOGY DESCRIPTION

The current and recent market for photovoltaics has been dominated by crystalline silicon technology, accounting for 81% of domestic shipments in 2008. Thin-film amorphous silicon technologies accounted for another 17% of the domestic shipments in 2008 and silicon-based photovoltaics, using solar concentrator technologies, accounted for most of the remaining 2% market share[95]. The solar concentrator technologies showed the highest energy-conversion efficiencies at the highest cost and the thin-film technologies showed the lowest efficiencies at the lowest cost. Crystalline-silicon-based photovoltaic modules were intermediate in cost and efficiency as shown in Table 6.1.

Table 6.1 Average solar cell module costs

Technology	**Module Cost ($/peak Watt)**	**Efficiency**
Crystalline silicon	$3.97	19%
Amorphous silicon	$2.82	8%
Concentrator silicon	$5.74	34%

Comparing these costs to the current residential cost of electricity of approximately $0.09/kWh, an initial module cost of $3.97/Watt, requires 5 years of use to recoup the investment, assuming that the module is continually operating at peak during that time. A more realistic estimate would include diminished performance under low light levels, including nighttime.

Thus, operating at an average of 50% of peak requires 10 years to recoup the initial investment. Emerging technologies in nanostructured solar cells have the potential of significantly reducing the module cost.

In a somewhat simplified model, photovoltaics function begins with the absorbance of light energy by an electron, which is subsequently freed from its association with any individual atomic center or localized set of atom-atom bonds. In photovoltaics based on semiconductors like silicon, one refers to the electron as being promoted from the "valence band." Valence electrons are bound to individual atoms, as opposed to conduction electrons that can move move freely and conduct electricity. When absorbance of light results in promotion of an electron to the conduction band, an electron-vacancy or "hole" is created in the

[95] The Energy Information Agency of the US Department of Energy

valence band. In order to harvest the electron's energy, and in order to create a directional flow of electrons as electricity, a built-in bias or voltage must be created to cause the electrons and holes to migrate in different directions, such that the electrons can be separated from the holes, with which they will otherwise recombine, and such that the electrons can be harvested at the electrode. In Crystalline silicon solar cells, this built-in bias is created at the junction where highly-purified silicon is differentially-doped with small amounts of specific impurities, designated as n-type or p-type. The built-in voltage, and thus a preferential direction for electron movement, is created at the junction where the p-type doped silicon meets the n-type doped silicon.

Crystalline silicon solar cells of this description are referred to as First-Generation Solar Cells. They show laboratory efficiencies in excess of 24% (conversion of light energy to electrical energy) and commercial-product efficiencies which averaged 19% in 2008. (See Table 6.1.) This may be compared to the historical energy conversion rate for coal-fired power plants of approximately 33%. Thus, first generation solar cells have favorable efficiencies and make use of a zero-cost fuel resource. Nevertheless, the cost of electricity from first-generation solar cells is estimated by the Energy Information Administration as four times that from conventional coal fired power plants. Much of that cost derives from the high-cost of processing the silicon and manufacturing the cells. First Generation Solar Cells are characterized by high efficiency and high cost. Second-Generation solar cell technologies result from a goal of reducing materials and processing cost. Thin film technologies, currently dominated by amorphous and polycrystalline silicon, fall into this category. Current examples show lower absolute efficiencies than first generation solar cells, but an overall lower cost per peak-KW. Second Generation solar cells are characterized by low cost and low efficiency. Third Generation Solar Cells represent an aspirational concept of solar cells with simultaneous low cost and high efficiency.

Several emerging technologies exist that address the issues of device cost and efficiency. Improvements through recent research suggest that some of these technologies will be competitive with conventional electricity sources and will be commercialized within the next five years. Two technologies appear to be particularly promising: Bulk Heterojunction Solar Cells and Dye-Sensitized Solar Cells (Graetzel cells).

6.2 TECHNOLOGY DEVELOPMENT PROGRESS

Bulk Heterojunction (BHJ) Solar Cells

The photoactive layer in a bulk heterojunction solar cell is composed of a mixture of a light absorbing polymer, wherein the conducting electrons are generated, and an acceptor molecule to which electrons are passed, under the influence of a molecular-level bias-voltage. The most common acceptor molecules under investigation are derivatives of buckministerfullerene (C_{60}) commonly referred to as buckyballs. The electrons passed to the acceptor molecule must hop from acceptor to acceptor molecule as they make their way toward the electrode (the anode). The holes are mobile in the polymer and must be transported to the cathode where they receive electrons back from the external circuit. The bulk heterojunction mixture itself provides no preferred spatial direction for either electron or hole movement. Instead, a polymer layer capable of conducting holes, but not electrons, is placed between the photoactive layer and the cathode and a hole-blocking layer, capable of conducting electrons, but not holes, is placed between the photoactive layer and the anode.

Thus the photocell is made of multiple very thin layers of flexible polymer and charge blocking films. It can be formed on a flexible substrate to give an overall flexible, lightweight solar cell. The solar cell can also be formed as a film on glass, to create semitransparent, energy generating windows. The color of the film is determined by the light absorbance of the photo-active polymer.

Advantages include low materials and processing costs, lightweight, flexible structure, and potential for high energy conversion efficiencies. Technological advances include development of novel, more efficient conducting polymers, new derivatives of the C_{60} acceptor, new formulations and methods for mixing the polymer donor and C_{60} acceptor, and new, inexpensive ways of laying down the layers with solution-based roll-to-roll processing.

Bulk heterojunction solar cells are now in the very early stages of commercial availability through Konarka, marketed as Power Plastic® with applications in microelectronics, portable power, remote power, and building integrated photovoltaics (BIPV). Konarka and Arch Aluminum and Glass announced in May 2009 their intent to explore development of a line of attractive, semi-transparent, glass BIPV products called Active Solar Glass® (ASG)[96]. Figure 6.1 shows a test project for a Power Plastic curtain wall at Arch Aluminum and Glass.

Figure 6.1*: As a test product, Konarka's Power Plastic Curtain Wall at Arch Aluminum and Glass produces 1.5 kW for the building, using bulk heterojunction solar cell technology.*

Dye-Sensitized Solar Cells (DSSC, Graetzel cells)

Dye-sensitized solar cells are based on very fine powders (nanoparticles) of a high-bandgap semiconductor, most commonly, titanium dioxide (TiO_2)[97]. The bandgap, which is the energy difference between the valence and conduction bands is so high that the semiconductor alone would require ultraviolet light in order to excite electrons to the conduction band. The semiconductor alone is transparent to visible light and can make no use of that part of the solar spectrum for electricity generation. However, if the powder is soaked with an appropriate dye, the dye—which adsorbs to the surface of the semiconductor nanoparticles—will absorb light in the visible spectrum. The excited electron from the dye can be passed to the semiconductor particle, which can subsequently pass it along to another particle, such that the electron ultimately ends up at the anode of the cell. The dye molecule is left with a hole that must be filled. Currently, this is accomplished with a liquid electrolyte (an iodine/iodide mixture, for example) that can both pass an electron to fill the hole in the dye and can pick up an electron from the cathode with which it is in direct contact.

Advantages include low materials and processing costs, light weight, flexible structure, and potential for moderate energy conversion efficiencies. Technological advances include development of new dyes which have good stability and can efficiently harvest light from the solar spectrum, development for new morphologies (rods vs. spheroids) for the semiconductor particles, development of new electrolytes that have good stability and capacity to quickly fill the holes in the excited dye, development of organized assemblies of particles for efficient electron transport, and development of new processing techniques for cost-effective production.

In November 2009, G24 Innovations (G24i), a company based in the United Kingdom, claimed the first commercial product to incorporate dye-sensitized thin-film solar cells in backpacks and handbags. They were marketed by Mascotte Industrial Associates (Hong Kong) Limited with the capability to power small gadgets like cell phones or MP3 players[98]. Samsung SDI described development of power generating, stained glass windows[99]. Yoon Lee announced SUNiT, a solar cell window blind which uses

[96] Press Release at http://www.archaluminum.net/press/pdf/Arch_Konarka.pdf
[97] Michael Graetzel, "Recent Advances in Sensitized Mesoscopic Solar Cells," *Acc. Chem. Res.*, 2009, *42* (11), pp 1788–1798.
[98] http://www.g24i.com/pages,profile,8.html
[99] http://samsungsdi.com/nextenergy/dssc-solar-cell-battery.jsp

DSSC technology and batteries to store energy during the day and provide nighttime lighting. Neither the Samsung Windows nor the SUNiT Window blinds appear to be commercially available.

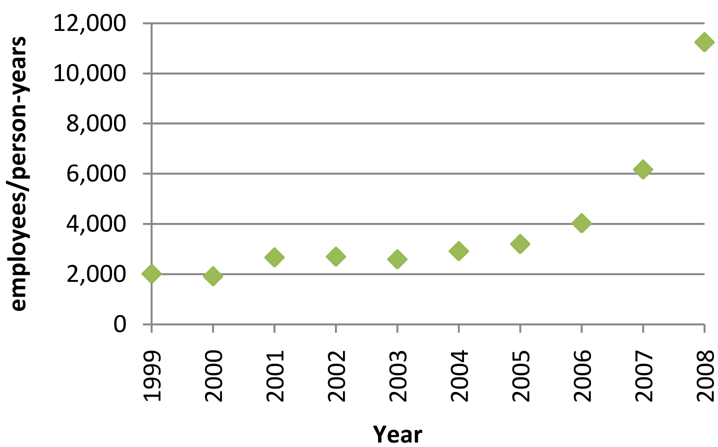
Figure 6.2: *Solar power backpack (G24i and Mascotte Industrial Associates) and SUNiT Solar powered window blinds make use of dye-sensitized solar cell technology.*

Launched only in 2009, commercial technology production and deployment is currently on a small scale, largely aimed at consumer products rather than large-scale power generation. With favorable development in cost, the consumer products market impact could be very large. However, production and deployment in consumer products can easily be performed overseas, and labor for production of these new technology solar cells will experience the same competitive forces which act upon the current solar cell industry. For larger-scale power generation, manufacturing will still experience competition from overseas but deployment in the US will necessarily have a labor impact in the US.

6.3 POTENTIAL JOB IMPACTS

In 2008, approximately 60% of US shipments of solar cells and modules were imports and most of those imports were derived from the Philippines, Japan, and China in that order. The fraction of imports has grown continually, surpassing the domestic production starting in 2005. Employment in the US photovoltaic manufacturing industry has also grown rapidly since 2005 as shown below in Figure 6.3.

Figure 6.3: Number of US employees in solar cell and module manufacturing



Total employment in the solar sector includes research and development, manufacturing, sales, distribution, installation design, installation, and maintenance, among others. Specific job titles are given in Table 6.2, derived from the Occupational Information Network (O*NET) website[100], an online resource developed under the sponsorship of the US Department of Labor/Employment and Training Administration (USDOL/ETA) through a grant to the North Carolina Employment Security Commission[101]. However, the employment statistics O*NET reports for photovoltaic-specific areas appear inflated when compared to manufacturing jobs given by the EIA and are furthermore accompanied by the disclaimer "This title represents an occupation for which data collection is currently underway." Thus, in the absence of data, one might roughly estimate that the total US employment in the solar sector, including sales, distribution, and installation of imported modules, to be on the order of 100,000 persons in 2008. However, manufacturing would indicate that this is a rapidly growing area of employment—quadrupling between 2005 and 2008.

[101] Reference O*Net website at http://online.onetcenter.org/

Table 6.2: Occupations in the Solar Sector Businesses in SD

Job Title	SOC	O*Net Salary (2009)	Projections
Engineering Managers	11-9041.00	$56.25 hourly, $117,000 annual	Green
Human Resources, Training, and Labor Relations Specialists, All Other	13-1079.00	$27.14 hourly, $56,440 annual	BO
Architectural Drafters	17-3011.01	$21.92 hourly, $45,600 annual	Green
Solar Energy Systems Engineers	17-2199.11	$43.06 hourly, $89,560 annual	BO, Green
Electronics Engineering Technicians	17-3023.01	$26.36 hourly, $54,820 annual	Green
Electrical and Electronic Equipment Assemblers	51-2022.00	$13.77 hourly, $28,640 annual	Green
Electricians	47-2111.00	$22.68 hourly, $47,180 annual	BO, Green
Solar Sales Representatives and Assessors	41-4011.07	$34.30 hourly, $71,340 annual	BO, Green
Sales Engineers	41-4011.07	$34.30 hourly, $71,340 annual	BO, Green
Solar Energy Installation Managers	47-1011.03	$28.04 hourly, $58,330 annual	BO, Green
Solar Photovoltaic Installers	47-4099.01	$16.34 hourly, $33,980 annual	BO, Green
Bookkeeping, Accounting, and Auditing Clerks	43-3031.00	$16.08 hourly, $33,450 annual	BO
Secretaries, Except Legal, Medical, and Executive	43-3031.00	$16.08 hourly, $33,450 annual	BO

In spite of rapid growth, solar sector employment currently impacts a very small part of the total US labor force. Employment is limited by market demand and market demand for photovoltaics is primarily limited by the high cost per peak Watt and the consequent long time interval for return on investment. Silicon is an abundant element, but it is expensive to process. A favorable shift in demand, and thus potentially in employment, can be driven by a reduction in the price per module or by an increase in the efficiency of the modules, the two factors which determine the cost per peak Watt. A shift in demand would also be expected if the price of electricity from conventional sources were to increase.

A search was made for solar sector companies in all of the Consortium states. Data were gathered from a leading on-line resource for renewable energy companies[102]. This directory may not be comprehensive.

In Table 6.3, the number of solar sector companies is given for each of the Consortium states. The source guide indicates the business types as manufacturing, design, retail, consulting, etc. Retail sales is the dominant business type in all states, followed by service (maintenance) and installation.

Table 6.3: Solar Related Industry Comparison Between SD, NE, WY, IA, MT, UT

State	Number of Solar Companies
SD	9
NE	10
WY	10
IA	22
MT	18
UT	40

The current economic impact of solar industries in Consortium states is small. Specific data about solar industry impacts in all Consortium states is not available, yet a survey of the solar companies in South Dakota was completed in 2010[103]. Information about solar employment in the remaining Consortium states could be extrapolated from this survey and the number of solar companies in each state.

The South Dakota solar company survey demonstrated that half entered the solar sector in the last year. Moreover, most companies are still in the early development stage of their product and only four of the companies reported significant revenues from solar activities. Table 6.4 gives the number of employees for each of the companies and the annual sales of solar cells, modules, and solar-powered devices in kilowatts (KW) and in dollars. The sales are divided between sales in SD and sales made to destinations outside of South Dakota. Over 70% of sales are delivered to out-of-state customers.

[102] http://www.sourceguides.com/index.html
[103] A survey of solar sector companies in South Dakota conducted for this report by Dustin Pratt and Mary Berry in July 2010.

Table 6.4: Number of Employees and Revenue from Solar-Sector Sales in South Dakota

Company	**Number of Employees in SD**	**Sales in SD (kW)**	**$**	**Sales Outside of SD (kW)**	**$**
GenPro Energy	22	18	$125,000	300	$2,000,000
PowerPlus Energy	13	300	$2,100,000	600	$4,200,000
Birdneck Renewable	1	<1	n/a	<1	n/a
Black Hills Solar	1	9	$63,000	n/a	n/a
Lynn's Heating and Air	2	<1	n/a	<1	n/a
Absolute Renewable	1	<1	n/a	<1	n/a
Cleaner Greener	2	<1	n/a	<1	n/a
Oakleaf, Inc.	5	n/a	n/a	n/a	n/a
Go Solar Distributing	2	5	$35,000	12	$84,000
Johnson Environmental	1	<1	n/a	<1	n/a
Total	**50**	**332**	**$2,323,000**	**912**	**$6,200,000**

Solar Sector activities in South Dakota were primarily related to solar panel installation, distribution, and design for implementation of solar power in operations (e.g., solar-powered water pumps by Gen Pro). No solar cell manufacturing was reported in South Dakota. Most of the solar cells sold were manufactured in China. South Dakota companies reported revenues from sales of solar cells, modules, and devices of $8.5M and 1.2 MW, with 73% of the sales made to destinations outside of South Dakota.

Manufacturing/Building Jobs

Manufacturing of third generation BHJ and DSSC solar cells will require facilities equipped with clean room environments (modest specifications) and thin-film coating capabilities. For solar cells built on flexible substrates, roll-to-roll processing is expected to be highly cost effective.

With roll-to-roll printing it will be feasible to print individual solar cells, integrated solar modules, or electronic devices with integrated solar cells. Roll-to-Roll processing is a well-established technology, already used in manufacturing of films and tapes, and electronic devices, and is a straightforward adaptation of traditional printing technology.

Construction Jobs

An increase in domestic manufacturing of DSSC and BHJ solar cells, modules, and devices will require construction of new manufacturing buildings and manufacture of roll-to-roll printers. New transmission lines, substations, etc. would only become relevant if solar power plants are built.

Marketing Jobs

This technology will likely first be marketed directly to consumers as a power source for small electronic devices or to manufacturers of small electronic devices. It may also be marketed to consumers and to construction/architectural firms for add-on solar panels for homes or for building-integrated photovoltaics (BIPV).

The labor impact will be development of new jobs for persons with expertise in sales and knowledge of photovoltaics and issues in power generation. For example, positions for the job title, Solar Sales Representatives and Assessors will be created.

Maintenance Jobs

Maintenance skills will be similar to installation skills providing employment opportunities for:

PV Installers/Electricians with NABCEP (National American Board of Certified Energy Practitioners) certification.

Education and Job Skills Training

Solar Sector Employers in South Dakota[3] were surveyed and cited a lack of a trained labor force as an obstacle even in the current generation of solar sector technology. They cited a lack of:

- PV Installers/Electricians with NABCEP (National American Board of Certified Energy Practitioners) certification
- Electrical Engineers with training emphasis on renewable energy.
- Candidates with experience working in industry.

The new technologies will also require for research and development:

- Materials scientists, chemists and chemical engineers
- Electrical engineers

Deployment and maintenance will require an increased number of:

- PV Installers/Electricians as above

Natural Resource Harvesting Education and Job Skills Training

This category is less intensive in the solar sector than to some other renewable energy sectors. Necessary natural resources for solar production include:

- land area for power generation
- petroleum-based feed stock for polymer and dye manufacturing
- titanium for TiO_2 active layer in DSSC
- indium for transparent conducting oxide (ITO)
- Calcium, titanium or zinc for metal oxides in hole-blocking layers of BHJ solar cells.

Harvesting these resources will require training in:

Mining (Mining and Geological Engineers, Including Mining Safety Engineers), Meteorology (Atmospheric and Space Scientists), and for harvesting,
Land and Water Management (Soil and Water Conservationists).

Manufacturing/Building Education and Job Skills Training

The US Bureau of Labor Statistics gives a list of jobs for Chemical Manufacturing (excluding drugs)—which is also appropriate for the manufacture of third generation (DSSC and BHJ) solar cells.

Table 6.5: Occupations for Solar Cell Manufacturing as adapted from Chemical Manufacturing Potentially Requiring Specialized Training

Management, business, and financial occupations
• Management occupations
• Business and financial operations occupations
Professional and related occupations
• Computer specialists
• Chemical engineers
• Industrial engineers
• Chemists
• Chemical technicians
Sales and related occupations
• Sales representatives, wholesale and manufacturing
Office and administrative support occupations
• Bookkeeping, accounting, and auditing clerks
• Customer service representatives
• Production, planning, and expediting clerks
• Shipping, receiving, and traffic clerks
• Secretaries and administrative assistants
• Office clerks, general
Installation, maintenance, and repair occupations
• Industrial machinery mechanics
• Maintenance and repair workers, general
Production occupations
• First-line supervisors/managers of production and operating workers
• Team assemblers
• Chemical plant and system operators
• Mixing and blending machine setters, operators, and tenders
• Extruding, forming, pressing, and compacting machine setters, operators, and tenders
• Inspectors, testers, sorters, samplers, and weighers
• Packaging and filling machine operators and tenders
• Miscellaneous production workers
Transportation and material moving occupations
• Driver/sales workers and truck drivers
• Laborers and material movers, hand
• Laborers and freight, stock, and material movers, hand
• Packers and packagers, hand

6.4 FUNDING SOURCES

Funding for research and development is available through numerous federal sources at this time including: from the

- National Science Foundation, through the Energy for Sustainability and CHE-DMR-DMS Solar Energy Initiative (SOLAR)[104] Programs;
- the US Department of Defense, DARPA- Defense Advanced Research Projects Agency;[105]
- the U.S. Department of Energy (DOE) Solar Energy Technologies Program.[106]

Private sector funding is available through venture capital groups. In an article in *Report Linker*—an online resource for industry reports—an article entitled "Industry Primer: Solar Energy" discusses venture capital funding in 2009 for solar energy.

