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Analysis of Fuel Flexibility Opportunities and Constraints in the U.S. Industrial Sector

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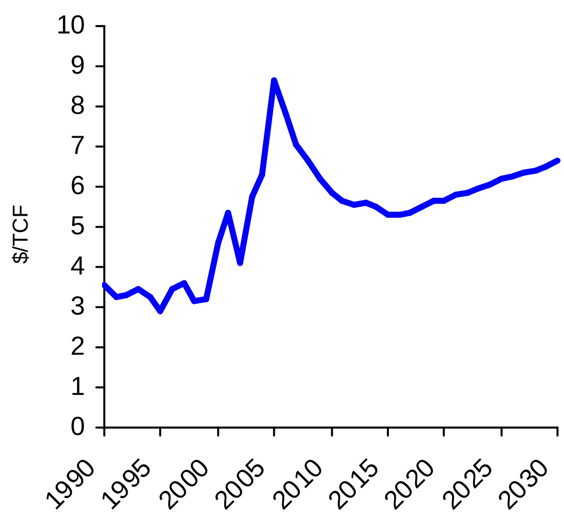
ES. EXECUTIVE SUMMARY

After decades during which natural gas for industrial use traded at or below \$3.50/thousand cubic feet (TCF), the turn of the millennium marked the beginning of unprecedented increases and volatility in natural gas prices. Increased use of the fuel across the economy coupled with diminishing domestic natural gas supply and production appear to have driven a fundamental shift in natural gas price behavior. In fact, Department of Energy (DOE) Energy Information Agency (EIA) projections indicate that the price of natural gas over the next 20 years will likely be more than double that of the past. In this environment, many industrial users whose energy investments are predicated on inexpensive natural gas must seek alternatives to fuel production.

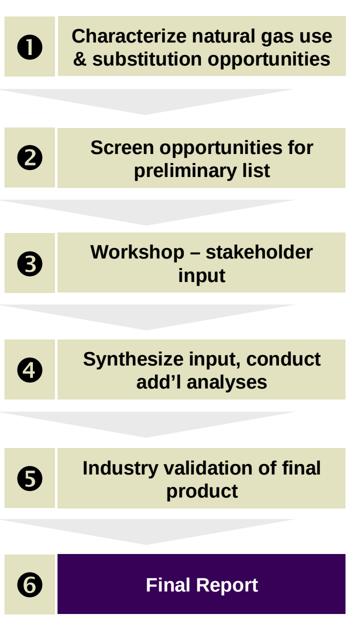
Figure ES-1: Past and projected natural gas prices



Source: EIA AEO 2007

The purpose of this assessment was to determine if flexible, alternative fuel use in industry, beyond switching from natural gas to petroleum derivatives, presents a sizeable opportunity for the reduction in use of natural gas. Furthermore, the assessment was to determine what programmatic activities DOE could undertake to accelerate a fuel flexibility program for industry. To this end, a six-part framework (see Figure ES-1) was used to identify the most promising fuel flexibility options, and what level of accomplishment could be achieved, based on DOE leadership.

Figure ES-2



It is important to note that this work was undertaken with significant input from industry. During the third step, which explored initial constraints and opportunities, DOE and Booz Allen conducted a workshop with attendees from many industrial sectors. In attendance were representatives from the petrochemical, refining, food and beverage, steel and metals, pulp and paper, cement and glass manufacturing industries; as well as representatives from industrial boiler manufacturers, technology providers, energy and waste service providers, the federal government and national laboratories, and developers and financiers. During the analysis phase, Booz Allen reached out to many of these same people and others to validate the list of potential actions as well as assumptions in the study. In the future, if a program is developed, it will be because industry and DOE are working in partnership to lead the initiative. The assessment has shown that two types of industry participants – end-users and technology vendors – are interested in putting their support behind this program. Industry will continue to be invaluable in program development, like road-mapping exercises.

Focusing on this report, the identification of opportunities and constraints was driven by four main questions, or hypotheses (see Table ES-1). Each of these main questions, with additional supporting questions, helped frame the analysis and provide context for understanding the results.