"In 2009, solar companies received more venture capital funding than any other segment of cleantech, in terms of both dollar value funded and number of deals closed. Solar M&A deal activity was up nearly 100% year-over-year in 2009, and deal flow has remained strong since the recent economic downturn rationalized public market valuations of solar energy companies. However, there are still drawbacks to solar energy adoption—in most circumstances, the relative price of generating electricity with solar is still not at 'grid parity' with fossil fuels such as coal, petroleum and crude oil. As a result, investing in solar energy companies remains a relatively "high-risk, high-reward strategy."

[104] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501026
[105] http://www.darpa.mil/
[106] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501026

Chapter 7. Geothermal Energy

7.1 Background

Geothermal energy has enormous potential for power production, but remains largely undeveloped in the Consortium states. Geothermal energy can be and already is accessed by drilling water or steam wells in a process similar to drilling for oil. Geothermal energy is clean (emits little or no greenhouse gases), reliable (average system reliability of 95%) and homegrown, reducing dependence on foreign oil[107].

Geothermal resources range from shallow ground to hot water and rock several miles below the Earth's surface, and even farther down to the extremely hot molten rock called magma. Mile-or-more-deep wells can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for use in a variety of applications.

One of the more common geothermal technologies is a process called radiogenic heat production, which makes geothermal energy directly available for heat and power generation. Power plants have used radiogenic heat production for dry steam plants, using steam from geothermal reservoirs and routing it directly to turbine/generator units to produce electricity. More common today are flash steam plants that pump water at temperatures greater than 360 degrees Fahrenheit and under high pressure to generation equipment. When the water reaches the generation equipment, pressure is reduced, allowing some hot water to convert into steam. The steam is then used to power turbine/generator units[108].

Other current geothermal technologies include binary cycle plants and geothermal heat pumps. Binary cycle plants pass moderately hot geothermal water by a secondary fluid with a lower boiling point than water, causing the secondary fluid to flash to vapor – which then drives the turbine. Geothermal heat pumps absorb heat from the ground to warm homes in the winter and reverse the process in the summer by removing heat and transferring it into the ground.

Geothermal electricity generation technologies are largely undeveloped in Consortium states, yet geothermal resources are abundant in these states. Figure 7.1 on page 166 demonstrates the significant potential for geothermal energy development in Consortium states.

[107] US DOE Geothermal Technologies Program, http://www1.eere.energy.gov/geothermal/
[108] Renewable Energy: Growth and Challenges In the Electric Power Industry. Edison Electric Institute. 2008.

Figure 7.1 Geothermal Resources of the United States

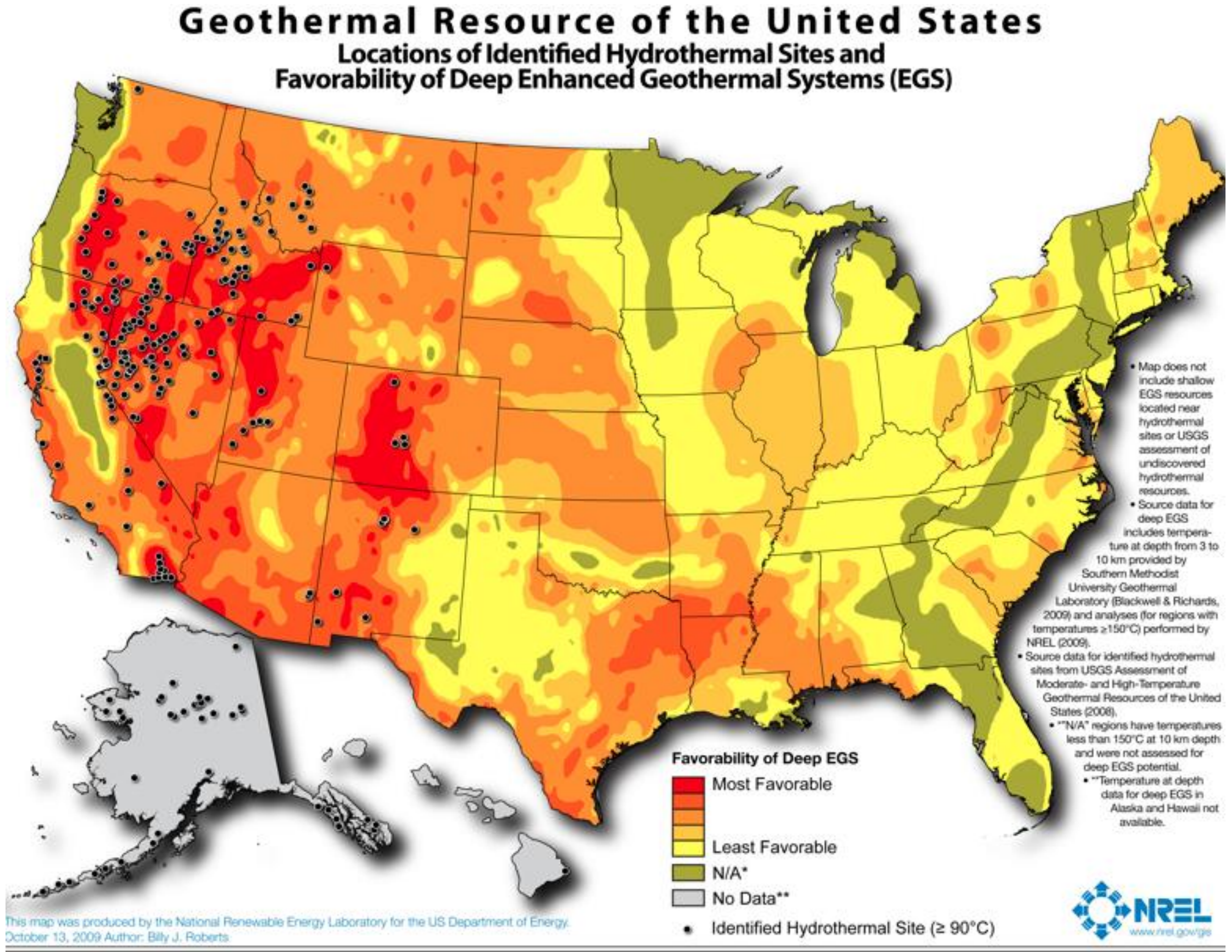
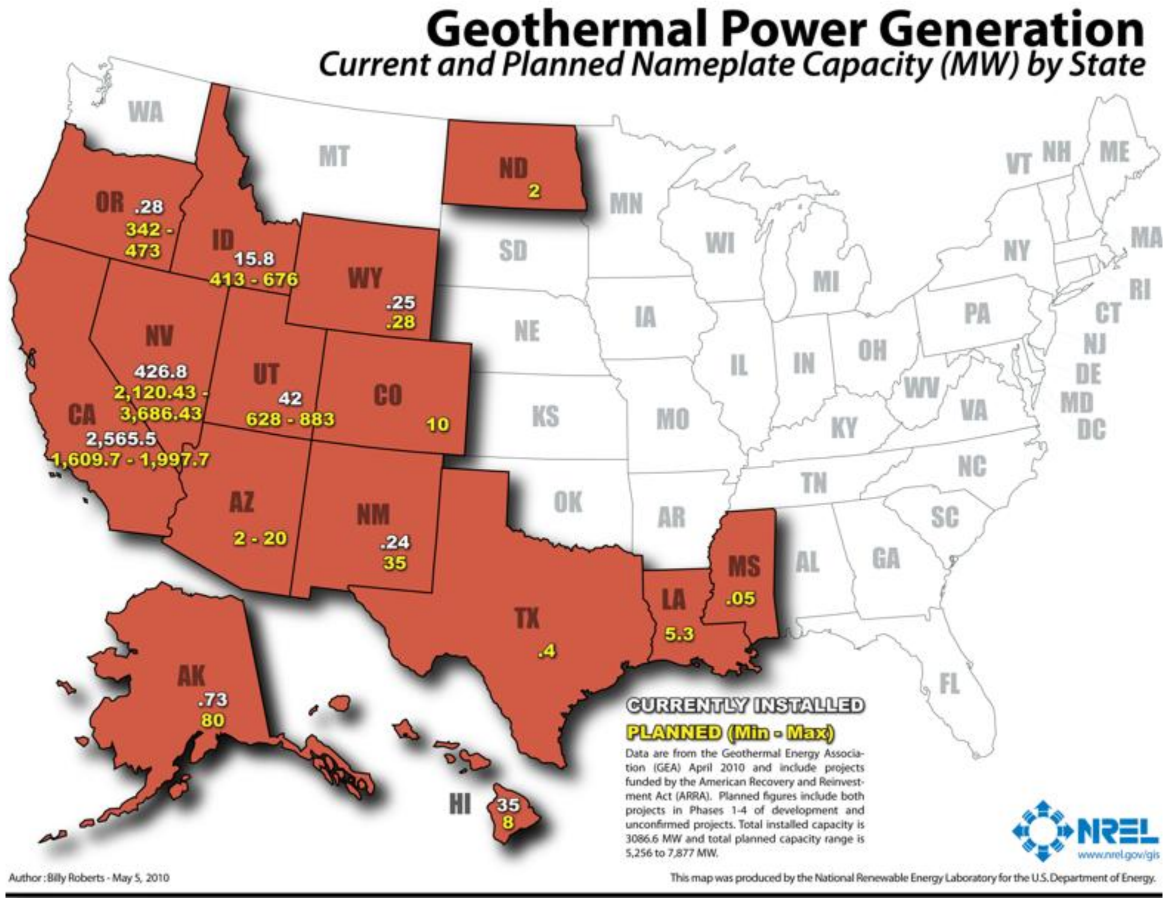


Figure 7.2 demonstrates the current and planned geothermal power generation capacities by MW of each state.



The State of Montana has more than 50 geothermal areas and at least 15 high-temperature sites[109]. High-temperature areas in western Montana are located near Helena, Bozeman, Ennis, Butte, Boulder and White Sulphur Springs. There are seven locations with surface temperatures above 149° F, plus 20 locations with temperatures above 110° F. The estimated deep-reservoir temperatures for some Montana sites are over 350° F.

Low- and moderate-temperature wells and springs can be found in nearly all areas of Montana. Site information includes location, flow, water and chemistry, as available. Most of the site data is from the late 1970s or 1980s.

Iowa, Nebraska and South Dakota are not well known for geothermal resources, However, South Dakota and Nebraska have a significant geothermal resource in the Madison Limestone formation—a well known aquifer and oil producing formation throughout the northern Great Plains and Rocky Mountains. The Madison contains about 179 miles of recoverable water with temperatures range from about 86^0 F to 216^0 F. The Madison is one of the two geothermal aquifers that are presently used in direct-heat applications. The other is the Newcastle-Dakota Sandstone[110].

Utah has over 5.7 million acres prospectively valuable for geothermal resource development[111]. Utah comprises parts of three major physiographic provinces, each with characteristic landforms and geology.

[109] http://www.deq.mt.gov/energy/geothermal/default.mcpx
[110] Lund, John. South Dakota Geothermal Resources. Geo Heat Center. GHC Bulletin, December 1997.
[111] Geothermal Resources of Utah. Utah Geological Survey. March, 2002.

These include the Basin and Range Province, the Middle Rocky Mountains Province, and the Colorado Plateau Province. An overlapping of two of these provinces essentially forms a fourth distinctive physiographic region. The Basin and Range-Colorado Plateau Transition Zone extends through central and southwestern Utah, and contains physiographic and geologic features similar to both the Basin and Range and Colorado Plateau Provinces.

Geothermal electricity generation also occurs in Utah. Utah Power has operated the single-flash, Blundell geothermal power station at the Roosevelt Hot Springs geothermal area near Milford in Beaver County since 1984. Intermountain Geothermal Company, a subsidiary of California Energy Company and the current field developer, produces geothermal brine for the Blundell plant from wells that tap a geothermal resource in fractured, crystalline rock. At Sulphurdale in Beaver County in 1985, Mother Earth Industries, in cooperation with the City of Provo, installed a geothermal binary-cycle power system and a steam-turbine generator. In 1990, Provo City and the Utah Municipal Power Agency, the current field operator, dedicated the Bonnett geothermal power plant, which became the third geothermal power facility to go on-line at Sulphurdale to provide electricity for Provo City.

Wyoming is an excellent spot for geothermal development. The state's connection to the high temperature resources of Yellowstone National Park and Hot Springs State Park will not likely be developed because of resource protection considerations, but low-temperature geothermal resources elsewhere in the state offer significant potential for development[112]. According to a study conducted by the Geo-Heat Center, five communities in Wyoming are within 5 miles of a geothermal resource with a temperature of at least 122º F, making them good candidates for heating or other geothermal uses[113].

Geothermal development in the West is not likely to include large-scale power plants in the near future. These plants require water at least 300° F. Some new technologies generate electricity at temperatures as low as 160° F, but these turbines are more suitable for smaller distributed generation projects where electricity is used on site rather than exported to the grid. However, industry stakeholders assert that Western geothermal resources have been overlooked due to the low fossil fuel energy prices, low population and lack of transmission access to remote locations[114].

Because of these limitations, this report focuses on the potential for development of thermal energy storage technologies including Thermal Energy Storage, Smart Thermosiphon Arrays and Advanced Adiabatic Compressed Air Energy Storage.

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[112] US Department of Energy, Energy Efficiency and Renewable Energy Center. Geothermal Technologies Program: Wyoming. eereic@ee.doe.gov

[113] Wittke, Seth. Geothermal Resources in Wyoming. Wyoming State Geological Survey

[114] http://commerce.mt.gov/Energy/geothermal.mcpx

7.1.1 Thermal Energy Storage

SME Information

Kent S. Udell received his BS, MS and PhD in Mechanical Engineering. He was a member of the faculty of the Department of Mechanical Engineering at the University of California, Berkeley from 1980 to 2006. He is now Professor and Director of the University of Utah's Sustainability Research Center.

Dr. Udell's area of expertise is in thermal sciences. His research career spans topics including petroleum reservoir engineering, environmental restoration, subsurface energy and fluid transport, geothermal energy and thermal energy storage. His current research and teaching focus is sustainable energy engineering.

7.1.2 TECHNOLOGY DESCRIPTION

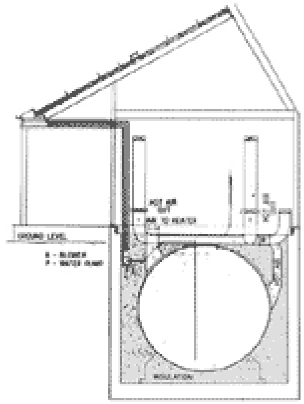
Thermal Energy Storage (TES) is an energy management strategy with various applications. As with batteries for electrical energy storage, thermal energy storage shifts energy capacity from low demand to high demand times. As such, it can be used for daily, weekly or seasonal energy storage applications. In most energy production or energy use installations, the economics and opportunities depend on both ambient conditions and energy availability. For example solar hot water heaters can produce enormous amounts of heat during summer months, but it is of little value since the needs for hot water or home heating during hot sunny days are few. But that heat could be saved in soils deep below the surface for winter heating. Another example is solar-thermal power production where daily peak capacity is hours away from peak demand. Effective thermal energy storage in geologic media is a way to shift energy availability to match energy demand, and thus economically harvest otherwise unavailable energy sources. In most applications, the use of thermal energy storage allows for more efficient use of electricity or heat, thus decreasing the amount of fossil fuel burned. In other applications such as seasonal energy storage, TES can nearly eliminate the need for fossil fuel fired electrical power or furnaces to cool or heat buildings.

By reducing fossil fuel combustion, pollution by various by-products is decreased. Further, some forms of thermal energy storage result in the elimination of fossil fuel use all together thus increasing the portion of renewable energy in the overall energy portfolio.

There are numerous variations of thermal energy storage strategies. Some most common ones are listed below:

- Underground or above ground tank storage with stratified liquid (*Fig. 7.1.1*)
- Lakes and solar ponds (*Fig. 7.1.2*)
- Earth pits (*Fig. 7.1.3*)
- Underground thermal energy storage (*Fig. 7.1.4*)

Fig. 7.1.1: Underground or above ground tank storage



(a) Underground storage tank of MIT's 1940 Solar House[115]

(b) Above ground energy storage tank

(c) Stratified liquid storage tanks[116]

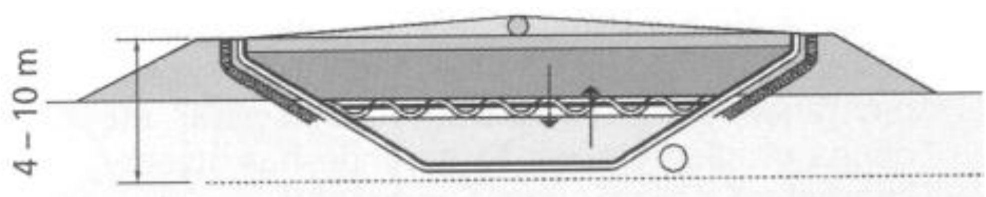
[115] Milestone Buildings of the 20th Century: http://www.artistsdomain.com/dev/eere/web/1940.html
[116] Faninger, Gerhard, "Thermal Energy Storage", International Energy Agency's Solar Heating and Cooling Programme, Task 28-2-6.

Fig. 7.1.2: Solar ponds

(a) Solar pond in Leuven, Belgium

(b) Solar pond in El Paso, University of Texas, USA [117]

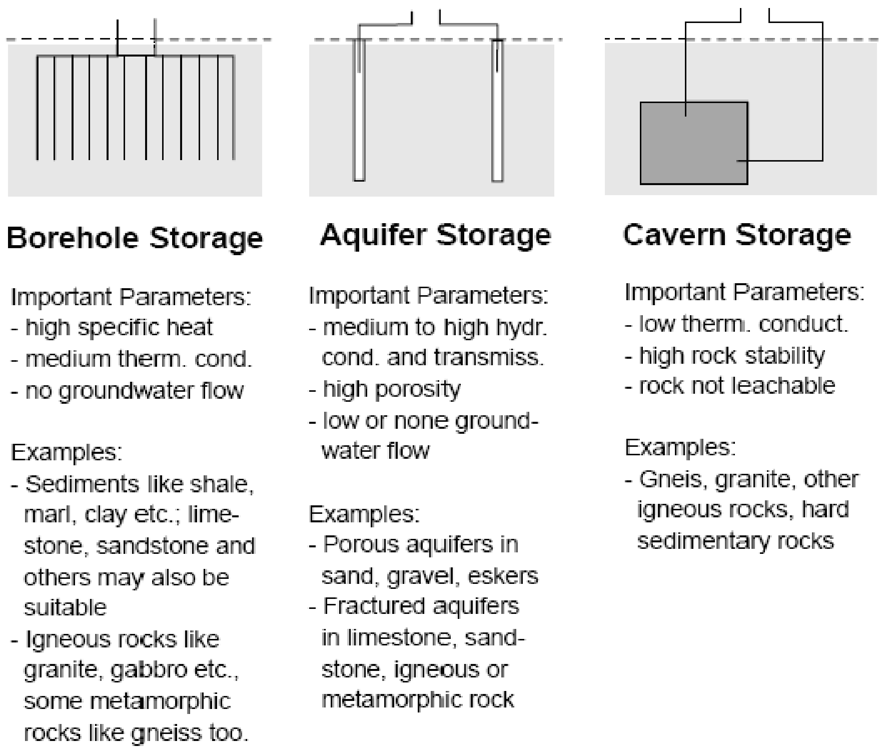
Figure 7.1.3: Earth pit storage[118]



[117] http://www.solarpond.utep.edu/

[118] Nielsen, Kai, "Thermal Energy Storage – A State-of-the-Art", A report within the research program *Smart Energy-Efficient Buildings* at Norwegian University of Science and Technology (NTNU) and SINTEF 2002-2006. Trondheim, January 2003.

Figure 7.1.4: Examples of underground thermal energy storage[119]



Each thermal energy storage strategy has positive and negative attributes, and the best choice for a given application would be determined by specific design requirements and local conditions. But of the options presented in this brief discussion, storage in native soil (Borehole Storage) is of particular interest:

- It is inexpensive (does not require reservoirs),
- It has sufficient thermal capacity and relatively low conductivity (lowering ambient heat losses),
- It has almost no size/volume restrictions (thus, its low energy density is not an issue and efficient energy storage on the time scale of a year is possible),
- It is universally available.

Furthermore, in climates where the temperatures in the winter drop below freezing for significant periods of time, the storage capacity of soil increases substantially due to the freezing of the water within the soil.

If soil is used as an energy storage medium, there is no restriction on the storage volume other than the potential constraint of keeping near-surface ground temperatures close to their natural values to avoid unwanted impact on surface soil flora and fauna. If heated and cooled in appropriate ways, soil not only provides a buffer for short-term fluctuations in supply and demand, but also can accommodate a complete annual heating/cooling load and serve a seasonal balancing function. Energy storage directly in the soil also reduces the cost sensitivity of reservoir depth on optimum capacity selection. The storage system can be easily sized to maximum expected load by a simple increase of depth in most cases.

Geo-material-based thermal energy storage has been considered by Isentropic[120], a company that markets thermal energy storage as a means of storing electrical energy. In that application, a heat pump is first

[119] Sanner, Burkhard, "A different Approach to Shallow Geothermal Energy – Underground Thermal Energy Storage (UTES)", International Summer School on Direct Application of Geothermal Energy, Justus-Liebig-University, Giessen, Germany.

used to heat gravel. The operation of the heat pump is then reversed to produce power when the heat is transferred from the high temperature storage to a low temperature reservoir.

Another application might be the use of subsurface media to accept steam injection for thermal energy storage. Steam injection is an established process of adding heat into the ground and has been shown to build a steam zone near injection wells. Depressurization of that steam zone result in the region becoming an *in situ* steam boiler with the produced steam exiting the depressurized well. If the surrounding media is nearly the same temperature as the injected steam as might be found near a geothermal site, then the thermal recovery efficiency approaches 100%. However, since the injected steam is at a higher pressure than the extracted steam, there is a small decrease in the thermodynamic availability (exergy) of the injection and production steam.

This mode of thermal energy storage is new and untested, but could provide significant benefit to solar thermal power production installations, particularly in regions where the solar potential coexists with geothermal potential.

7.1.3 TECHNOLOGY DEVELOPMENT PROGRESS

TES has been widely used on a commercial basis for cooling applications. A good example—Ice Energy[121]—which makes ice at night when electricity rates and ambient temperatures are lower and delivers the energy during the day during the peak of the day to provide cooling to a building or the use of chilled water tanks to store cold water at night for daytime space heating applications. Another example is Isentropic[6] where thermal energy is stored as a form of electrical power storage where a heat pump is used to raise the temperature of media such as a gravel bed by transferring energy from the ambient environments, then running the heat pump in the reverse direction (as a turbine) to produce power when needed.

Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) systems would have significant thermal energy storage needs. In that application, the mining operations to produce the storage volume could be modified to leave a volume of rock that had been reduced to small sizes (< 10 cm) to serve as a thermal energy storage medium. Alternatively, above ground stratified thermal energy storage volumes, likely stratified tanks, would be employed to save the thermal energy removed from the compressors and compressed air. There is no known pilot of an AA-CAES system. The demand for this energy storage technology will likely grow as the percentage of power coming from solar and wind power infrastructure increases.

Daily storage of thermal energy in tanks is currently practiced in many solar thermal power plants and with chilled water storage tanks. As with AA-CAES, the demand for this type of storage system will likely grow as wind and solar energy industry grows.

Thermal energy storage in geologic media to efficiently manage power plant transients is an emerging technology that has not yet been tested – even on a pilot scale.

7.1.4 TECHNOLOGY PRODUCTION AND DEPLOYMENT

The market for thermal energy storage is just now beginning to develop. IceEnergy and chilled water storage applications are two examples of storing low cost energy for peak demand use. As the cost drops to the range of $0.01/kW-hr/cycle, enormous growth would be expected. However, there is little history of growth in this sector on which to base broad projections. Regardless, two approaches might be considered for thermal energy storage that would have both broad applicability and reasonable economics: above ground storage and underground storage.

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[120] http://www.isentropic.co.uk/index.php
[121] http://www.ice-energy.com/

Increased use of above ground thermal energy storage would lead to growth in businesses that manufacture and install tanks. Depending on the storage media (ceramics, salts, thermo-chemical "batteries", etc.), there will need to be and additional industry created to harvest, process and manufacture that storage material. For a daily storage application allowing the storage of 100 MW-hr thermal energy storage system with a service life of 15 years, the cost of the thermal energy storage system would be $5.5M at $0.01/kW-hr/cycle.

7.1.5 POTENTIAL JOB IMPACTS

Assuming that the cost would be split 50% labor and 50% materials and equipment, and that one job would be generated for each $100,000 in labor cost, the installation of a 100 MW-hr storage facility would generate 28 jobs. If 100 of these plants were to be installed each year, 2800 jobs would be created.

Increased use of underground thermal energy storage would lead to growth in businesses engaged in drilling or excavation. For a similar cost per kW-hr/cycle as for aboveground storage, a similar labor pool would be required to install a 100 MW-hr underground thermal energy storage system as was estimated for the above ground system. Thus, if 100 underground thermal energy storage systems were to be installed each year, approximately 2800 jobs would be produced.

7.1.6 NATURAL RESOURCE HARVESTING

For the above ground applications, carbon steel piping and tanks for storage would need to be produced. The material could either come from recycled metal waste or from new mining. The storage material would also need to be harvested or manufactured. Material for ceramic solids used in a solid-based high temperature storage system would need to be mined and processed. Salts for sodium storage would need to be mined and processed as well. This will likely be less than 15% of the aboveground TES workforce.

For underground energy storage systems, steel well casing/stainless steel screens will be needed to inject or produce energy into or out of regions planned for thermal energy storage, would need to be manufactured. Approximately 2500 feet of casing and about 400 feet of screen could be needed to inject 100 MW-hr of thermal energy over 8 hours. Also, cement grout will be need produced and the gravel pack for the 400 feet of screen will need to be harvested and sorted.

7.2 Smart Thermosiphon Arrays

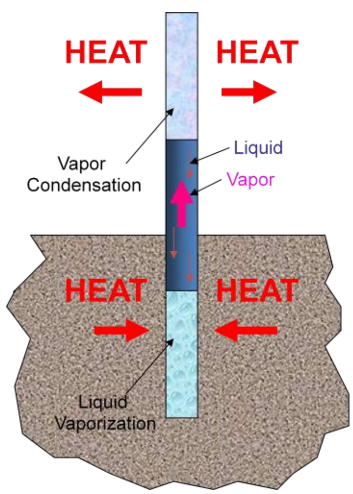
SME Information

Dr. Kent S. Udell, University of Utah

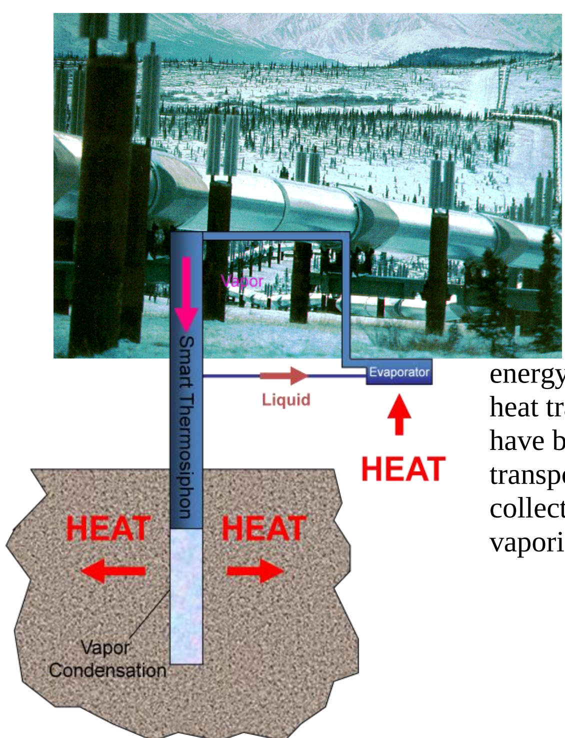
7.2.1 TECHNOLOGY DESCRIPTION

An obvious and virtually fossil-fuel-free method of heating and cooling buildings in most climates is to store summer heat for winter use and winter "cold" for summer cooling. In essence, the idea is to "TiVo" seasonal weather. All buildings sit on a vast volume of geological material – nearly all of it deep enough to store heat (or "cold") without surface environmental effects. To use this free and sustainable energy resource, effective and inexpensive systems to transfer heat between the conditioned space, the soil, and the environment, are required.

Efficient heat transfer to and from soils can be realized with vapor/liquid phase change, improving thermal performance of each borehole. Push technologies can be economically used to insert the tubing into the ground since liquid and vapor flow lines do not require large pipes for the large energy they can transport.



An interesting version of this phase change transport mechanism is the thermosiphon heat pipe. A thermosiphon heat pipe consists of a vertical sealed pipe that is partially filled with a liquid; the top portion of the pipe is filled with the liquid's vapor. When the bottom portion is hotter than the top, the liquid is vaporized at a rate proportional to the rate of heat transfer from the soil. Due to temperature-gradient-induced pressure gradients, the vapors flow to the cooled end and condense. As the vapor condenses, it releases its energy at a rate proportional to the heat transfer from the pipe. Gravity feeds the condensate back to the bottom evaporator. Thus, a thermosiphon heat pipe effectively operates as a super thermal conductivity heat diode, transferring energy only in the upward direction. In this "passive" mode of operation, thermosiphons are very effective in transferring heat from the soils as would be desired if using heated soils for winter space heating or, as practiced in the creation of ice-ball footings for structures constructed in permafrost locations (see Alaskan pipeline figure to the left), the chilling or freezing of soils near the regions of the thermosiphon pipe where the liquid is boiling.



While thermosiphon heat pipes have proven their ability to transfer energy from the soil at high rates, the problem with their use for seasonal underground thermal energy storage is that there are specific times when enhanced heat transfer <u>to</u> the soil is desired. Thus Smart Thermosiphons have been invented. Upon demand, Smart Thermosiphons transport the volatile liquid to other heat sources such as solar collectors or air-conditioning evaporator coils, where it vaporizes. The produced vapors travel back to the thermosiphons and transfer energy to the subsurface when the vapors condense on the cool thermosiphon walls. In either mode, the thermosiphons operate as thermal superconductors, providing Smart Thermosiphons both passive and precisely controlled directional enhanced heat transfer between the subsurface, conditioned space and the exterior environment. And since the thermosiphon pipes need not be large, they can be inserted into the soil using direct push or GeoProbe techniques at costs of about $1/ft – one tenth the cost of looped tubing boreholes used for Ground Coupled Heat Pumps.

Single Smart Thermosiphons cannot provide much energy storage since energy is lost to the surrounding soils before it can be recovered. Thus, the thermosiphons need to be configured in an array to concentrate the stored energy in the target volume defined by the distribution of the active thermosiphons.

Since smart thermosiphon arrays (STAs) use no (or minimal) fossil fuel for operation, they replace existing pollution sources such as the burning of oil, wood or coal for heating. Likewise, they can eliminate the need for electricity from gas- or coal-fired power plants to run typical vapor compression cooling systems. In essence, STAs produce “negawatts” – the elimination of fossil fuels that would otherwise be burned to meet our energy need.

7.2.2 TECHNOLOGY DEVELOPMENT PROGRESS

Basic operation of thermosiphon heat pipes for soil freezing, a fundamental component of STAs for cooling, has been demonstrated with over 100,000 devices in operation in Arctic climates for geotechnical applications such as supports for the Alaskan pipeline in permafrost locations. However, these devices operate as thermal diodes without active “smart” pumping capabilities and are not capable of significant storage of “cold” since heat transfer to the produced ice from warmer soils away from a single thermosiphon diminishes storage efficiency.

The advancement of the technology comes with the concept of placing a liquid pump and controlling liquid level switch in the bottom of a thermosiphon pipe (termed Smart Thermosiphon[122]). Supporting this development was the observation that Smart Thermosiphons needed to be clustered for efficient energy storage.

[122] Udell, K. S., “Ground-Coupled Heat Exchange for Heating and Air Conditioning Applications”, U.S. Application # 12,742,080.

Computational studies of STAs have been conducted to demonstrate that the clustering of smart thermosiphons can provide ice storage in the ground that will last through a cooling season. An array of seven thermosiphons as shown in Figure 7.2.1 was modeled using the commercially available software package COMSOL Multiphysics version 3.3. The 2-D conduction model included the passive freezing of soil and the use of that frozen soil as an air conditioning heat sink.

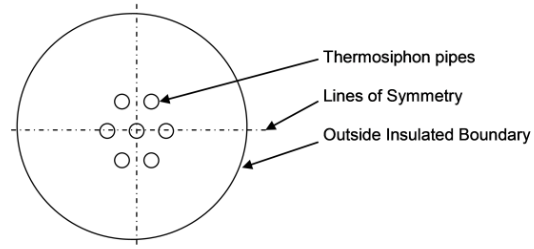
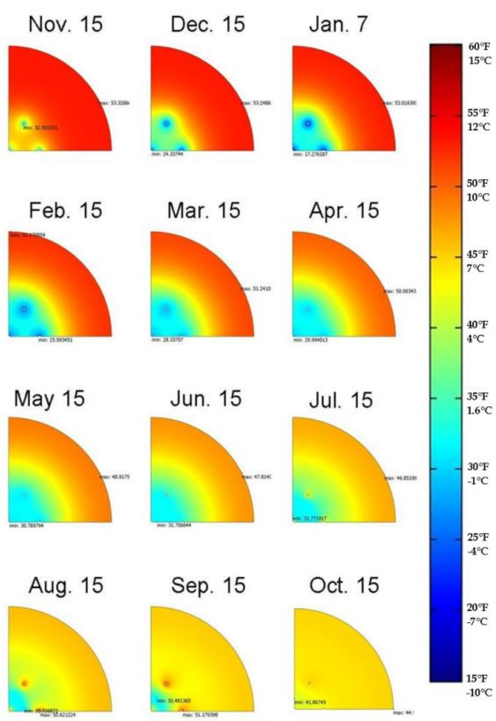


Figure 7.2.1. *Plan view of thermosiphon pattern. Using the symmetry of the pattern of 7 wells, the two dashed lines are planes of temperature and heat flux symmetry.*



The geometry chosen for the analysis was an array of six thermosiphons placed at the corners of a regular hexagon with a seventh thermosiphon placed at the center of the hexagon. Utilizing the symmetry of the system, a quarter-circle with a 5 m radius was chosen as the domain of interest. Three thermosiphons were modeled in this domain: one positioned centrally and the other two placed 60 degrees apart with one of them on the axis of symmetry. The spacing between thermosiphons was 1.5 m.

The simulated temperature distributions on the 15th of each month are shown in Figure 7.2.2. The absolute minimum temperature (-8°C, 17°F) occurs in January next to the wall of the heat pipe. The maximum temperature that occurs next to the heat pipe during the summer season does not exceed initial conditions. As can be seen, the soil between the thermosiphon heat pipes freezes during the winter and remains frozen throughout the summer and into September.

A critical concept functional prototype of a smart thermosiphon has been constructed and operated as designed. The prototype is capable of reversing the direction of working fluid (R-134a or ethanol) liquid flow and simulates the heat transfer to or from smart thermosiphons in contact with various media. Experiments with the thermosiphon inserted in an insulated tank filled with water in subzero outdoor temperatures demonstrated uniform ice buildup on the outside wall of the thermosiphon and complete freezing of the water in the tank during passive operation.

A pilot installation of a STA in soils using Geoprobe direct push technology has been completed with the testing of the pumps and controls for air cooling completed in September, 2010. The pilot STA has been installed in a residential location. Seven 2-inch nominal galvanized steel pipes were installed to a depth of 10 ft (3 m) in the configuration shown in Figure 7.2.1. Based on commercial bids, GeoProbe installation costs are about one tenth the cost of drilling an 8-inch borehole using conventional methods. Direct push installation also eliminated the need for drilling mud and handling of removed soils.

The above-ground heat exchanger panels were constructed of copper pipe consisting of 40 vertical tubes connected by headers measuring 5 ft x 5 ft (1.5 m x 1.5 m) and cooled by natural convection. R-134a is currently being used as the working fluid although ethanol could easily be substituted for that refrigerant. The array was charged in February 2010 and experienced almost two months of intermittent freezing temperatures operating in a passive mode. Subzero temperatures are observed near the thermosiphons and some cooling in the regions between the thermosiphons occurred. These data compare well with the first month temperature profile from the calculations (Nov. 15).

Once some standardization of installation materials and techniques occurs, the cost will decrease, the reliability will improve, and installation capacity will increase dramatically. The initial projects will prove out and demonstrate STAs over the next three years. However, once the technology is demonstrated on full-scale applications, project installations could be self-financing through a Power Purchase Agreement utility style model. On-going maintenance of existing systems would then be a permanent part of the work force. Major space-cooling-intensive data center users appear to be a good initial market interest in STA technology once it is demonstrated. Both private equity firms and corporate strategic partners have expressed interest in providing the capital necessary to finance expansion needs at that point.

Rapid national and international expansion is foreseen in the coming 6 years. The expansion will require the training of engineers and installers in businesses closely aligned with the practices of STA installation and maintenance. Those include cone penetration testing (CPT)/GeoProbe rig operators, thermosiphon tubing manufacturers, GeoProbe manufacturers, small pump and switch manufacturers, and heating, ventilation and air conditioning (HVAC) professionals.

7.2.3 TECHNOLOGY PRODUCTION AND DEPLOYMENT

A typical commercial cooling system could be of the order of an array providing 10 ton cooling at a 0.15 capacity factor. For wet soils in climates where subfreezing temperatures are common in the winter, a 40' diameter (37 thermosiphons) by 40' thick zone would need to be frozen zone. This is defined as the scalable unit.

The design for a particular application, once routine, would not be time intensive. Designers will mostly use design portfolios of existing reliable systems based on climate, soil conditions, and required capacity. Engineering design per site would be less about 2 days of effort.

The next step is the installation of the STA array. The installation of the STA array would require the full-time operation of a direct push machine such as GeoProbe for a week. The installation of 37 thermosiphons to a depth of 60 feet would cost approximately $15,000, split 50% labor, 30% equipment use, and 20% materials.

After the STA installation, pipefitters will be needed to make connections from the STAs to the heat exchangers and ducting. It is estimated that the labor and materials would cost another $5000. If a new project, not a retrofit of an existing air conditioning unit, another $5000 for heat exchangers would be needed. So the total cost for installation of a new system would cost about $25,000 and a retrofit costing closer to $20,000.

Finally the system would be tested and adjusted, requiring an additional day of work.

7.2.4 POTENTIAL JOB IMPACTS

The breakdown of manufacturing jobs is as follows:

Design Engineer	2 days
Thermosiphon Installers: 3 for 5 days	15 days
Piping manufacture and delivery	2 days
Heat Exchanger retrofitting and hookup to thermosiphons	10 days
Heat Exchanger Manufacture and shipping	5 days
Testing and adjustments	1 day
Total	**35 days**

Assuming 500,000 sites installed each year, 70,000 jobs would be created—or about 7 jobs per installed system. The industry of STA installation would create over $10B/year in business.

It is estimated that nearly 100 installations around the country will be required before the reliability is proven and the economics are established. At the estimated cost of $35,000 ($10,000 more per site to account for learning curve), and $1M in direct research funding to develop design software and climate databases, $4.5 million in investment will be needed to launch this industry.

The development would follow the description in section 7.2.2 at 100 sites. For the 100 sites, 3500 days of work, employing 14 employees for a year, would be needed at a minimum.

Engineering design per site would be about 2 days of effort.

The installation of the STA array would require the full-time operation of a direct push machine such as GeoProbe for a week. The installation of 37 thermosiphons to a depth of 60 feet would cost approximately $15,000, split 50% labor, 30% equipment use, and 20% materials.