Table ES-1: The Driving Questions Behind This Analysis

1. Is fuel flexibility a reasonable alternative?
➢ Are the technical solutions available at a cost, environmental and performance level that industry will consider using?
➢ Are the alternative fuels/resources readily available today?
➢ Are the costs required to adopt fuel flexibility options manageable, or are they at the "bet the firm" level?
2. Is industry interested in this initiative?
➢ What has industry already done to adopt fuel flexible solutions?
➢ What does industry see as constraints (e.g., regulatory, technical)? Are these constraints reasonably surmountable?
➢ What opportunities are available to overcome these constraints?
3. What role can the government play (specifically DOE)?
➢ Is there a gap between actions industry has already taken and the identified constraints? Which constraints are best addressed by the federal government?
➢ What targeted actions can DOE take to optimize the impact of industrial fuel flexibility and achieve displacement goals?
4. How much natural gas can be displaced by adopting fuel flexibility?
➢ What quantities can be displaced within which industrial sectors?
➢ What are realistic short-term and long-term goals?

Question 1: Is fuel flexibility a reasonable alternative? The analysis shows that all of the primary conversion technologies needed are commercially available or very close to being so. In mapping the different fuel sources (e.g., coal, biomass, petcoke) with various conversion technologies (e.g., gasification, liquefaction, direct combustion)—and including some technologies outside the traditional process, such as electro-technology—we find that extensive research and development is not required to bring these technologies to market. There is work to be done regarding scaling, optimization, and regulatory application, but the fundamental technologies are well developed. The analysis also shows that sources of alternative fuel, such as biomass, petcoke, and coal, are readily available in many regions, although the distribution is not uniform. Regarding costs, many of these technologies require significant capital expenditures, yet

none are so high as to be at the "bet the firm" level. Overall cost—including the levelized cost of fuel—is an important factor that is currently deterring industry, although there are several applications underway, leading to the conclusion that initial applications will depend on site-specific economic factors.

Combined Heat and Power (CHP) would appear to be a good match for fuel flexibility programs. One difficulty in terms of fuel flexibility is that CHP technology is in many ways quite mature and it is already the subject of substantial private investment. Nonetheless, many of the highest-value CHP projects are natural-gas driven turbines and reciprocating engines, and fuel flexibility resources may be usefully leveraged by linking CHP to gasification systems.

It should be noted that if regulation or taxing of carbon becomes a reality, it is unclear how it will impact fuel flexibility initiatives. The broader nature of the impact will depend on how regulations or carbon costs are effected; however, under any scenario it will be important to consider the carbon balance of the entire fuel flexibility portfolio and not just a single project. It is predicted that some projects will be less carbon intensive than the present situation with natural gas and that some will be more carbon intensive.

Question 2: Is industry interested in this initiative? Our discussions with industry, as well as additional research, show that there is indeed general interest. Below is a sampling of the several fuel flexibility projects that have been announced or started.

- Hunton Energy in Texas has contracted with Valero Energy to provide gasified petcoke from "over the fence" to provide energy to a utility.
- U.S. Pipe has contracted with Intrinergy to provide gasified biomass, again as an "over the fence" leasing operation, to provide syngas to their process equipment.
- Worldwide, electro-technology is fairly widespread in the primary metals, food, petroleum, and paper industrial sectors.
- Faustina Hydrogen Products and Mosaic, Inc. have recently announced plans to be partners in a gasification project in Southern Louisiana that would produce ammonia and othe chemicals through gasification of coal and petcoke.
- In July 2007, Eastman Chemicals and several partners announced plans to locate a gasification plant that will use petcoke to make hydrogen, methanol and ammonia.

It is quite clear, however, that industry sees many constraints that either slow down or preclude the adoption of fuel flexible technologies. Table ES-2 presents a summary of the major constraints (some 23 constraints) as seen by industry—grouped into four categories: 1) business process, integration and finance issues; 2) emissions and regulatory issues; 3) locational constraints; and 4) technology development and engineering economics.