Pipefitters will be needed to make connections from the STAs to the heat exchangers and ducting. It is estimated that the labor and materials would cost another $5000. If a new project, not a retrofit of an existing air conditioning unit, another $5000 for heat exchangers would be needed. So the total cost for installation of a new system would cost about $25,000 and a retrofit costing closer to $20,000.

Finally the system would be tested and adjusted, requiring an additional day of work.

7.2.5 MARKETING

The technology would first be marketed through technical conference participation, press releases, and website exposure. The marketing needs are expected to much less than the design, installation, and maintenance needs since the mass-market news programs would likely provide free marketing of the technology since the approach is unusual. The marketing component of a national technology implementation industry would be approximately 2% of the total job force.

7.2.6 MAINTENANCE

The actual maintenance needs are difficult to assess since there is not performance history on which to base an estimate. However, it is expected that each system will require routine yearly maintenance for 1 day per visit.

However, with the number of installations growing by 500,000/yr, after 10 years, there would be a need for 20,000 maintenance technicians.

7.2.7 EDUCATION AND JOB SKILLS TRAINING

There will be substantial education needs for engineers, and installers. The engineers should hold at least a B.S. degree. The installers should also have sufficient post high-school science education to understand basic thermodynamic and principles, and basic electrical circuit analysis.

Additional education and job training would be required for the maintenance crews. The maintenance personnel should also have sufficient post high-school science education to understand basic thermodynamic and principles, and basic electronics.

7.2.8 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

The introduction of seasonal energy storage will vary by geography. In more Northern climates where the summers are milder, but the winters are harsh, cooling will likely be the first applications since soil freezing is a more efficient means of storing “cold” than temperature change only, and the cooling load is less allowing full cooling installations with a lower capital investment. In Southern states, the heating application may be the first entry into the market. Heating is preferred in warmer sunny climates where the total winter heating load is relatively small and where thermal solar hot water heaters have extended seasonal use and enormous unused summer thermal energy capture potential. In states with the highest electrical rates, adoption of the technology will be faster.

Economic Constraints

It is estimated that 100 installations around the country will be required before the reliability is proven and the economics are established. At an assumed cost of $35,000 ($10,000 more per site to account for learning curve), and $1M in direct research funding to develop design software and climate databases, $4.5 million in investment will be needed to launch this industry.

Social Constraints

The concept of harvesting renewable, sustainable, quiet and clean energy for heating and air conditioning would likely receive broad acceptance. However, as with any big change in the way energy supplied, there will likely be some public opposition. Worries about tree roots, frost heave and deep microorganism ecology disruption will persist without full testing and competent engineering. In areas of drinkable groundwater flow, there may be opposition to any artificial change in groundwater temperature or groundwater flow patterns.

Environmental Constraints

In many locations, the local water quality control board may need to approve and permit the installation of the thermosiphon pipes just as they now have authority over the installation of the U-tube wellbores for ground-source heat pumps. Careful and considerate implementation in the first stage of technology introduction will reduce the risk of accidents that may unnecessarily increase regulatory oversight.

In Europe, there is a regulatory push to reduce the volume of refrigerants used in various applications. The use of exotic liquids may prove cost prohibitive. Liquids such as ethanol, propanol or carbon dioxide would be preferred in the EU due to their environmental compatibility or sustainable biomass source.

Depending on the refrigerant, special precaution may be necessary due to questions of refrigerant flammability, toxicity or environmental fate. For the heating technology applications where there is no need to operate at temperatures below freezing, significant regulatory advantage would be gained by using water as the refrigerant.

Transportation Constraints

There are no significant transportation constraints to the deployment of seasonal energy storage using STAs. The challenge of deployment of appropriate drilling rigs around the country may limit implementation in some geographic locations. The manufacture and transportation of thermosiphon pipe may also constrain early adoption, but once a stead market is in place, those constraints should ease.

Political Constraints

The concept of harvesting renewable, sustainable, quiet and clean energy for heating and air conditioning would likely receive broad acceptance. However, as with any big change in the way energy supplied, there will likely be some public opposition. It is possible that gas or electric utilities might attempt to delay deployment if the growth of seasonal energy storage were substantial.

Environmental groups may also be skeptical about wide spread use of STAs for seasonal energy storage due to worries about trees, frost heave and deep micro-organism ecology disruption. In areas of drinkable groundwater flow, there may be concern that any artificial change in groundwater temperature, groundwater flow patterns or groundwater contamination due to pipe leaks.

However, there is no existing opposition to the concept.

7.2.9 FUNDING SOURCES

The funding sources driving the development of the STA technology have been derived from universities and private sources. No funding has been provided by any outside federal or state agency. Seasonal energy heating research and development is being funded by the US Department of Defense through their Strategic Environmental Research and Development Program.

7.3 Advanced Adiabatic Compressed Air Energy Storage

SME Information

Dr. Kent S. Udell, University of Utah

7.3.1 TECHNOLOGY DESCRIPTION

Compressed air energy storage is a method to meet high peak load electrical power demands and to level power from intermittent renewable energy sources such as solar and wind. The concept is to run high efficiency compressors when electrical energy availability is high (such as when wind is blowing and electrical demand is low) to compress ambient air. The compressed air is then stored in a large cavern or volume until additional power is needed. When additional power is needed, the compressed air is released through a turbine connected to an electrical generator to produce power, much like pneumatic tools connected to a compressed air tank. Ideally, the overall compression and expansion cycle would be adiabatic, meaning that no heat is lost or added to the process. When operated in this fashion, the system is called an Advanced Adiabatic Compressed Air Energy Storage (AA-CAES).

Currently, there are no AA-CAES systems in operation. There are two plants in operation that use natural gas combustion to supply energy to the high-pressure air before expansion in the turbine. The requirement for additional energy is due to the energy lost by cooling the compressors and the heat loss from hot compressed gas to the walls of the containment vessel. In essence, the existing plants that use natural gas as an energy source operate in a manner similar to a Brayton cycle (the motor for a turbo-prop aircraft), except that the air compression and air expansion components operate at different times. Thus, the compressor operates when the electricity demands are low and the turbines produce power when the electrical demand is high.

AA-CAES cycles don't need energy from the combustion of natural gas since the thermal energy removed from the compressors would be stored and released to the air before it exits the turbine. Figure 7.3.1 shows a schematic of an AA-CAES cycle. As shown, the thermal energy removed from the 1st and 2nd stage compressors is stored in a thermal energy storage (TES) device. That energy is later transferred from the TES to the air flowing to the 1st and 2nd stage turbine cycles.

AA-CAES systems can produce no CO_2 emissions or pollution and would be expected to be 70-75% efficient [123].

[123] Crotogino, F., Mohmeyer, K.-U. and Scharf, R., *Huntorf CAES: More than 20 Years of Successful Operation, SMRI Spring Meeting 2001*, Orlando, 23.-24.04.2001, 2001, pp. 351-357

Figure 7.3.1 Advanced adiabatic compressed air energy storage cycle schematic[124].

7.3.2 TECHNOLOGY DEVELOPMENT PROGRESS

The concept of compressed air energy storage (CAES) with gas fired air heating is well proven and has been in use for over 30 years. In 1978 the first CAES facility was built in Huntorf, Germany and has a capacity of 290 MW. The EN Krauftwerke owned German plant stores compressed air in two salt caverns with volumes of 140,000 m3 and 170,000 m3. Compression requires 12 hrs to fill the caverns and consume 720 MW-hr of municipal power. The plant injects the compressed air into a natural gas burner before entering the expansion cycle and can generate power for up to 3 hrs. Its two main purposes are to supply supplemental power for peak demand loads and produce emergency power[1].

CAES technology was later introduced to the US in 1991 with a 110 MW plant in McIntosh, Alabama. Compressed air is stored in a 19,000,000 m^3 salt cavern and can generate power for 26 hrs. The Alabama Electric Cooperative (AEC) improved on the CAES design by recovering waste heat, with the addition of a regenerator, to the expansion cycle reducing fuel consumption by ~25% compared to the Huntorf Plant. Construction of the site cost $65M or approximately $591/kW[125].

Norton Energy Storage (NES) is in the process of opening a 2700 MW plant in Norton, Ohio but it has been put on hold due to financial problems. The design of the proposed site in Norton, Ohio would use hard rock mines for storage. A six-month feasibility study to determine if the hard rock mines at the Norton Ohio site can be used for compressed air storage validated the use of the mines for cyclic pressure vessels[126]. An added benefit to using a hard rock mine shaft is the modularity of expansion by adding additional turbines and sealing additional shafts. NES will bring their plant

[124]Beeman, Michael, "Design and Evaluation of an Advanced Adiabatic Compressed Air Energy Storage System at the Michigan-Utah Mine", MS Thesis, Dept. of Mech Eng, Univ. of Utah, August, 2010.
[125] Gardner, John and Haynes, Todd, *Overview of Compressed Air Energy Storage*, Office of Energy Research, Policy and Campus Sustainability. ER-07-001. December 2007.
[126] Burroughs, Chris, *Solution to Some of Country's Energy woes Might be Little More than Hot Air*, Sandia Lab News (Online Publication), Vol. 53, No. 7, April 6, 2001.

online in 300 MW increments as units become available[127].

According to a study conducted by CERI, the capital costs associated with CAES are comparable to natural gas turbines: these typically range between $400 and $500/kW. Accounting for the additional equipment and reservoir costs, capital investments will range between $600 and $700/kW[128]. Off-peak power is currently priced at $0.04/kWh and peak prices are $0.07/kWh in Utah. After accounting for plant efficiency, this means power can be re-sold at a profit of $0.02/kWh. Profits will increase as energy costs rise. AA-CAES technology has been shown to be cost effective but a system that avoids the need for a gas burner will require further research and development before it can be implemented. It is not expected that AA-CAES will progress beyond the pilot stage in the next 4 years.

7.3.3 TECHNOLOGY PRODUCTION AND DEPLOYMENT

For the purposes if this study, it will be assumed that the AA-CAES system uses a subsurface storage volume rather than an above ground tank. However, there may be applications at a smaller, residential scale where daily storage cycles are the norm. Long-term storage for small systems would be problematic since a larger portion of the stored heat would be lost by heat transfer to the environment than would be observed for large industrial storage systems.

The first step in site preparation, besides the geological investigation to identify an appropriate location to create the compressed air storage volume, is to mine the cavern. Ideally, the site would be in a geologic formation that would not be conducive to gas leakage. The material to be mined would be relatively easy to remove. Salt domes are a preferred choice in both regards.

However, abandoned hard rock mines may also be good candidates. Their use would require surveys to determine leak rates (water in and air out), depth below the local water table, and depth below ground surface. The best locations (deep and thousands of feet below the local groundwater elevation) would likely be flooded if the mine had not operated in past years. Thus surveys would be difficult in that environment.

Compressed natural gas is routinely stored in underground gas reservoirs and such structures might be considered for CAES. The storage volume is typically below a structural trap in an underground volume where gas has previously been found under pressure. However, as a compressed air energy storage volume, the porous structures of such reservoirs create a large resistance to air flow, which increases the output pressure of the compressor and decreases the output of the turbine, dropping the efficiency of the system. There may also be problems with methane release using reservoirs previously used to store natural gas unless CAES system's energy is augmented by natural gas combustion.

After the volume of rock or salt is mined from the subsurface using hard-rock removal, or with salt -solution mining, and piping to the subsurface cavern is installed, the plant construction would begin. Plant construction would involve the installation of thermal energy storage system, the installation of compressors, the installation of turbines, and the installation of piping to and from compressors, the TES systems and turbines.

[127] Bullough, Chris, *Advanced Adiabatic Compressed Air Energy Storage for the Integration of Wind*, European Wind Energy Conference, London UK, February 2004.
[128] Levine, Jonah, *Large Scale Electrical Energy Storage in Colorado,* CERI Research Group Report, June 30, 2007.

7.3.4 NATURAL RESOURCE HARVESTING

Storage volume might be recycled from abandoned mines. Excavation material from mining could be used for other geotechnical applications. Solution mining of salt from salt domes might create a large volume of salt to be produced and used rather than injecting the brine into deep saline aquifers. The job impact of that recycling effort would be minimal, creating around 10 temporary jobs for each installation.

7.3.5 POTENTIAL JOB IMPACTS

Manufacturing

The installation of a large AA-CAES system (capacity of the order of 100 MWe) would cost approximately $60,000,000 based on estimates of $600/kWe capacity. The elements of the fabrication would include compressor and turbine manufacturing ($10,000,000 each producing 150 full-time jobs for one year). The thermal energy storage system is estimated to cost $3,000,000, creating 40 jobs. Plant construction would involve the installation of thermal energy storage system, the installation of compressors, the installation of turbines, and the installation of piping to and from compressors, the TES systems and turbines. The workforce for the installation activity is estimated to be an additional 210 employees. Thus, the total workforce to manufacture and install a 100 MWe system is estimated to be of the order of 400 employees working one year.

Marketing

Marketing would be to municipalities, large power users, power production and distribution companies, and renewable energy production companies. The concept, if proven to be economic and reliable, would be sought by operators of wind farms or engineers from power management firms. An engineering education for the sales workforce would be valuable in order to market the technology to technical representatives from the targeted municipalities and industries. However, marketing jobs will be mostly for those producing bids in response to requests.

Maintenance

Maintenance of compressors, turbines, generators, motors and occasional inspection of caverns/storage volumes would be needed on a continuing basis. The maintenance crew would need experience with training on an operational system. Operators would need similar training with experience in power production equipment operation. Two operators employed 24 hours per day, 7 days a week, will be required for safe operation. The operational work force would be 10 people for each plant.

7.3.6 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

Economic Constraints

The expansion of the use of this technology will require lat least three successful demonstrations – successful in terms of both economic and technical goals. Best practices designs will decrease the cost, but most equipment costs such as piping, turbines, compressors, thermal energy storage systems will be fixed with little opportunity for cost savings with knowledge improvement. Subsidies of 50 percent of the cost of installation would stimulate demonstration plants with industrial cost-sharing, reducing the risk and increasing the design knowledge. The research and development cost would then be approximately $15M.

Demonstrations should be planned in locations where there are large peak and nighttime electrical power rates differences to best demonstrate the economic potential.

One of the most pressing cost-effectiveness considerations is the availability of the turbine and compressors. Manufacturers who have the capability of producing either piece of equipment are using their production capability to produce larger equipment for natural gas powered power production.

Social Constraints

The installation of AA-CAES will likely be in rural areas where the land prices are low. The primary concerns the public will be the environmental issues associated with water production and waste disposal. However, the operation would be clean, producing local jobs and power backup. Thus, there would not be significant opposition to the installation and operation of such a system.

Environmental Constraints

Water quality issues (acid mine drainage, lubricants leaking into the groundwater, brine disposal from solution mining of salt domes) are the greatest threats to the environment and thus will drive the permitting needs. The permits to re-inject produced water into subsurface horizons or to discharge water into surface streams would likely be at the state level. Redistribution of power back into the grid would require permitting with the local power transmission line operator.

Transportation Constraints

Since commercial scale AA-CAES would likely find first use storing nuclear or renewable energy power resources. Renewable energy production is inherently intermittent. So energy storage is a premium when coupled with power output leveling needs characteristic of wind and solar power. However, nighttime storage of nuclear power would be a potential market since constant-rate power output operation is best for those facilities. Thus, nuclear power is known for producing large differences between high and low rates – creating an arbitrage economic opportunity.

Transmission would not be an additional burden if the AA-CAES system were located on a transmission line between the power source and the end user. Thus, many appropriate geologic options for storage volume (including existing hard-rock mining drifts, salt domes, gas reservoirs) may be available near thousands of miles of existing or planned power lines.

Political Constraints

Water rights conflicts and water quality regulations may apply to sites near fresh water aquifers. Seismic event analyses may be needed to insure that no induced seismicity could occur or that natural seismic events would not expose the public to additional danger. However, this type of project, given its clean nature and potential to facilitate more renewable energy production capacity, should be relatively well received.

7.3.7 FUNDING SOURCES

The research and development cost would consist of subsidies of approximately $15M to stimulate the construction of three demonstration plants. A 50 percent industrial cost-share would be expected, reducing the risk and increasing the design knowledge share to either private investors or an existing power company. Funding would most likely come from the US DOE and private/public cooperatives.

Chapter 8, Other "Green" and "Traditional" Technologies

SME INFORMATION

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President and CEO, Hybrid Power Technologies, LLC

B.S. Nuclear Engineering, University of Virginia, 1972

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M.B.A. St. Martin's College, 1986

Hybrid Power Technologies LLC was formed by Mr. Keller in the summer of 2005 to develop a new family of patent-pending hybrid power plants that use nuclear and fossil fuel sources. The emerging hybrid-nuclear technology is a major breakthrough that dramatically reduces greenhouse gas emissions and leads to energy independence.

Mr. Keller is a veteran of the power industry having directed and performed a wide variety of power station efforts, including: engineering, construction and start-up; as well as plant operations, maintenance, and overhauls. He has managed a broad range of activities, including: power plant daily operations; capital budgeting; power sales; regulatory compliance; health and safety; emergency planning; financial Pro Forma analysis; loss prevention; plant/process engineering; scheduling; human resources; facility management; strategic planning; and business development.

8.1 Hybrid-Nuclear Energy

America possesses hundreds of years of low-cost coal resources that are becoming increasingly unpopular due to climate-change concerns. The high cost of conventional nuclear power greatly hampers the building of new such facilities, while the promise of the nuclear gas reactor also remains out-of-reach as a result of technical and competiveness shortfalls.

An emerging hybrid-nuclear technology is a breakthrough energy solution that allows the US to utilize our most abundant resource, coal, while dramatically reducing air pollution as well as greenhouse gas emissions without resorting to problematic CO_2 sequestration. The hybrid is a significant efficiency improvement ideally suited for operation in high-altitude mountainous regions. The technology also handily supports intermittent wind and solar resources.

The hybrid is based on the integration of the existing, well-proven technologies of the combustion turbine, combined-cycle power plant and coal gasification as well as the maturing helium gas reactor being developed by the DOE. The absolutely fail-safe nuclear reactor cannot melt and the hybrid is significantly safer than the current generation of nuclear power plants.

A strategic goal of the technology is to replace our existing fleet of coal plants with dramatically more efficient hybrid-nuclear/coal units while simultaneously appreciably extending the life of economically recoverable coal (and natural gas) reserves. Hybrid-nuclear energy also supports coal-to-liquids production of transportation fuels.

The components used by the hybrid technology can be readily manufactured in the US using our existing industrial base. The hybrid also seamlessly merges with our existing coal production and transportation infrastructures.

Deployment of hybrid-nuclear facilities can save thousands of jobs within the five states of the Consortium while tens of thousands of new US jobs can be created by manufacturing, building and operating hybrid energy production facilities that are fueled by US resources.

The economic and environmental potential of hybrid-nuclear energy is dramatic for the US as a whole and the Consortium states in particular. Coal production can remain a major revenue source, electrical power can remain a reasonably priced commodity with greenhouse gas emissions dramatically reduced, and the otherwise inevitable massive job losses caused by phasing out the use of coal can be avoided.

8.1.1 TECHNOLOGY DESCRIPTION

This promising, emerging energy production technology directly integrates the use of nuclear and fossil fuels, particularly coal, of which the US possesses massive but increasingly out of favor reserves. The hybrid approach inherently reduces all air emissions by roughly 50 percent.

The unique, patent-pending hybrid-nuclear technology springs from the observation that that roughly half the power produced by a combustion turbine is used to compress air. By using a highly efficient helium gas reactor system to drive the combustion turbine's compressor, a number of benefits ensue. For instance, because most of the combustion turbine's power is used for generation, the plant's electrical output is nearly doubled, relative to a standard gas turbine.

As can be observed by Figure 8.1.1, the hybrid's air compressor is not coupled to the combustion turbine. This feature has a number of profound implications; the most powerful being that the compressor can operate at variable speeds, thereby providing massive quantities of air for multiple simultaneous applications, particularly coal gasification. The hybrid's unique design also opens the door for the production of fuels (diesel, jet fuel, gasoline, substitute natural gas, etc.) from coal with dramatic reductions in emissions, particularly greenhouse gases.

Physically, a hybrid-nuclear plant is, in large measure, a combined-cycle power plant, as illustrated by the Figure 8.1.2 artist's rendering and the Figure 8.1.3 arrangement sketch. The hybrid is roughly 40 percent more efficient than conventional coal and coal gasification plants due to the use of highly efficient gas turbine technologies, as discussed later in this report.

The key elements of the hybrid technology are the reactor, the helium turbo-compressor, the combustion turbine and the heat recovery steam generator. The helium gas reactor has been the subject of extensive research, development and testing—the turbo-compressor less so, but machines have been built and tested.

At higher elevations, the output of a conventional combustion turbine (and coal gasification plants) can be reduced by 10 to 15 percent due to their fixed speed design. Unlike conventional designs, the hybrid's combustion turbine is largely unaffected by altitude because the reduction of air flow (due to less dense air) that would otherwise occur is overcome by increasing the speed of the air compressor. That is, the power supplied to the air compressor by the reactor block is essentially constant. The hybrid is ideally suited for high-altitude regions. The hybrid is also less affected by hot weather, relative to conventional combined-cycle plants.

Figure 8.1.1: Overview of Hybrid-Nuclear Energy

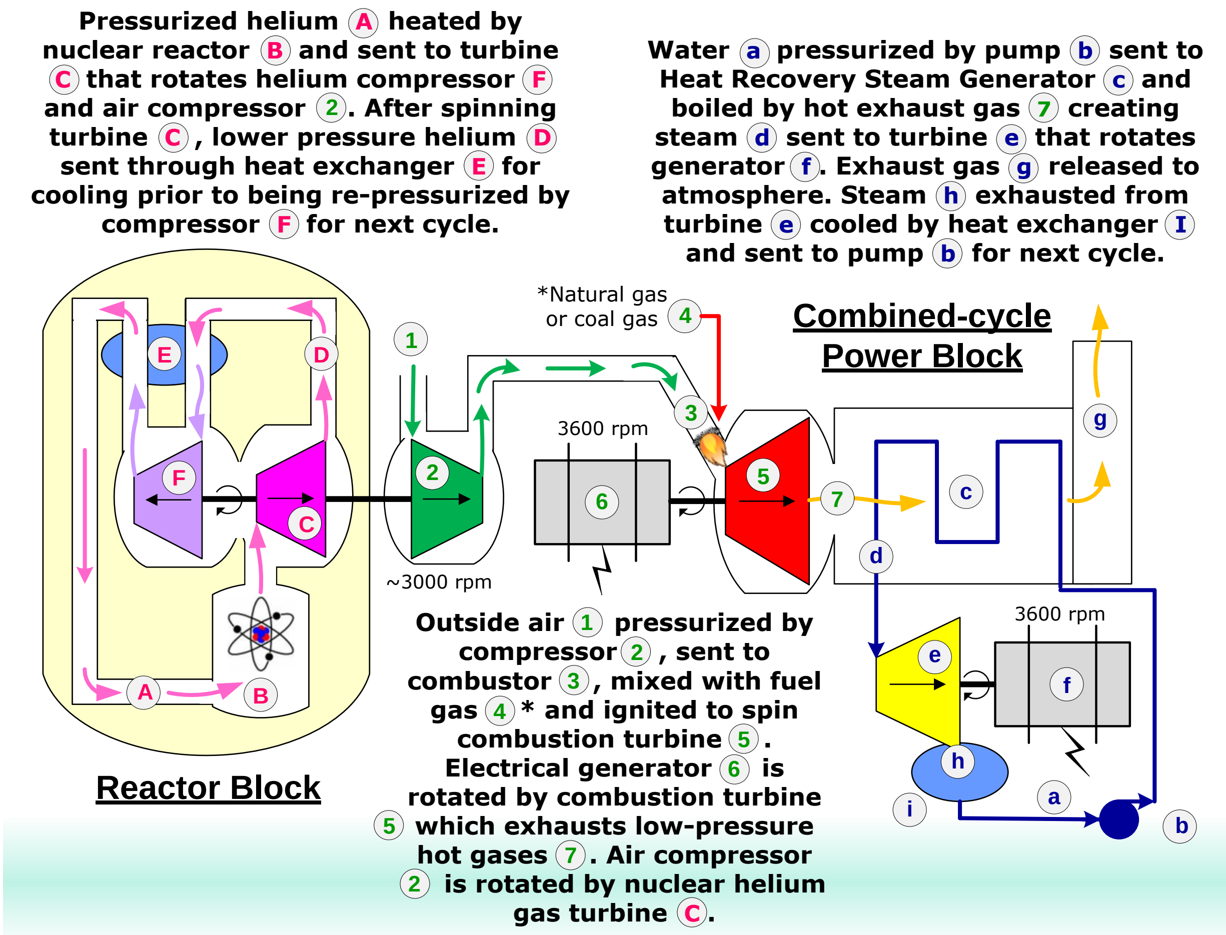


Figure 8.1.2: Artist rendering Hybrid-Nuclear Power Plant Energy

Figure 8.1.3 – Plant Arrangement

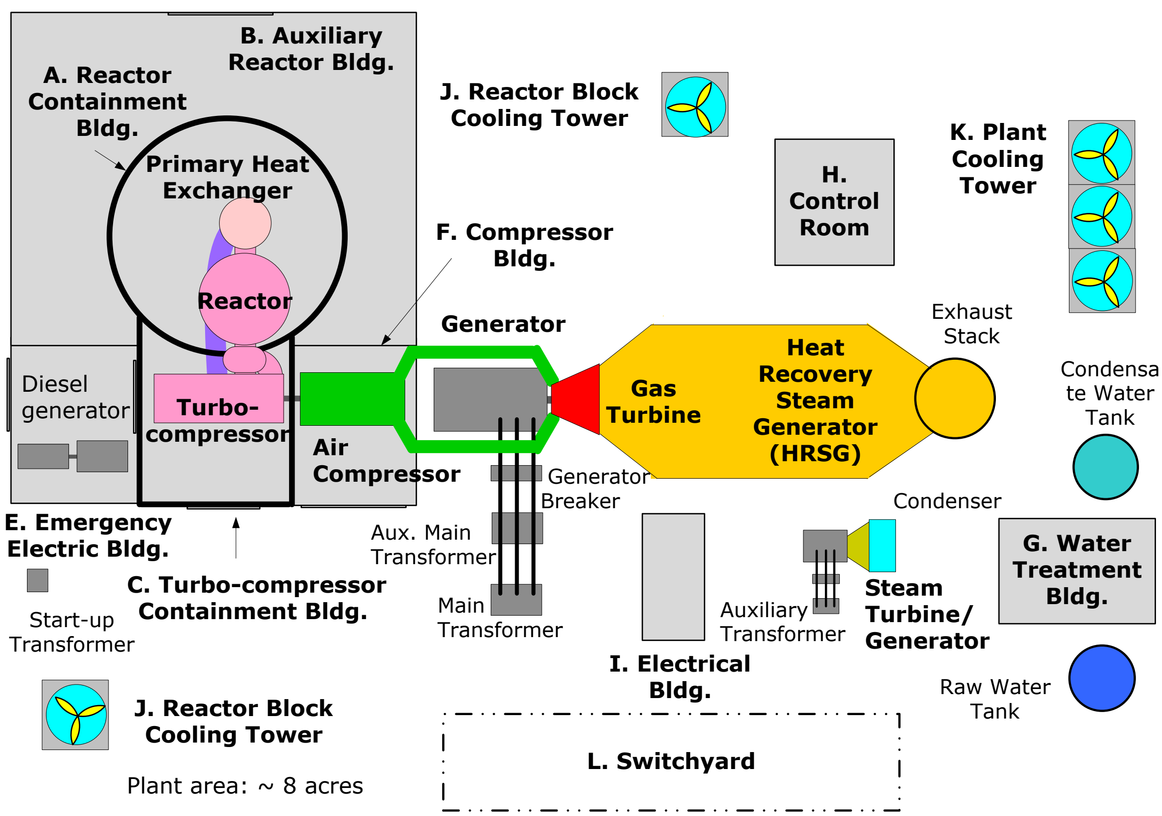
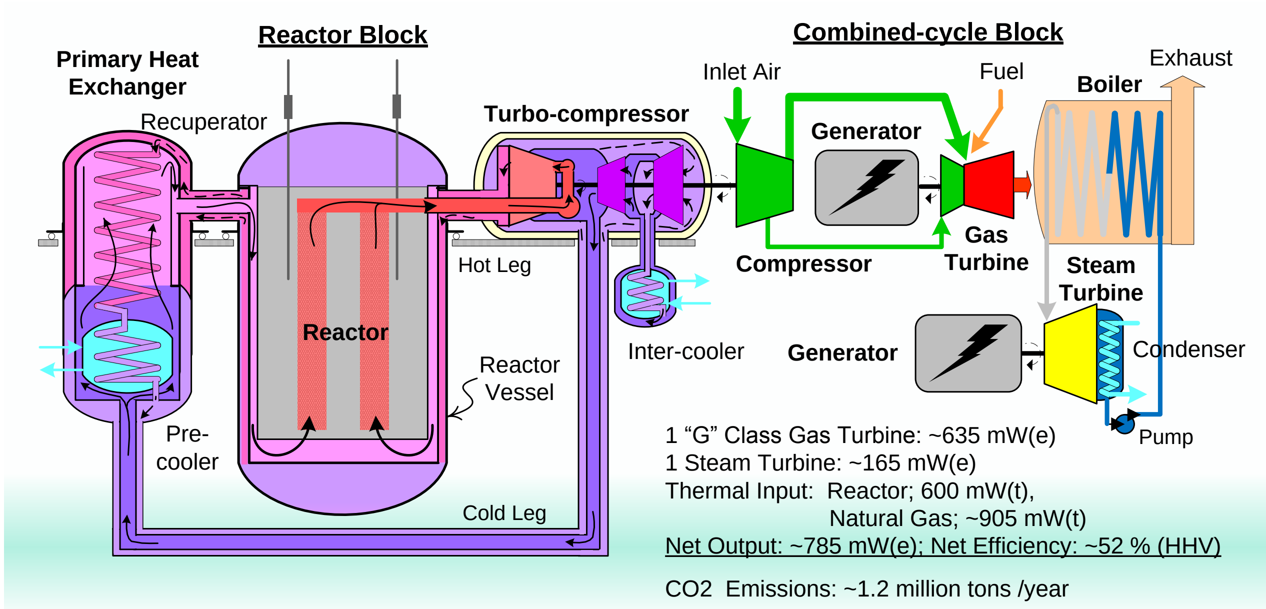


Figure 8.1.4 illustrates the basic elements that define a hybrid-nuclear plant. The hybrid's unique design overcomes the commercial competitiveness shortfalls as well as design and material issues that have long hampered wide-scale deployment of the gas reactor.

A fundamental objective of the hybrid design is to employ proven materials and fabrication techniques to avoid the problems that complicate current gas reactor designs. Major components reside within separate multiple-walled vessels, with the outer vessels subjected to relatively moderate pressures and temperatures. The hybrid-nuclear concept embodies proven and reliable features that have evolved over the 50-year history of combustion turbines and gas reactors. Rugged equipment and components are used, consistent with the needs of utility power plants and process facilities. All key components are designed to readily support maintenance, overhaul and refueling activities.

One of the key features of the hybrid design is the distinctive vessel-within-a-vessel configuration, as implied by Figure 8.1.4. This arrangement causes the reactor vessel to be subjected to significantly lower pressures and temperatures than current concepts, thus enabling the use of materials essentially qualified to American Society of Mechanical Engineers (ASME) nuclear requirements. Further, the vessel wall, with a thickness of roughly 80 mm, can be readily fabricated (as rolled plate) by a number of domestic manufacturing facilities - e.g. US shipyards and heavy vessel manufacturing facilities. Field welding can be readily accomplished using existing, proven technologies. The vessel thickness of current gas reactor concepts is about 250 mm and is well outside established manufacturing capabilities.

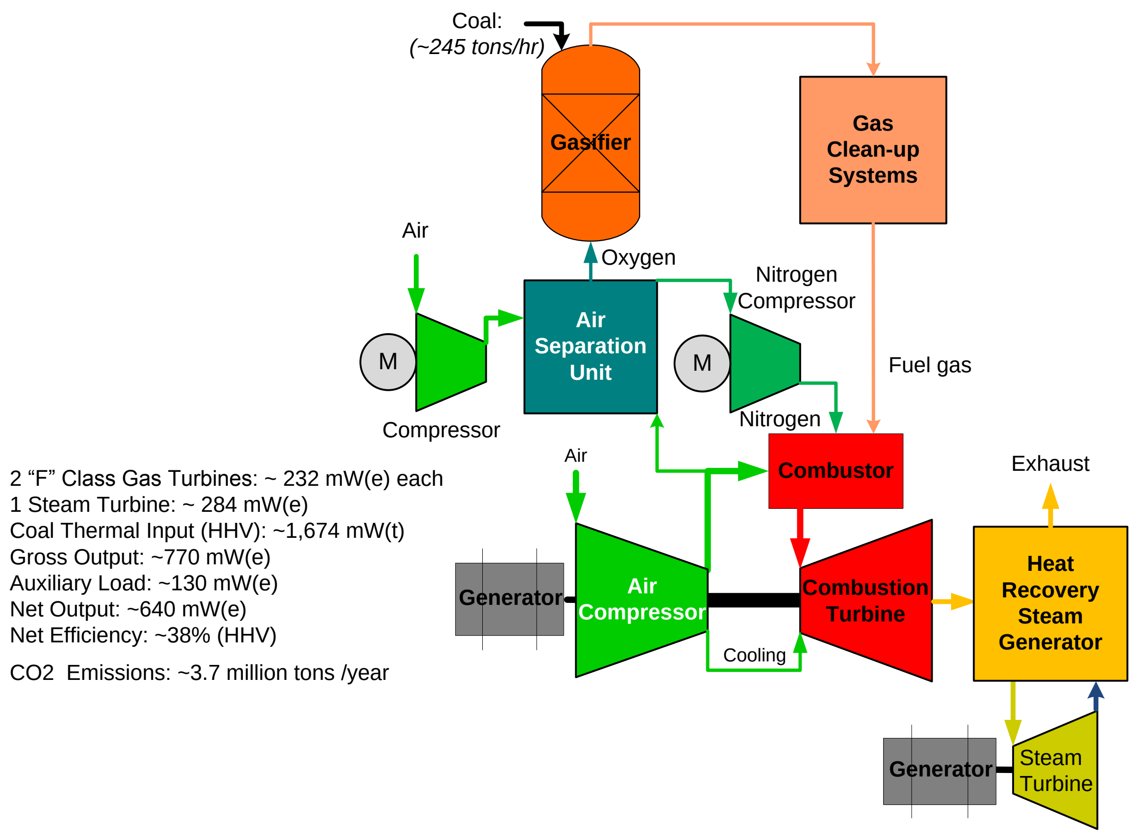
Figure 8.1.4 – Basic Elements, Hybrid-Nuclear Plant



Conventional Coal Gasification. Figure 8.1.5 summarizes the general characteristics of a typical conventional Integrated Gasification Combined-cycle (IGCC) power plant. The plant is based on employing two slurry fed gasification trains – such units are generally limited to using eastern US coal because of the relatively low heat content of Powder River Basin coal. The 2 x 50 percent gasifiers operate at maximum capacity. The gas clean-up system includes synthetic gas cooling and re-heating as well as removal of mercury, sulfur and allied pollutants.

The combustion turbine provides about 30% of the air required by the Air Separation Unit (ASU) that supplies oxygen to the gasifier. The largest portion (nearly 70%) of the plant's auxiliary load is associated with the air and nitrogen compressors used by the ASU. The nitrogen is used to reduce nitrogen oxide (NO_x) emissions while also increasing the output of the combustion turbine.

Figure 8.1.5 – Overview of Conventional Coal Gasification Process



<u>Hybrid-nuclear Coal Gasification</u>. Figure 8.1.6 is a simplified overview of a hybrid-nuclear IGCC plant. The design is based on employing two dry fed gasification trains that can use any type of coal, including those from Western regions of the US. Each of the 2 x 50 percent gasifiers operates at maximum capacity. The gas clean-up system includes synthetic gas cooling and re-heating as well as removal of mercury, sulfur and allied pollutants.

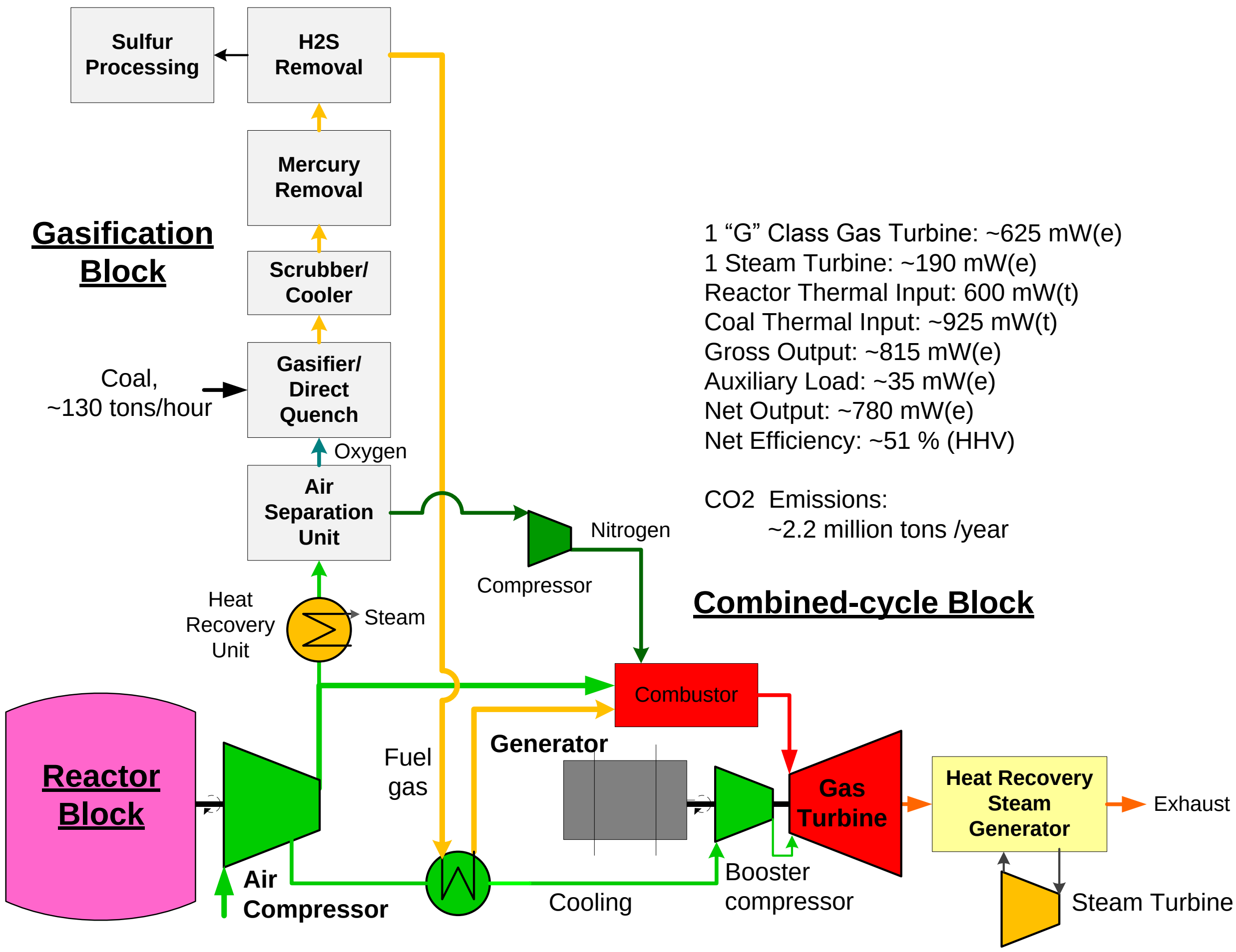
The most significant differences relative to conventional IGCC plants include:

- The combustion turbine's main air compressor is driven by the reactor's variable speed helium turbo-compressor.
- All of the air required by the ASU is provided by the helium turbo-compressor driven air compressor. The variable speed of the turbo-compressor makes this configuration feasible, being quite unlike conventional fixed speed designs.
- The combustion turbine drives a small booster compressor that increases the pressure of the cooling air used by the combustion turbine (expander).

The first two differences dramatically reduce auxiliary power requirements and are major reasons for the hybrid's much higher output and net efficiency, relative to conventional IGCC plants.