Question 3: What role can the government play, specifically DOE? This question is related to the constraints discussed above. Fuel flexibility technologies can expose users to high levels of risk because they are unsupported by the same level of operating experience, legal support, and infrastructure as natural gas. Government entities such as DOE can make important contributions in this area by supporting early demonstrations that provide data to inform decision-making. An effective DOE program initiative would have several types of activities to re-define the context in which business decisions are made: 1) filling information gaps, 2) using its convening power, 3) supporting early stage R&D.

Through these initiatives, success will depend on the government differentiating among the stakeholders necessary to mobilizing a fuel flexibility effort. Broadly, government is uniquely qualified to partner with three sets of stakeholders for different purposes. It can help *technology developers* by providing early state R&D grants and demonstration support, with emphasis on technologies for which markets exist. It can bring *specialized energy companies* together with customers and government agencies to familiarize the parties with the new technologies and facilitate adoption. Finally, government can help better inform the ultimate *end-users* of the benefits of these technologies through demonstrations and education.

In Table ES-2 there is also an indication of actions or opportunities that can be undertaken, mainly by DOE, as a way of addressing these specific, industry-identified constraints. Prioritization of specific activities associated with the list below will be necessary to identify short- and long-term actions and balance competing priorities. Prioritization activities were not part of the scope of this study.

Table ES-2: Summary of Constraints Identified by Industry and an Indication of Potential DOE Opportunities

Constraints to Fuel Flexibility
Challenges to integration with business process, manufacturing process, and financing ➢ Alternative fuel devices often do not integrate easily into existing industrial processes and financial decision frameworks, or their impact is unknown.
Emissions and regulatory frameworks ➢ Regulatory regimes sometimes penalize alternative technologies due to a lack of actual experience or long-term data.
Locational problem ➢ Alternative fuels are often not located in the places they are needed, and a lack of infrastructure can challenge their economical transportation.
Technology development and engineering economics ➢ Advances in the scaling of fuel flexible machinery itself (e.g., gasifiers) are needed in order for them to be considered for integration with processes.
Broad Areas for DOE Action
Fill information gaps: ➢ Advanced technologies have limited performance records, resulting in limited sets of information upon which users, financiers, and regulators can make informed judgments. DOE as a neutral party can provide credible information that will prevent decision-makers from defaulting to traditional energy sources
Leverage power to convene parties: ➢ DOE has the capacity to assemble both market actors and market shapers who would not otherwise be drawn into cooperation. This includes linking energy technology vendors with potential users as well as serving as an interlocutor with regulatory agencies such as the EPA.
Support early stage technology RD&D: ➢ Private entities will avoid supporting research and development for technologies with commercial application far off into the future or that create value in areas difficult to monetize such as environmental benefits and national security.

Question 4: How much natural gas can be displaced by adopting fuel flexibility options? Success of a fuel flexibility initiative would be measured ultimately in the amount of natural gas not used by industry. While it is always hard to project future actions, it is possible to analyze the current industrial situation, make reasonable and transparent assumptions about future incentives and actions, and calculate an estimate of natural gas displacement. The bulk of this report focuses on understanding the current industrial situation—e.g., distribution among industries of natural gas use in process equipment, such as boilers, kilns, driers, etc. Based on this detailed information, our discussions with industry, and assumptions regarding lower-cost fuel

switching options, we have developed a sector-by-sector estimate of potential natural gas displacement by 2012 (See Figure ES-2). The result of this analysis is that with implementation of a program by DOE, a short-term displacement is achievable by 2012 without extraordinary measures on the part of industry. Estimated potential displacement is 263 TBtu/yr or 5 percent of the expected amount of natural gas consumption – absent a fuel flexibility program – of 5,200 TBtu/yr. For contrast, this is approximately the amount of gas imported through a single LNG terminal.