The hybrid approach avoids the need for advanced hydrogen fired combustion. A relatively standard gas turbine can be used because converting the synthetic gas to hydrogen is unnecessary, and it is this conversion of the synthetic gas to hydrogen that creates CO_2. Also, since the combustion turbine's fuel gas is mostly carbon monoxide (by weight) with modest hydrogen levels, existing diffusion combustor (firing chamber) designs can be used, with nitrogen diluents used to aid control of nitrogen oxides.

Figure 8.1.6 – Overview of Hybrid-Nuclear IGCC Plant Coal Gasification Process

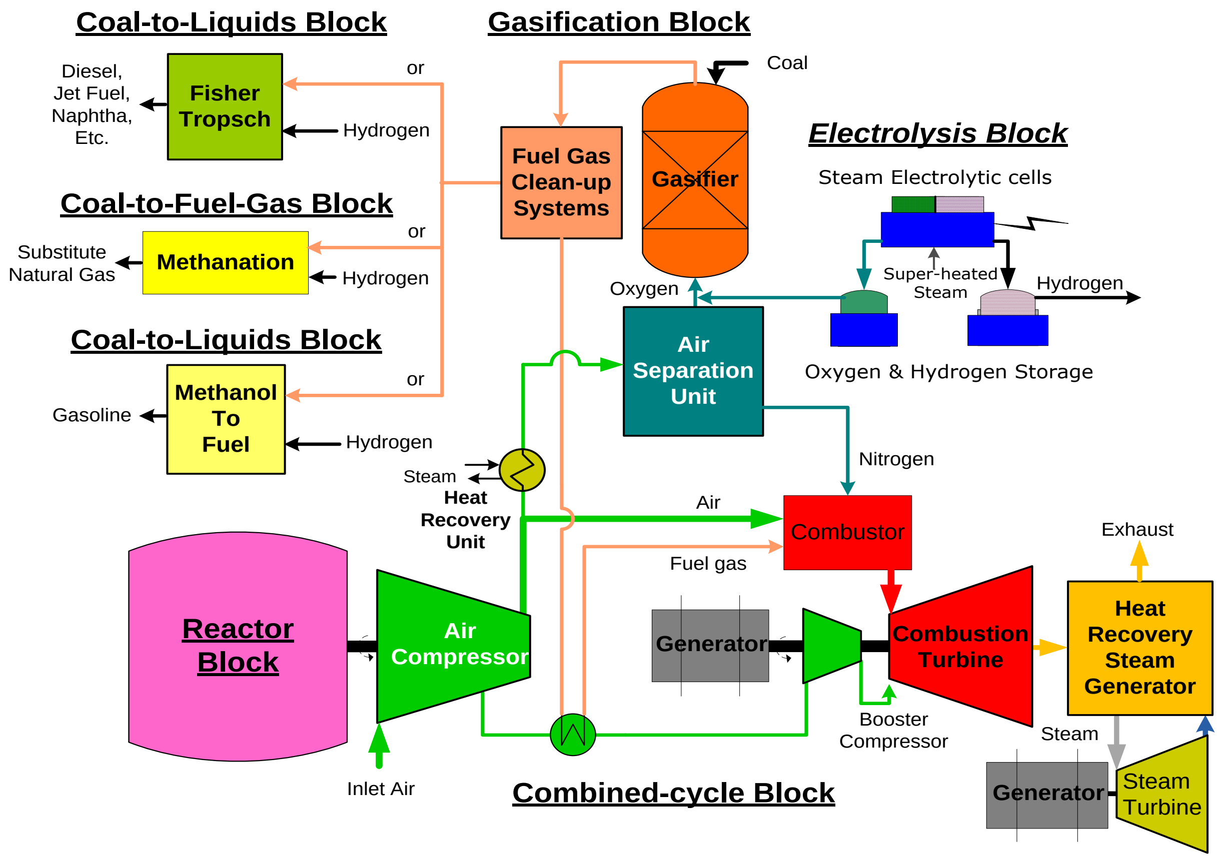


The gasification plant, ASU and clean-up systems are about ½ the size of equivalent conventional IGCC plants while only a single combustion turbine is used. This means the capital cost of the gasification block is reduced by roughly 50%. While the capital cost of the reactor block is moderate, the aggregate cost of the plant is very similar to that of a conventional IGCC plant. However, the net production costs are much lower due, in part, to a much higher efficiency and output.

Process Applications. Figure 8.1.7 provides an overview of integrated hybrid-nuclear fuel production processes that are readily capable of producing an exceptionally wide range of co-products. These capabilities greatly exceed those of the current gas reactor concepts.

The hybrid can be used to produce electrical power when using natural gas or synthetic gas produced by coal gasification. When paired with coal-to-fuels processes, a broad spectrum transportation fuels and substitute natural gas and industrial chemicals can be co-produced. Hybrid-nuclear energy can lead directly to energy independence.

Figure 8.1.7 – Overview Hybrid-Nuclear Coal-to-Fuels Production



Current gas reactor concepts envision employing reactor heat to support process applications. The hybrid's alternate approach overcomes the severe operational, technical and material complications inherent in moving very hot, high-pressure gases (over 900^{o} C and about 7 bars) through complex arrangements of pipes and components.

The hybrid uses the tried and proven technology of the heat recovery steam generator of the combined cycle block to produce process steam heat. Such an arrangement is commonly employed in industry and is exceptionally flexible, with steam supplied at pressures of up to about 138 bars (2000 psig) and at temperatures of about 565^{o} C (1050^{o} F). Steam at high temperatures (~730^{o} C or ~1350^{o} F) and moderate pressures (~27 bars or ~400 psig) can be provided for by using duct burners mounted in the heat recovery steam generator (HRSG). Such equipment is common on combined-cycle power plants.

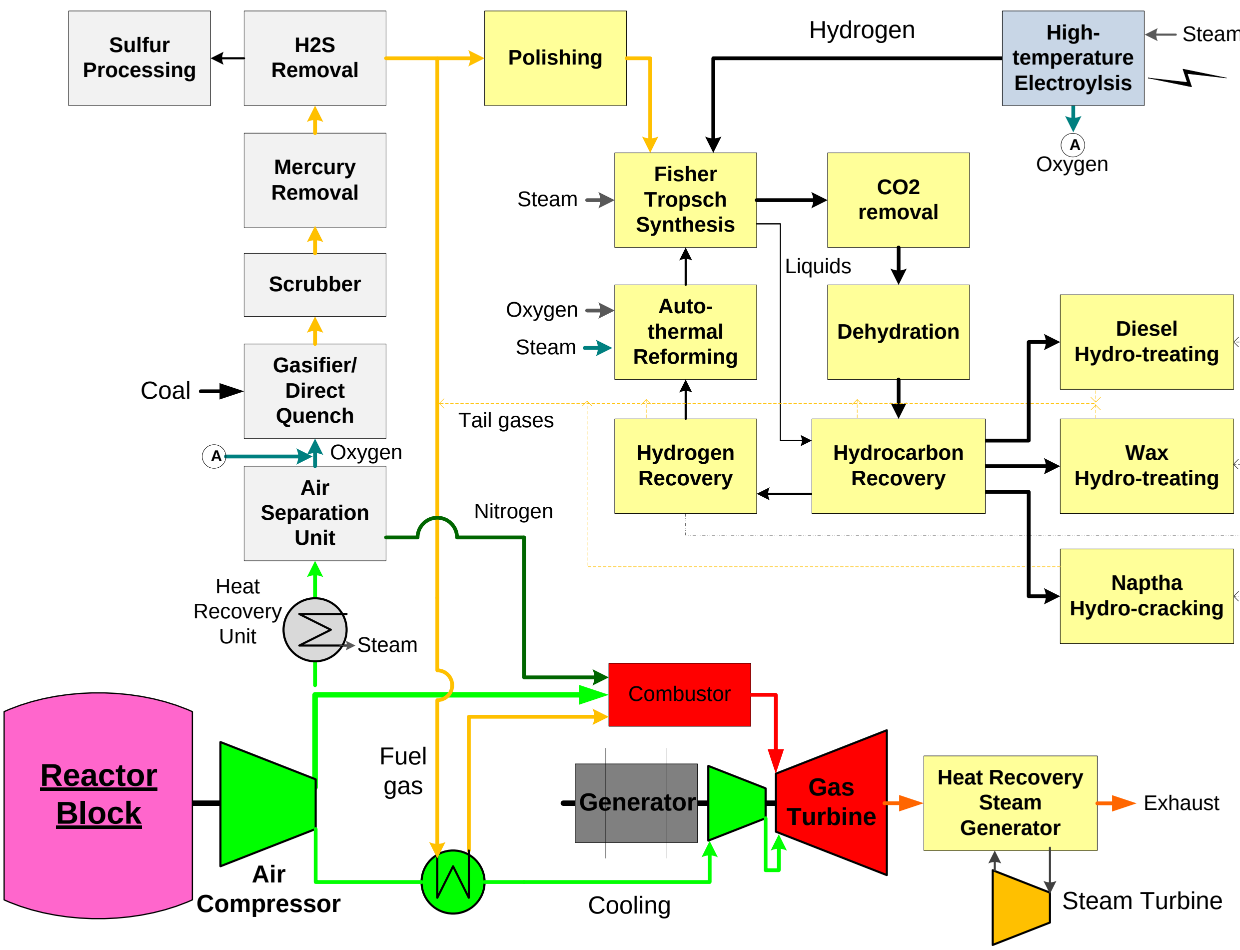
Moderate pressure, high-temperature process steam can be employed with a steam electrolysis block to produce hydrogen; this is a much more efficient process than conventional hydrolysis. If the electrolysis block is used in conjunction with a coal gasification block, the oxygen produced by electrolysis can also be used by the gasifier. Further, the hydrogen is used with the gas-to-fuels blocks to significantly increase production output while simultaneously reducing the CO_2 ultimately directed to the combustion turbine of the combined-cycle block. This occurs by minimization of the conventional water gas shift reaction ($CO+H_20 \rightarrow H_2+CO_2$) that produces large quantities of CO_2 in addition to the extra hydrogen needed to create fuels (e.g. C_nH_{2n+2} carbon chains, where n is an integer) from the gasified coal. The hybrid's large power output makes the electrolysis approach practically feasible.

Compressed air (or more accurately, the oxygen separated from the air) is the key to the coal gasification process, which in turn, is the basis for subsequent processes that produce all manner of fuels and chemicals from coal. Production methods include:

- Fischer-Tropsch process that employs synthetic coal gas to produce a wide variety of hydro-carbons used as liquid transportation fuels, including: diesel, jet fuel, naphtha, etc. Figure 8.1.8 illustrates a typical hybrid-nuclear/Fischer-Tropsch fuel production process capable of producing thousands of barrels of fuel per day from coal as well as hundreds of MW of power.
- Methanation processes that can convert coal to substitute natural gas.
- Coal-to-gasoline processes that convert methanol to high quality gasoline, with the methanol synthesized from gasified coal.

In all cases, the primary fuel source for the combustion turbine is the synthetic gas produced by the gasifier, as augmented by tail gases from the coal-to-liquids/fuels blocks. This approach allows the combustion turbine to operate independently of the coal-to-fuels block. In addition and typical of IGCC plants, the combustion turbine can be fired with natural gas, thereby allowing power operations with the gasifier out of service.

Figure 8.1.8 – Overview of Hybrid-Nuclear/Coal-to-Diesel & Jet Fuel Production



8.1.2 TECHNOLOGY DEVELOPMENT PROGRESS

Hybrid-nuclear energy is expected to be commercially available within five years because the technology is a union of already proven technologies: the combustion turbine; the combined-cycle power plant; and coal gasification; and the maturing helium gas reactor. A more rapid deployment is possible with widespread recognition of the hybrid's strategic potential to dramatically reduce greenhouse gas emissions while simultaneously leading the way to US energy independence.

The underlying technologies are discussed below.

A. Combustion (gas) Turbines. Gas turbines have evolved significantly from the early unreliable and low efficiency generating machines developed in the 1950's. Advanced "G" and emerging "J" class machines produce nearly 300 MW (electric) at efficiencies approaching 40%. These large and efficient machines are key reasons for the hybrid's competitiveness.
B. Combined-Cycle Power Plants: Literally hundreds of such power plants are in operation throughout the world with advanced units operating on natural gas achieving efficiencies approaching 60% efficiencies while producing less than half the greenhouse gas emissions of comparable conventional coal power plants.
C. Coal Gasification: This technology is quite mature and has been in use for over 50 years. Dozens of such facilities have been constructed all over the world, with several operational gasification plants located in North Dakota, Florida and Indiana. A number of facilities are under construction worldwide, with one facility being built in the US—Duke Energy's Edwardsport IGCC plant—located in Indiana. Several US plants are also in the final development stage, including, Tenaska's Taylorville plant in Illinois.

   However, as a result of pending regulations involving greenhouse gas emissions, the future progress of coal gasification in the US is problematic, with literally dozens of projects having been cancelled within the last few years. The same fate has also befallen proposed new coal power plants, with many older units being shut down. While carbon sequestration is a proposed solution, the massive scale of such underground storage (billions of tons of CO_2) is daunting and major technical challenges stand in the way of commercial deployment of the technology, including using hydrogen fired combustion turbines and very poor plant efficiencies. Hybrid-nuclear technology does not require sequestration because of low CO_2 emissions.

D. Gas Reactor: Carbon dioxide gas cooled reactors have been in operation for over 50 years in England. However, the helium gas reactor has realized only limited commercial success, including the 330 MW(e) Fort Saint Vrain constructed in Colorado in the mid 1970's and the German 300 MW(e) Thorium High Temperature operated in the mid 1980's - see www.World-nuclear.org. The relatively small size of these plants was a contributing factor in their lack of success. However, a relatively small reactor (about 600 MW thermal output) is required to retain a fail-safe design (i.e. fuel cannot melt).

The US Department of Energy has invested hundreds of millions of dollars in development and testing high-temperature helium gas reactors through various programs, including, most recently, the on-going Next Generation Nuclear Plant (NGNPP) - see www.ne.doe.gov. The hybrid is based on the gas reactor being developed for the NGNPP by General Atomics located in San Diego, CA – see www.ga.com. However, a number of simplifications are employed because of the hybrid's more conventional configuration. Also, the extensive reactor related work of the DOE is readily transferable to the hybrid design, as is the General Atomics work.

Japan has built and is operating a High Temperature Test Reactor that serves as a prototype high-temperature helium gas reactor.

Because the hybrid-nuclear technology is fundamentally based on existing technologies, deployment is largely a straightforward engineering integration effort.

There are, however, several areas that will require some development by equipment manufacturers, as discussed below.

1. Helium turbo-compressor. Relatively few helium-turbo compressors have been constructed, largely because there has been no commercial demand for such machines. Germany and Japan have built and tested helium turbo-compressors, while South Africa has designed a machine for the Pebble Bed Modular Reactor program. As a general perspective, modern combustion turbines operate at temperatures exceeding 1340^{o} C (2450^{o} F), well above the 850^{o} C (1562 F) inlet temperature of the hybrid's helium turbine. While further design, development and testing work will be required, the basic technology is not a cutting edge application. Thus development of the helium turbo-compressor is considered to be a relatively straightforward engineering effort well within the capabilities of combustion turbine manufacturers.
2. Combustion Turbine. The hybrid's combustion turbine is a variant of a conventional configuration in that the compressor section is de-coupled from the turbine. While such separations are actually not that unusual, testing will be required to confirm the hybrid configuration, as routinely done with all turbine designs.
3. Reactor Vessel. While the reactor vessel intended for the hybrid is a much simpler design than those proposed for the NGNPP program, some design development and testing work will be required, although a considerable amount of work has already been accomplished under the auspices of the NGNP. However, because the hybrid's configuration is specifically aimed at staying within the acceptance parameters of existing design codes, the required effort is considered straight forward.

Given the large body of existing technical work in these areas, a few years will be necessary to complete design and testing efforts. Realistically, several hundred million dollars will be required to move through the design development and testing efforts required to insure high reliability of the key features of the design.

Because the hybrid is based on using a nuclear reactor, licensing of the technology by the Nuclear Regulatory Commission will be required. Realistically, the regulatory arena is expected to require the longest development time frame. Such licensing work is already well underway under the auspices of the Next Generation Nuclear Plant (NGNP) effort – see www.nrc.gov/reactors/advanced/ngnp. However, the hybrid-design is less complex than the NGNP, thus a number of the major hurdles faced by the NGNP are avoided.

8.1.3 TECHNOLOGY PRODUCTION AND DEPLOYMENT

A strategic objective of the hybrid is to phase out the hundreds of aging US coal plants and replace them with standardized hybrid-nuclear units. A secondary objective is to provide for new electrical generation plants to be fueled by either coal or natural gas. Standardized hybrid units would be built. Given this scale, literally tens of thousands of mining, manufacturing, construction and production jobs are involved.

The advantages for the Consortium states of the widespread use of hybrid-nuclear/coal gasification technology include the following:

1. Allows Wyoming, Montana and Utah to continue extracting the coal currently providing major economic benefits to these states while also providing the remaining Consortium states with an economically produced fuel source.
2. Allows all the Consortium states to dramatically reduce power plant greenhouse gas emissions but still use the region's coal. Coal fired generating plants form the backbone of power

production in all the Consortium states and the loss of these electrical generating facilities would have severe economic repercussions.

3. Supports producing transportation fuels from the region's large coal reserves, thereby helping reduce exposure to volatile foreign sources for gasoline, diesel and jet fuel.

Tens of thousands of jobs and billions of dollars of direct wages are associated with coal extraction and power production within the Consortium states. Pending climate change legislation is directly threatening the use of this valuable resource and by extension directly threatening the region's jobs and economies.

Hybrid-nuclear facilities are designed to be mass-produced with standardized basic modules consisting of a 600 MW (thermal) reactor block and combined-cycle power block generating roughly 750 MW of power. Gasification and coal-to-fuel blocks would be sized based on the particular production emphasis. Each facility would directly employ several hundred workers. Construction of a hybrid-nuclear facility would involve several thousand jobs over the course of several years.

General Overview – electrical generation. Table 8.1.1 summarizes electrical power production by the Consortium States, sources www.eia.gov and www.sourcewatch.org.

Table 8.1.1: Regional Electrical Power Production

State	Capacity, mW(e)	US Rank	Generation, mWh x10^6	Retail price ¢/kWh	Percent Coal	Coal Generation, mW(e)	Estimated Employment
Iowa	13,711	28	53.1	6.89	~47%	6490	4300
Utah	7,132	33	46.6	6.49	~75%	5080	3800
Wyoming	7,145	34	46.5	5.67	~85%	6165	3800
Nebraska	7,024	39	32.4	6.58	~43%	3205	2600
Montana	5,614	41	29.6	7.72	~47%	2535	2400
South Dakota	3,105	46	7.1	7.14	~15%	475	575

A large portion of the region's power is produced using coal. Replacement of the Consortium states' 68 coal power stations with hybrid-nuclear/coal gasification facilities would involve construction of about 32 standardized ~750 MWe hybrid units.

8.1.4 POTENTIAL JOB IMPACTS

General Overview – electrical generation jobs. Nationwide, electrical power production employs over 404,000 individuals per the US Department of Labor, with a breakdown as follows: over 40% of these jobs involve production or installation, maintenance, and repair occupations; about 21% of jobs involve office and administrative support occupations; 15% are professional and related occupations; and 13% are in management, business, and financial occupations; The remaining jobs are in construction, transportation, sales, and service occupations – see www.bls.gov. Attempting to sum employment numbers using Standard Occupational Codes is difficult, given the diverse nature of power plant jobs, including: operators (*SOC code 51-8011, 51-8013*); electricians (*49-2095*); ironworkers (*47-2221*); millwrights (*49-9044*); pipefitters (*47-2152*) boiler makers (*47-2011*); laborers (*42-2061*); engineers (*17-xxxx*), management (*11-xxxx*), etc. However, about 17,500 individuals are estimated to be employed in power production within the Consortium states, using a simple ratio based on power generation and the more general Bureau of Labor statistics. Net wages are estimated to be roughly $1.1 billion dollars.

Employment estimates for operation of a typical new coal fired power plant, per www.holcombstation.com, are as follows:

> "The 206 positions in Western Kansas include 70 full-time workers to operate the Holcomb Station, once the unit goes into commercial operation. This will increase the total workforce at Holcomb Station to approximately 220. The new positions required for these additions will range from entry-level workers through management staff. Their total expected annual payroll will total more than $9 million and … annual property taxes of more than $5 million."

A hybrid-nuclear/coal gasification station is likely to employ a somewhat similar number of workers, while equivalent property taxes would be roughly 50% higher due to the hybrid's higher value.

Natural Resource Harvesting Jobs

General Overview – resources. Table 8.1.2 summarizes coal, natural gas and crude oil production within the Consortium states.

Table 8.1.2: Regional Fuel Production

State	Coal,		Gas,		Crude Oil,	
	millions of ton	*US Rank*	billions of cubic feet	*% US Total*	Millions of barrels	*US Rank*
Wyoming	13,711	*1*	2,488	*9.5%*	51	*7*
Montana	7,132	*5*	119	*0.5 %*	33	*10*
Utah	7,145	*14*	442	*1.7 %*	16	*13*
Nebraska	0	*n/a*	3	*< 0.1 %*	2	*21*
Iowa	0	*n/a*	0	*n/a*	0	*n/a*
South Dakota	0	*n/a*	12	*< 0.1 %*	1	*25*

* 2008 data, complied from US Energy Information Agency, www.EIA.gov

As can be observed, Wyoming, Montana and Utah produce large quantities of coal, thereby providing significant economic benefits as well as major revenues for these three states. Wyoming extracts significant amounts of natural gas, with Utah and Montana extracting smaller quantities. Crude oil extraction is a noticeable source of economic activity in Wyoming, Montana and Utah, with some minor extraction in Nebraska and South Dakota.

Table 8.1.3 summarizes approximate employment data related to extraction of coal, natural gas and petroleum.

Table 8.1.3: Jobs and Economic Activity – Mineral Resource Harvesting

State	Jobs Material Moving (Group 047-5000)	Jobs Extraction (Group 053-7000)	Jobs Supervision & Management (Group 047, 053-1010)	Net Jobs	Net Wages,
Wyoming	9,730	*7,005*	1675	~18,400	$760 million
Montana	1,835	*6,950*	880	~9,660	$290 million
Utah	5,460	*25,360*	2880	~33,900	$1.2 billion
Nebraska	-	-	-	-	-
Iowa	-	-	-	-	-
South Dakota	-	-	-	-	-

* Source, US Bureau of Labor Statistics roughly modified to filter out unrelated jobs, www.BLS.gov

Collectively, coal and uranium fuels extraction and transportation activities are estimated to directly account for roughly over 15,000 thousand jobs and wages of over $500 million within the region's economies.

Hybrid Resource Needs. Hybrid-nuclear facilities use uranium, coal or natural gas using existing conventional methods.

Widespread deployment of hybrid-nuclear facilities is expected to maintain coal production and allied regional employment at current levels and avoid the decline that will inevitably occur when climate change regulations are imposed nationwide. The ability to avoid job losses is the direct result of the hybrid's ability to achieve massive reductions in CO_2 emissions.

Most uranium used in the US is imported. The US possesses about 5% of the world's uranium reserves, with major concentrations in Utah and Wyoming. However, tens of thousands of jobs in the domestic uranium mining industry have been lost over the last 25 years for a variety of reasons.

The hybrid uses only about $1/4^{th}$ as much nuclear fuel as a conventional reactor. Further, the helium gas reactor is ideally suited to also employ thorium as a fuel source, of which the US posses about 15% of the world's reserves (see World Nuclear Association, www.World-nuclear.org), with large high-grade deposits located on the Montana-Idaho border. Thus, the widespread use of the hybrid-nuclear technology is expected to reinvigorate the environmentally sound harvesting of both uranium and thorium, with a reasonable expectation for the creation of tens of thousands of new direct and indirect jobs.

Manufacturing Jobs

The hybrid is manufactured basically like existing types of power and heavy industrial plants. The technology does not require the use of new and unproven manufacturing methods.
Power plants are constructed from all manner of mechanical, electrical and structural elements manufactured and supplied by literally thousands of companies. Attempting to estimate the number of jobs involved is difficult. However, as broadly summarized below, over a million US workers are involved with manufacturing equipment and materials used by power plant and related heavy industry projects.

Table 8.1.4: US Manufacturing Employment

Power Plant & Heavy Industry Related

Category	**US Total, thousands**	**NAICS Code**
Primary Metal Manufacturing	362.8	331
Fabricated Metal Product Manufacturing	365.8	332
Industrial Machinery Manufacturing	984.5	333
Computer and Electronic Product Manufacturing	1,093	334
Electrical Equipment Manufacturing	365.9	335

* Source www.bls.gov, April 2010

The envisioned large-scale deployment of hybrid-nuclear energy plants would help lead to a resurgence in employment within our recession-affected manufacturing sectors.

Construction Jobs

Hybrid-nuclear plants are specifically designed to be constructed in any location suitable for a typical power plant. The hybrid, however, occupies a much smaller land area relative to a comparable generating plant that only uses fossil fuels.

A strategic objective is to replace the aging fleet of over 600 US coal power plants with hybrid-nuclear/coal gasification facilities. Thus existing substations, transmission lines, coal handling facilities and allied infrastructure would be reused or re-configured.

Construction of a power plant is carried out by skilled trades, including: boilermakers (SOC *47-2011*); welders (*47-5121*); pipefitters (*47-2152*); ironworkers (*47-2221*); millwrights (*49-9044*); electricians and electronic technicians (*47-2111*); operating engineers (*47-2073*); sheet metal workers (*47-2211*); insulators (*47-2131 & 32*); painters (*47-2141*); heating & ventilation (49-9021); carpenters (*47-2031*); laborers (*47-2061*); construction supervisors (*47-1011*); construction managers (*11-9021*); cost estimators (*13-1051*) as well as engineers (*17-xxxx*) and various management jobs (*11-xxxx*). Construction of a power plant typically directly requires about 2000 workers over a 3 to 4 year period.

Recent economic forecasts for construction of a new coal fired power plant in western Kansas are summarized below (see www.holcommbstation.com):

> "Over the four-year construction cycle, 1,900 construction workers will earn more than $121 million and spend more than $8 million on food and lodging. The project will also cause purchase of approximately $56 million of local construction related services and equipment."

Construction of a hybrid-nuclear coal gasification plant would likely involve closer to 2500 workers over a 3 to 4 year timeframe.

Marketing Jobs

The market for the hybrid-nuclear technology is all energy production in the US, including: electricity; transportation fuels; substitute natural gas; as well as all manner of chemicals derived from coal. Users include electric and gas utilities as well as the coal and chemical industries.

Although hybrid-nuclear energy is based on existing technologies, the unique combination has never been previously proposed. There is little precedent for shifting industries onto a major path that was simply overlooked. A further complication is that both coal and nuclear energy suffer from a less-than-positive image in many quarters. Nevertheless, there are examples where new and unexpected applications prevailed in spectacular fashion (the personal computer, for instance) and therein lies the key to the marketing of the hybrid. Namely, the hybrid provides for a universal need (clean energy in this case) at a reasonable price.

The number of jobs involved with marketing the far-reaching breakthrough that hybrid-nuclear energy represents is very difficult to estimate. Support must be gathered from industry and labor as well as local state and federal government. That requires marketing and lobbying activities.

The best guess is that a hundred direct marketing related jobs will be created within the Consortium states and roughly a thousand nationwide as the hybrid moves from the introductory stage through commercialization over the space of five years.

Maintenance Jobs

Repair and maintenance of power generating plants is conducted by the same skilled craft workers that build such facilities. The required support varies but generally a large power plant will utilize several dozen workers on a direct, full time equivalent basis in support of maintenance activities.

8.1.5 EDUCATION AND JOBS TRAINING

Hybrid-nuclear energy is an advanced technology that requires skilled professionals to design, manufacture, construct, operate and maintain the facilities. Educational and training support is required at the secondary, trade school, community college and post secondary (university) level. Forecasting the magnitude of the need is difficult, being dependent on the scale of deployment of the hybrid technology. However, technical, professional and vocational education is needed on a greater scale than that of today's badly depressed levels caused by the current major recession. Thousands of educational jobs are expected to be required nationwide.

Besides the need for a broad based education, special needs include: secondary vocational education teachers (SOC *25-2032*) and counselors (*21-1012*). Post secondary education teachers and assistants, including: business (*25-1011*), computer science (*25-1021*) and engineering (*25-1032*) and administrators (*11-9033*) are also needed.

Table 8.1.5 summarizes current educational jobs in the Consortium states involving engineering, computer science, business and vocational jobs in the secondary and post secondary sectors.

Table 8.1.5: Educational Jobs – Technically Related

State	Jobs Post Secondary – business, computer science, engineering, vocational (25-1021, 1032, 1194)	Jobs Secondary - Vocational (25-2032)	Net Jobs	Net Wages, x10^6
Wyoming	410	230	640	$347
Montana	880	280	1160	$264
Utah	3760	530	4290	$337
Nebraska	2290	490	2780	$315
Iowa	2940	980	3920	$337
South Dakota	590	370	960	$212

*Source Bureau of Labor Statistic, www.BLS.gov

In the Consortium states, some 13,750 are employed in these special areas of the education sector, with wages of about $1.8 million. The best guess is that hybrid related efforts would entail a 10-to-20% improvement in these areas.

Natural Resources Harvesting Education and Job Skills

Skilled personnel are necessary for recovering coal, uranium and natural gas, as supported by trade schools, vocational schools, community colleges and universities. No extra-ordinary education efforts are considered necessary.

Manufacturing/Building Education and Job Skills

Given the envisioned scale of the envisioned hybrid-nuclear energy, the manufacturing sector will experience considerable growth, with an attendant need for a skilled and educated workforce to design and manufacture the myriad of necessary components and equipment. No extra-ordinary education efforts are considered necessary.

Construction Education and Job Skills

The skills associated with construction of plants for heavy industry are necessary, as supported by trade schools, vocational schools, community colleges and universities. However, no extra-ordinary specialized education efforts are considered necessary.

Marketing Education and Job Skills

While marketing is a consideration for deployment of the hybrid, basic educational skills would be needed, although a familiarity with energy production would be helpful. No extra-ordinary specialized education skills are considered necessary.

Maintenance Education and Job Skills

Maintenance of power plants requires essentially all the specialized skills used to build the facilities, but at lower use levels. Vocational and technical education is required to support maintenance of a hybrid-nuclear power plant as well as maintenance of mining operations. However, no extra-ordinary specialized education skills are considered necessary.

8.1.6 POTENTIAL CONSTRAINTS/OBSTACLES TO DEPLOYMENT

The unique characteristics of hybrid-nuclear energy cause the technology to be environmentally friendly, competitive with other energy sources, able to readily use existing transportation and electrical transmission system infrastructure, and lead to energy independence. There are no particular constraints to deploying hybrid-nuclear technology in all Consortium member states, although those members closer to coal reserves would benefit from lower transportation costs. In passing, the technology works equally well at sea level or at higher elevations areas.

Development of the hybrid technology will require support at the national level as well as the collective efforts of manufacturing, engineering and construction firms. However, as the hybrid relies on adaptation of existing technologies, no cutting-edge efforts are required. Thus, the technology is primarily implementation related, as opposed to research and development oriented, although some testing work will be required.

The extraordinarily high level of safety of the hybrid is expected to help insure both social and political acceptance of this technology.

Economic Constraints

Commercial competitiveness is the key to the success of the hybrid-nuclear approach. Table 8.1.6 provides a summary comparison of options for large new power plants.

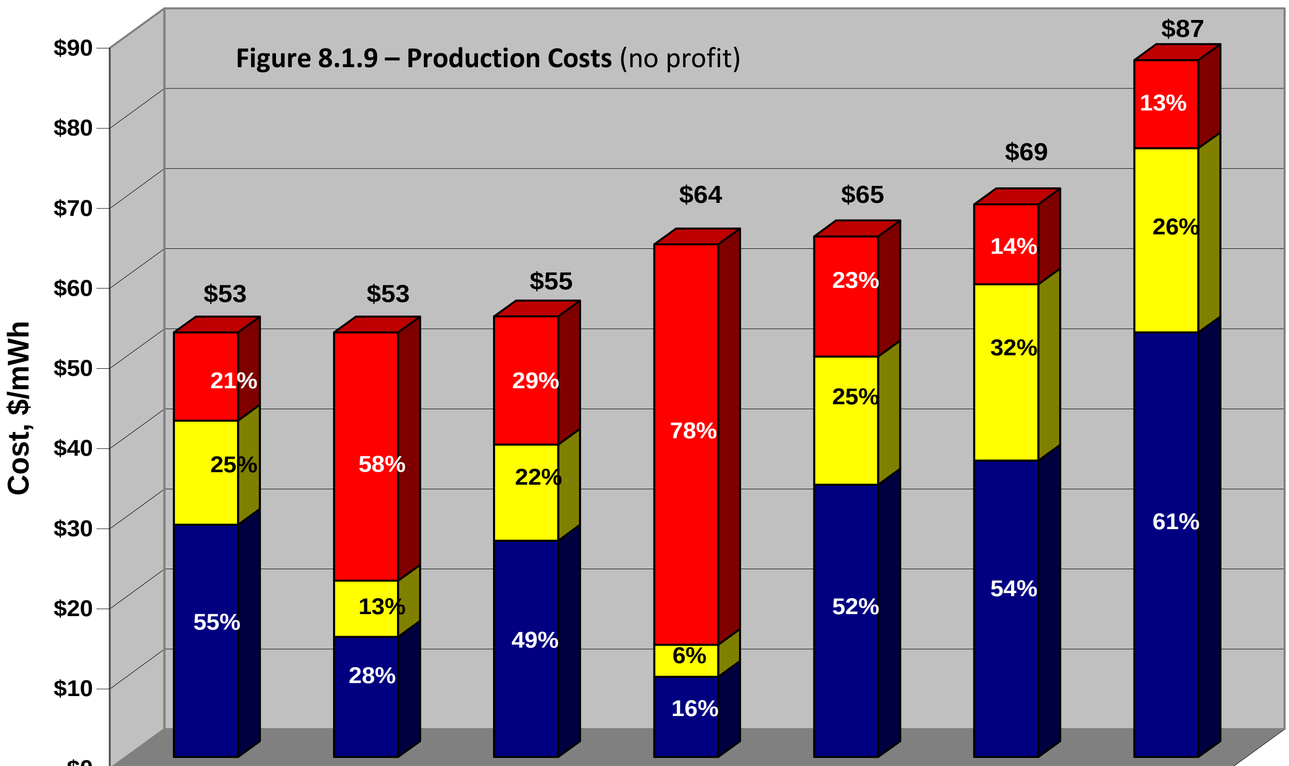
Table 8.1.6: Summary of Generation Options

Plant Type	**Output mW(e)**	**Build Cost, $ Billions**	**$/kW**
Natural Gas Combined Cycle	775	0.85	$1100
Hybrid-nuclear Combined-cycle/Gas	770	1.2	$1500
Super-critical Pulverized Coal	550	1.5	$2800
Integrated Gasification Combined-cycle	630	2.1	$3500
Hybrid-nuclear/Coal Gasification	770	2.3	$3000
Helium Gas Reactor	285	1.1	$4000
Conventional Nuclear	1300	7.2	$5500

Figure 8.1.9 provides forecast production costs for the options listed in Table 8.1.6. Conventional nuclear power plants are expensive to build (see fixed cost) but the fuel is economical. Combined-cycle plants are inexpensive to construct, have low operating costs (O&M) but have the highest fuel cost by a significant margin. The price of natural gas is also volatile. Coal plants are predicted to have the lowest production costs of the conventional group.

Investors expect a return on their investment in proportion to perceived risk. A 10% return before taxes (a somewhat typical power plant target) yields the sell price of power needed to meet investor's expectations. Figure 8.1.11 provides a summary of the tariff (price) required to achieve the target profit. However, the desired sell price of power is not necessarily compatible with the actual price that can be obtained in the open (or regulated) marketplace.

The 2006 average market price for power in the Eastern US was about $52/MWh. A simple analysis would predict: coal plants would achieve positive returns for investors; new combined-cycle power plants would post small losses while only operating during the day; and new nuclear plants would post large losses. Stated somewhat differently, coal plants would have been the preferred new power source with few combined-cycle plants being built. This was indeed the situation in 2006, with dozens of new coal plants in the project planning stages, while new combined-cycle plants were either mothballed, deferred or canceled due to high-cost natural gas.



	Hybrid Coal	Hybrid Gas	Coal	Gas	Gasification	Gas Reactor	Nuclear
Fuel	$11	$31	$16	$50	$15	$10	$11
O&M	$13	$7	$12	$4	$16	$22	$23
Fixed	$29	$15	$27	$10	$34	$37	$53

The specific penalties for greenhouse gas emissions remain uncertain. However, forecasting the impact on electrical generation is straightforward, as illustrated by Figure 8.1.10.

Figure 8.1.10 – Price of Power – 10% Return on Investment

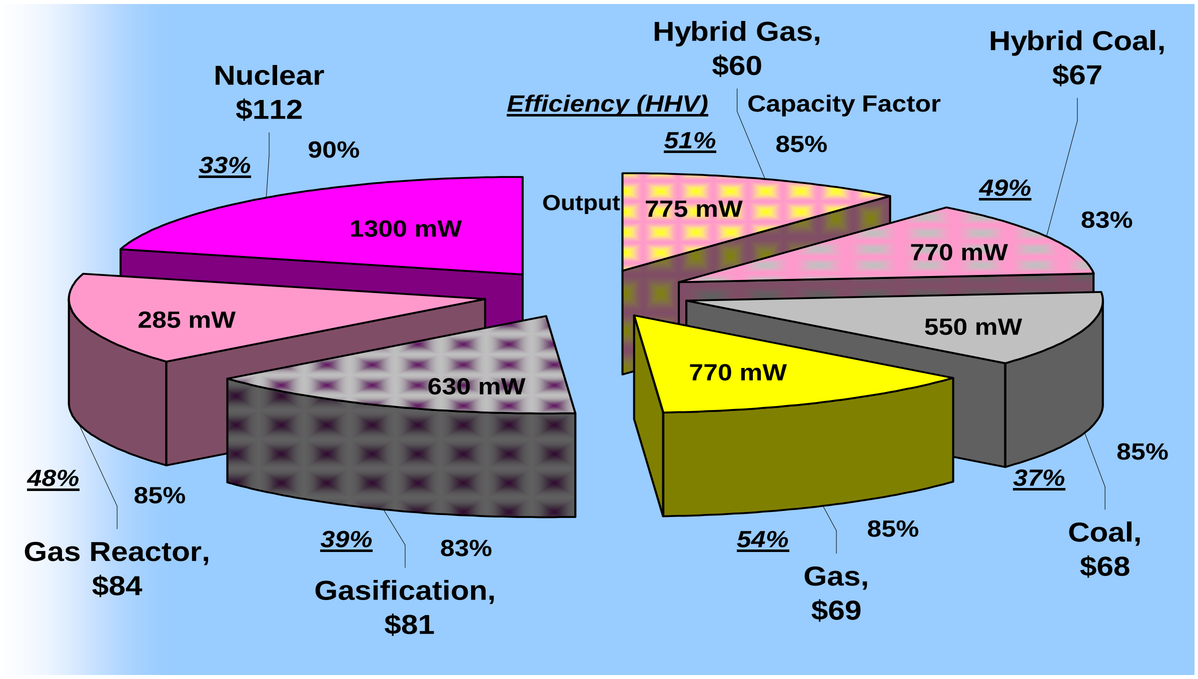
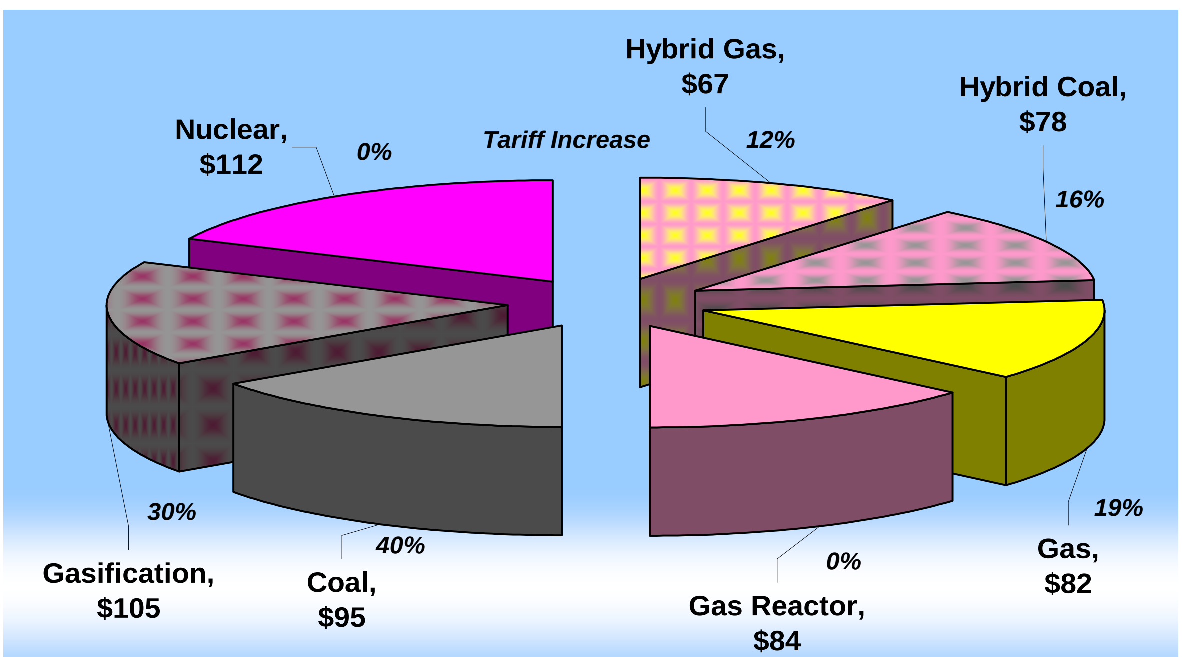


Figure 8.1.11 – Price of Power; $30/ton Penalty on CO_2 Emissions



Social Constraints

As discussed below, the hybrid is expected to avoid the unease that nuclear power can engender within the public. Since the inception of nuclear energy, varying levels of opposition have existed. While the overwhelming majority of conventional nuclear power plants are demonstrably safe, the Three Mile Island accident in 1979, the Chernobyl catastrophe in 1986 and the reactor shutdowns in Japan after the Sendai earthquake and tsunami in 2011 did little to instill public confidence. In the case of the pressurized water reactors used in the US, assurance of the public safety involves employing massive containment structures and a multitude of active engineered systems, but at a high cost to build the facilities. Still, the possibility of melting the nuclear fuel and the potential for unacceptable radiation releases cannot be dismissed.