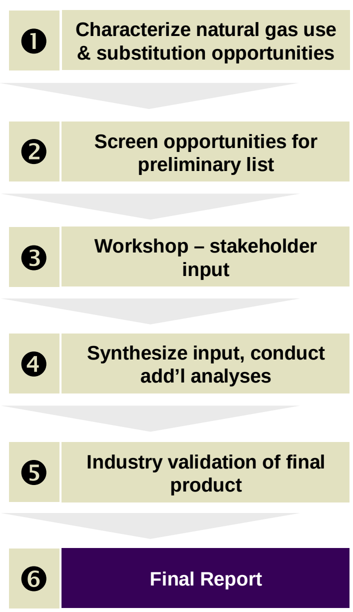
The largest impact is a result of biomass gasification and consumption, followed by the industry specific application of petcoke fuel/syngas. While widespread globally, the application of electro-technology will be evolving among various industries domestically, therefore, it is of lower impact in the short term.

Longer-term displacements are more difficult to project, and it is less reliable to use the current industrial situation as a basis for extrapolation. However, looking at substantial switching in important industrial sectors (e.g., a broad switching in the pulp and paper sector, significant switching for boilers in the chemicals and refining industry, and moderate switching in most of the other industrial areas) we believe that a long-term, total displacement of 15% to 20% is achievable.

1.0 FUEL FLEXIBILITY STUDY PROCESS

The purpose of this assessment was to determine if flexible fuel use in industry, beyond switching from natural gas to petroleum derivatives, presents a sizeable opportunity for the reduction in use of natural gas. Furthermore, the assessment was to determine what programmatic activities DOE could undertake to accelerate a fuel flexibility program for industry. To this end, a six-part framework (*see Figure 1-1*) was used to identify the most promising fuel flexibility options, and what level of accomplishment could be achieved, based on DOE leadership.

Figure 1-1: Study Process

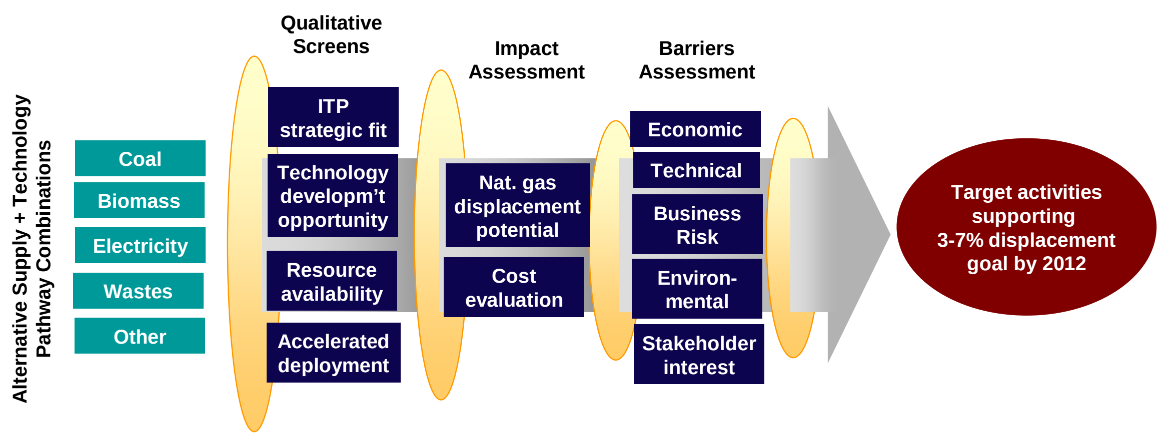


The first step required identifying the range of alternative energy sources and associated fuel processing pathways, and how they align with current uses for natural gas in industry. Because energy use in the industrial sector is highly specific, and alternative energy sources cannot necessarily substitute for natural gas in all processes and industries, this step provided the basis for linking industrial processes to specific alternative fuels.

The second step consisted of a rigorous screening process to identify which of these fuel pathways and associated technologies would have applicability in industry *(see Figure 1-2)*. This step consisted of an initial screening process to eliminate clearly flawed options followed by a more detailed investigation of pathways showing more promise.

The initial qualitative screening criteria included whether the specific opportunity offered a strategic fit with DOE mission and goals and whether the needed research activities were already underway in other areas of DOE. It also included a brief

Figure 1-2: Analytical screening framework



assessment as to whether the needed technology development efforts could be reasonably achievable in the near- to mid-term.

In more detailed analysis, alternatives meeting the initial screens were analyzed according to specific performance criteria to approximate the level of natural gas displacement potentially achievable through each option an indication of its impact. In addition, technical, business, and regulatory barriers obstructing market deployment were identified and characterized. Fuel options with low impact potential and substantial market deployment barriers were eliminated from further consideration. For the remaining, high-value options, potential DOE interventions were brainstormed, based on the market deployment barriers. This analysis produced a concentrated set of development activities that, if carried to completion, would result in potential natural gas displacement of 3%-7% by 2012 and higher by 2020 *(See Table 1-1 below).*

Table 1-1: Estimate of near-term gas displacement potential from DOE activities

Example Alternative Fuel Sources	Substitution Potential (TBTU/yr)	Alternative Fuel (ITP Impact Potential)	Primary Alternative Fuel Industrial Utilization Pathways				
			Gasification	Fermentation	Pyrolysis	Liquefaction	Direct Fire
Biomass	4,000	6-12	3	1	1	1	1
Coal	5,000-16,000	143-358	3	n/a	0	1	1
MSW	1,350	10-20	2	1	1	1	2
Petroleum Coke	525	90-184	3	n/a	0	1	2
Black Liquor	46	16-32	4	n/a	0	1	0
Gaseous Industrial By-products	132	20-40	n/a	n/a	n/a	n/a	4

Legend – natural gas displacement potential resulting from successful FF programming

0 *None*	1 *Limited*	2 *Moderate*	3 *Considerable*	4 *Major*

Notes: Coal potential- lower bound is EIA projection for supply increase by 2025; upper bound is National Coal Council's potential for increased supply by 2025
Black liquor- Based on potential increased efficiency of black liquor gasification over existing black liquor boilers
Source: ORNL, EIA, National Coal Council, EPA, Energetics, Booz Allen analysis

The assumptions, analysis, conclusions, and associated target activities were presented at a Fuels Flexibility workshop that gathered a select group of leading technology developers, vendors, end-users, financiers, consultants, and national laboratory researchers. The objective of the workshop was to ensure that the results of the independent analysis align with the financial, operational, and managerial realities of commercial sector decision-makers. In addition, it served to ensure that the analysis incorporated the most-up-to-date and credible information. The research team synthesized a range of constructive criticism, refinements, and areas for further inquiry from the workshop into a draft report. To ensure the accuracy of the synthesis and to further explore promising lines of inquiry, the updated report was again provided to a select group of stakeholders for additional evaluation. The results of this analysis comprise the remainder of this final report.

In conducting the analysis for this report, the identification of opportunities and constraints was driven by four main questions, or hypotheses (see Table 1-2). Each of these main questions, with additional supporting questions, helped frame the analysis and provide context for understanding the results. The remainder of this report presents, in detail, the answers to these main questions.

Table 1-2: The Driving Questions Behind This Analysis

1. Is fuel flexibility a reasonable alternative?
➢ Are the technical solutions available at a cost, environmental and performance level that industry will consider using?
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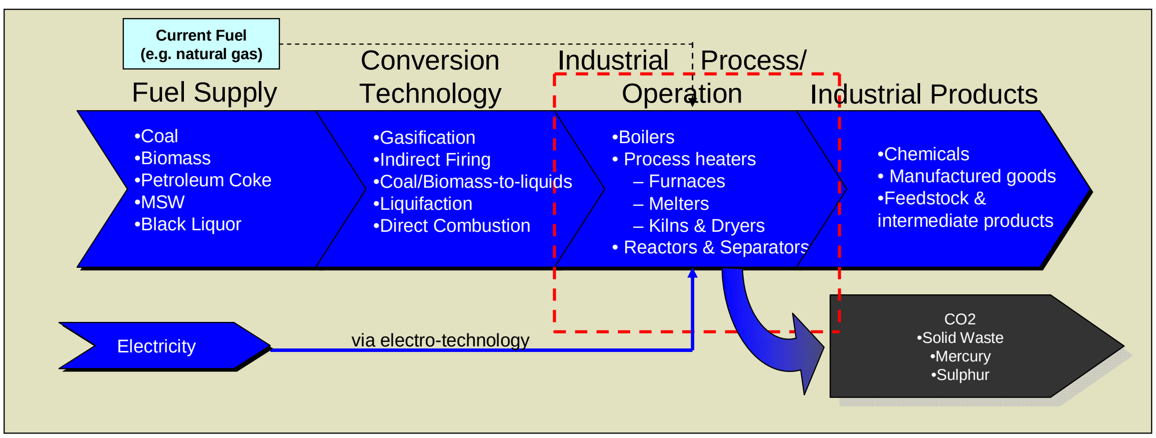
2.0 IS FUEL FLEXIBILITY A REASONABLE ALTERNATIVE TO NATURAL GAS?

2.1 Natural gas can be displaced by reconfiguring the industrial energy value chain

Natural gas fulfills two essential needs in industry: first, it is an energy-dense and readily transportable energy source necessary to fuel manufacturing processes. Secondly, its chemical foundation (CH_4, or methane) is the raw material for essential industrial chemicals such as hydrogen, methanol, and ammonia.

Figure 2-1: The industrial fuel flexibility supply chain provides significant options

The Industrial Fuel Flexibility Value Chain



Both these needs are served by a simple and well-defined natural gas supply chain (*see Figure 2-1 above*) which has contributed importantly to the desirability of the fuel; however, many other pathways for meeting industrial energy needs exist. Deploying them requires two important modifications to the industrial energy value chain. First, alternative fuel supplies are sourced in much different ways than natural gas. Second, alternative fuels generally require some form of conversion technologies in order to transform the alternative energy source into a form better suited to industrial energy needs. The next two sections illuminate further how these unique features differ from the fuel flexible supply chain.

2.1.1 Fuel supply

Fuels that can potentially displace natural gas in industrial processes generally fall into three categories:

- **Renewables,** notably biomass, wind, and solar.
- **Fossil fuels,** which include coal and petroleum derivatives such as diesel and distillate fuels;
- **Opportunity fuels**, which encompass the wastes and waste by-products generated by industry and society. The opportunity fuels analyzed here are petroleum coke (petcoke), black liquor, and municipal solid waste (MSW).

Electro-technologies are not a fuel supply in the conventional sense but draw from purchased electricity and can provide an alternative to natural gas.

Encompassing such an array of resources, the supply of alternative energy resources is vast, diverse, and domestically abundant. In some cases they can be procured at costs similar to those for natural gas; and use of wastes in fact can potentially result in cash-flow positive energy. Their integration into the flexible fuel supply chain is influenced by a number of physical characteristics (e.g. energy density, presence of pollutants, and physical state). An overview of these follows.

- **Renewables**

Renewable fuels are those that can be replenished on a sustainable basis by the earth's natural processes or human activity. Those with greatest applicability in industry are biomass, wind, solar.

Biomass

Defined as organic matter producible on a renewable basis, the key distinguishing physical characteristics of biomass relative to natural gas are that it is not as energy dense, and is a solid fuel. Biomass resources have the added benefits that they can potentially close the carbon cycle, enabling energy use with zero or minimal contribution to greenhouse gas emissions, and they can be sustainably produced in large quantities domestically.

The biomass resource base considered as feedstock for natural gas replacement consists of both forest resources (e.g., forest products industry processing residues, timberland, and forest land thinnings) and agricultural resources (e.g., corn stover and grain straw, corn and soy grain by-products, perennial grasses and woody crops). It is highly heterogeneous, with varying moisture content, energy density, and other characteristics that influence its properties as an energy source.

Although biomass energy production has boomed in response to high oil prices prevailing since 2004, use of biomass outside the forest products industries is rare. These industries are in fact major users of biomass energy, however, almost all this energy results from re-use of production processes by-products. This leaves the specific contract mechanisms, and related price, risk, and performance issues to be negotiated between the industrial user and the biomass supplier.

Solar and wind

These are non-polluting, renewable, domestic resources fully immune to fossil fuel spot price fluctuations