The helium gas cooled reactor is a major technical innovation in the sense that the fuel cannot melt – this is achieved by limiting the size of the reactor and employing passive heat removal features.

The hybrid technology employs the fail-safe heat removal feature of the helium gas reactor. However, the hybrid also employs a number of well-proven design features and avoids cutting edge technology approaches envisioned for next generation nuclear plants. For instance a full containment design is envisioned instead of the confinement approach (where initial accident releases are vented to the atmosphere) favored by contemporary helium gas reactor design. The large output of the hybrid means that the cost minimization approach of a lesser confinement design can be avoided.

A hybrid-nuclear facility can be shutdown and remain safe with virtually no human interaction and no need for active cooling of the nuclear fuel. This ability is expected to help win over the vast majority of the public.

Environmental Constraints

Overview Table 8.1.7 provides an overview of the power plant coal consumption and greenhouse gas emission for each of the Consortium states.

Table 8.1.7: Electrical Power Sector - Coal Environmental Data for Consortium States

State	Coal Consumption[1] Tons x 10^6	CO2 Emissions lbm/mWh	Relative US Rank	Actual CO_2 emission,[2] tons x 10^6	Relative US Rank	Hybrid-nuclear CO2 Reduction
Wyoming	6.9	2205	1	51.3	20	38%
Iowa	6.0	1902	8	50.5	24	21%
Utah	4.2	1861	10	43.3	27	34%
Nebraska	3.2	1519	18	24.6	35	19%
Montana	3.2	1505	20	22.3	36	21%
South Dakota	0.6	1248	31	4.5	46	7%

(1.) 2009 electrical generating plants per www.eia.doe.gov/cneaf/electricity

(2). 2008 emissions data per www.eia.doe.gov/cneaf/electricity

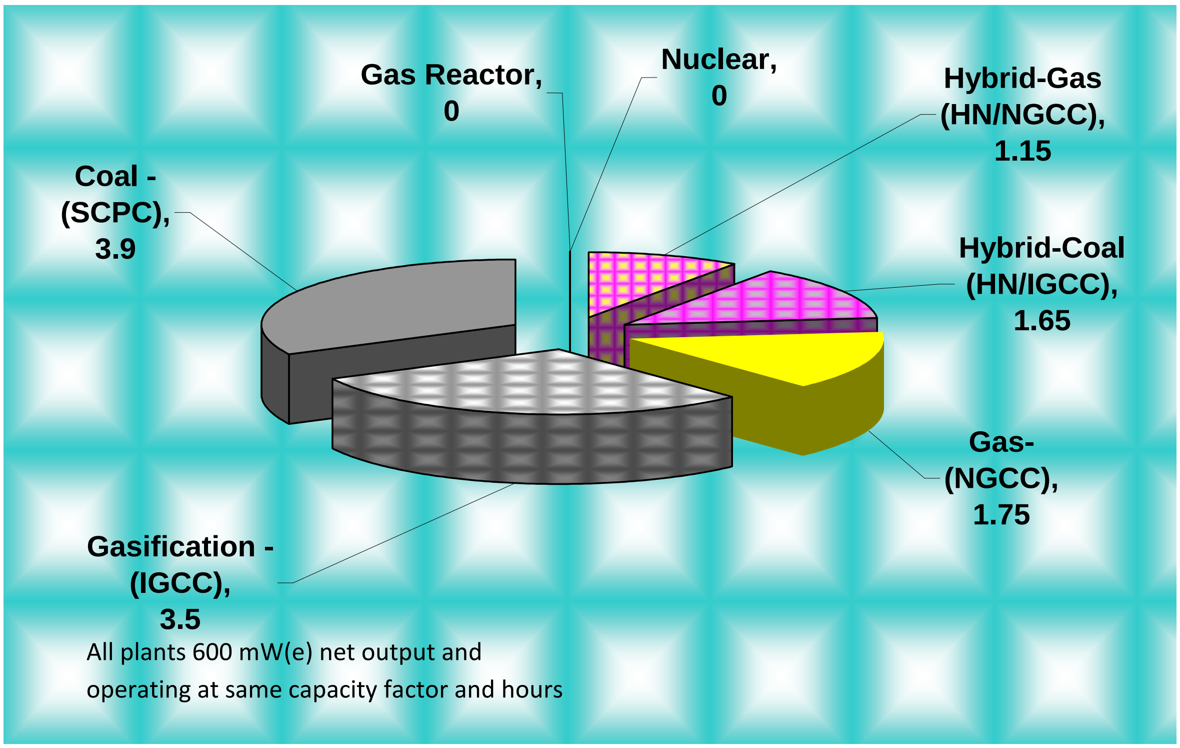
Replacement of the Consortium states' coal plants with hybrid-nuclear/gasification units would reduce net CO_2 emissions by about 54 million tons per year or about a 23% reduction.

Hybrid-nuclear Environmental Impacts. The inherent characteristics of the hybrid-nuclear technology create remarkably small environmental impacts, with no real constraints envisioned. Air pollutant emissions, solid waste discharges, and water usage are all significantly less than those associated with more conventional technologies. Further, greenhouse gas emissions are dramatically reduced.

- Air Discharges. The hybrid-nuclear emissions philosophy is straightforward: minimize the production of air-borne pollutants by partial use of nuclear energy, thereby reducing discharges by a factor of nearly two. Air pollutants of all types (including NOx, SO_2, CO, Hg and particulates) are all dramatically reduced relative to comparable conventional power plants – a roughly 50% reduction is achieved.

As illustrated by Figure 8.1.12, greenhouse gas emissions from a hybrid-nuclear coal gasification plant are about the same as a natural gas combined-cycle plant, without resorting to sequestration. Given the relative absence of proven underground formations to permanently store massive quantities of CO_2, the hybrid approach is a more practical solution to dramatically lowering greenhouse gas emissions.

Figure 8.1.12: Greenhouse Gas Emissions, millions of tons per year



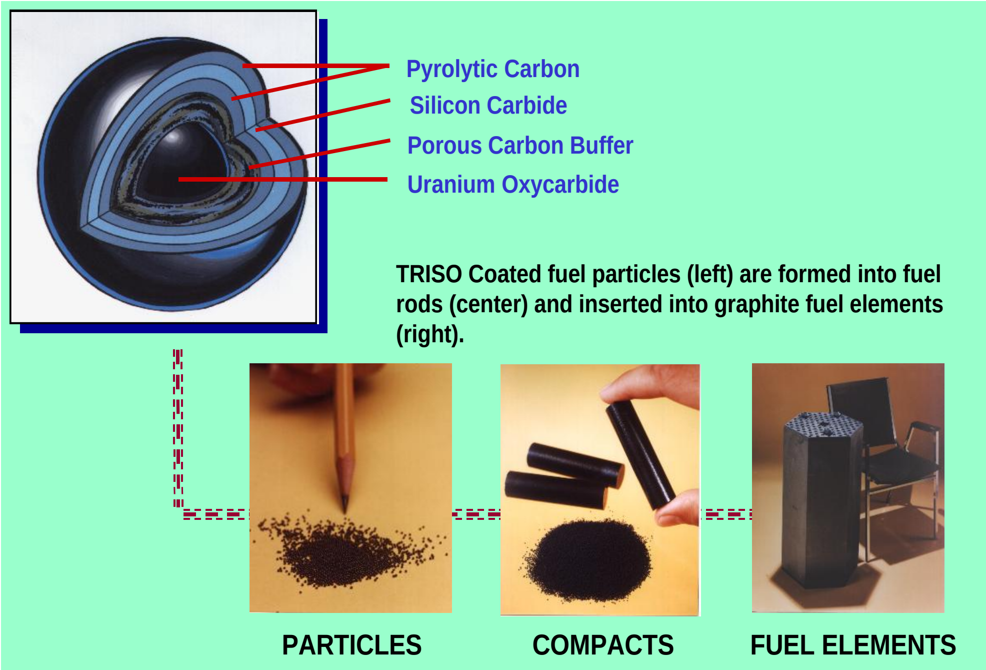
- Nuclear Wastes. The hybrid-nuclear reactor is small by conventional standards and efficient, with the plant also partly fueled by fossil energy. Thus, only a few tons of radioactive spent fuel are produced each year by a typical plant. A roughly 80% reduction is achieved relative to a comparable conventional reactor.

The hybrid uses a silicon carbide nuclear fuel (see Figure 8.1.13) that is exceptionally stable, with the spent fuel containing much lower levels of highly radioactive materials than uranium oxide fueled conventional nuclear plants.

The dispersed nature of the hybrid's fuel, coupled with the fuel's high resistance to chemical attack, create significant difficulties when attempting to extract fissile material. The fuel is essentially worthless for nuclear bomb making purposes.

- Coal Wastes. Coal plant ash is becoming an increasingly difficult environmental problem due to the presence of toxic contaminants, such as heavy metals, and emerging regulations governing disposal of the waste. However, ash discharged from a hybrid-nuclear/coal gasification plant is an environmentally benign, non-leaching glass-like slag that has many commercial uses (such as aggregate in cement). Also, the gasification process coupled with the reactor greatly reduces the volume of coal wastes and eliminates sludge as well as ash ponds.

Figure 8.1.13: Helium Gas Reactor fuel, -- *courtesy General Atomics*.



- Water Resources. Cooling needs by a hybrid-nuclear plant are a fraction (~1/3rd) of those of similarly sized coal or conventional nuclear power plants. Dry cooling tower technology would reduce water consumption to nearly zero.

- Greenhouse Gas Reduction Goals. CO_2 emissions from a hybrid-nuclear/coal gasification plant approach those of natural gas fired combined-cycle plants. This characteristic means that dramatic greenhouse gas reductions could occur by phasing out our over 500 aging coal plants and replacing them with hybrid-nuclear/coal gasification facilities. As coal power plants currently produce about 33% of total US greenhouse gas emissions, net US CO_2 emissions could be reduced by about 17% without resorting to problematic and expensive underground sequestration.

Permitting. As with any large power plant, a broad array of permits will be required at the local, state and federal level. In particular, as a nuclear power plant, the Nuclear Regulatory Commission (NRC) must license the hybrid. This process is extensive. However, as indicated earlier, the DOE and NRC are already heavily invested in licensing work for the NGNP reactor. As the hybrid is a related but much simpler configuration, the required effort will be less.

The hybrid must also obtain an air permit from state authorities, acting under the regulations of the EPA. However, because the hybrid produces significantly fewer emissions of all types than comparable fossil fuel plants, the air permitting effort is expected to be straightforward in nature.

Transportation Constraints

No particular transportation constraints are expected; the existing rail and power transmission systems are quite adequate. In particular, additional rail transport capacity is actually expected to be freed up because replacement hybrid-nuclear/coal gasification plants use about half the coal of the original conventional coal plant. Stated somewhat differently, the hybrid-nuclear replacement plants could double the number of coal power plants (in hybrid configurations) without adversely impacting the existing transportation systems.

Political Constraints

Hybrid-nuclear energy is a clean technology that dramatically reduces greenhouse gas emissions, solves a number of vexing problems associated with coal and nuclear energy, can create tens of thousands of US jobs while leading the way to energy independence using our abundant coal resources. Further, the facilities are significantly safer than conventional nuclear plants because the fuel cannot melt. No major political constraints are expected, although because coal and nuclear power are employed, some level of opposition will always exist irrespective of the formidable merits of the hybrid technology.

8.1.7 FUNDING SOURCES

Thus far, development of the hybrid-nuclear technology has been privately funded with no help from the federal government, although a team of firms (including Hybrid Power Technologies LLC, General Atomics, and Black & Veatch) jointly submitted several proposals to the DOE (including the Advanced Research Projects Agency or ARPA) and Department of Defense (DOD Defense Advanced Research Projects Agency or DARPA). The hybrid-nuclear process is a pending patent owned by the author of the SME report.

With more widespread recognition of the far-reaching and strategic capabilities of the hybrid nuclear technology, greater access to the existing array of private and public funding should become more pronounced, including federal sources (DOE and DOD), investment firms, manufacturers, nuclear and coal industry organizations and foreign sources.

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Chapter 9. Technologies Of Interest But Not Included In SME Reports

9.1 Hydroelectricity

Hydroelectric generation remains one of the cornerstones of power generation in the West, despite the challenges of water availability in arid climates and ongoing objections to effects on fisheries, recreation and other environmental impacts.

Among the Consortium states, hydroelectricity varies in significance in terms of percentage of each state's total net electricity generation. Table 9.1.1 displays the percentage of each Consortium state's total net electricity generation filled by hydroelectricity.

Table 9.1 Consortium state hydroelectricity generation (EIA)[129].

State	Percent Generation by Hydroelectricity
Iowa	10%
Montana	34%
Nebraska	10%
South Dakota	67%
Utah	16%
Wyoming	15%

Hydropower is one of the most economic energy resources available and has an average lifespan of 100 years per facility. By upgrading and increasing the efficiencies and capacities of existing facilities, hydropower can continue to support our nation's growing energy needs[130]. Hydropower also has more non-power benefits than other generation sources, including water supply, flood control, navigation, irrigation, and recreation.

9.1.1 Upgrades and New Facilities

Large dams across the nation are upgrading century-old powerhouses and replacing decades-old turbines in order to increase efficiency and generate additional megawatts. In Montana, 70 MW Kerr Dam on the Flathead River near Polson was upgraded in 2005 with a new runner to better control the water that drives the turbine. This upgrade added 10 MW of generating capacity to the unit[131]. Rainbow Dam, a 36 MW facility on the Missouri River near Great Falls is currently being upgraded with a new powerhouse. This project is expected to increase the generating capacity by 25 MW and employ a crew of 200 construction workers[132].

A number of smaller storage dams around the West are exploring the feasibility of producing electricity. For example, developers of the Gibson Dam Hydroelectric Project near Augusta, Montana expect to receive a license from the Federal Energy Regulatory Commission (FERC) in 2011 to proceed with plans to install hydroelectric equipment at that facility[133]. Similar applications have been submitted to FERC for other impoundments, including Clark Canyon Dam near Dillon, Montana and Quake Lake near West Yellowstone, Montana.

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[129] Energy Power Annual, U.S. Energy Information Administration, www.eia.doe.gov
[130] Idaho National Energy Laboratory, http://hydropower.inel.gov
[131] PPL Montana, www.pplmontana.com
[132] Puckett, Karl. Energy powers hundreds of construction jobs, Great Falls Tribune, February 27, 2011
[133] www.tollhouseenergy.com

9.1.2 Instream Hydrokinetic Energy

Upgrades to existing hydroelectric facilities and electricity generation at storage dams will certainly help Western states meet demand for electricity. However, the emerging technology of instream hydrokinetic electricity generation will make the west's water resources even more productive. Instead of damming a river to capture its potential energy, instream hydrokinetic power relies on free-flowing currents that spin underwater turbines.

Inland cities and towns along the nation's rivers can benefit from electricity generated from free-flowing waters. With the Southeast United States' limited onshore wind energy prospects, in-stream power installations could help to fill the renewable energy gap in some parts of the region[134].

The Federal Energy Regulatory Commission (FERC) issued its first full license for an in-stream hydrokinetic power plant on December 13, 2008. The project, known as Hydro+ is situated on the Mississippi River near Hastings, Minnesota and operates in the tailrace of a small hydroelectric dam operated by the City of Hastings. The project became operational in early 2009 and generates as much as 250 kW of electricity—a 5.7% increase in renewable energy at the existing site[135].

For the Hydro+ project, turbines are suspended from a barge, and each turbine drives a generator that is mounted atop the barge. The barge-mounted power plant is meant to be permanent, but it could easily be removed if any problems are found with the system. The barge is anchored to the riverbed and tethered about 50 feet downstream from the hydropower dam.

Hydro Green Energy instream hydrokinetic energy project, Hastings, MN
Source: Hydro Green Energy

FERC granted preliminary permits to a Louisiana company in 2008 to test sections of the Mississippi River for the purpose of submerging a network of slow-spinning turbines. These10-foot turbines are designed to sit passively in the river, generating about 10 kilowatts in 7.4-feet-per-second flows and 40 kilowatts in 10-feet-per-second currents[136].

[134] Hanlon, Peter. Hydrokinetic Energy: Here, There But Not Everywhere. EcoCentric, January 25, 2011
[135] Hydro Green Energy, www.hgenergy.com/hastings.html
[136] www.smartplanet.com/business/blog/intelligent-energy/hydrokinetic-energy-on-the-mississippi

Instream hydrokinetic generation turbine
Source: SmartPlanet

Instream hydrokinetic generation systems rely mainly on the existing kinetic energy in the water stream. They do not rely upon any artificial water-head, such as impoundments, to be created as the energy source for operation. These systems do not require large civil works, but they can be placed in existing tailraces and channels, utilizing the kinetic energy available. They do not require the diversion of water through manmade channels, riverbeds, or pipes, although they may have applications in such conduits.

Extensive environmental monitoring tests are required for instream hydrokinetic generation projects to determine impacts on fish and other aquatic species, as well as birds, recreation and public safety[137].

FERC currently has a total of 11 pending permits for instream hydroelectric generation for a total generating capacity of 31 MW[138]. These projects will be built on the Niagara, Ohio, St. Clair and Tennessee Rivers.

The consortium states are blessed with significant river systems such as Iowa (Mississippi, Missouri and Des Moines Rivers), Montana (Missouri, Flathead and Clark Fork Rivers), Nebraska (Missouri and North Platte Rivers), South Dakota (Missouri River), Utah (Green and Colorado Rivers) and Wyoming (Big Horn, Green and North Platte Rivers). Each of these river systems may be of suitable velocity and depth to support instream hydrokinetic electricity generation.

[137] Verdant Power Canada ULC, Technology Evaluation of Existing and Emerging Technologies, Water Current Turbines for River Applications, June 15, 2006

[138] Federal Energy Regulatory Commission, www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp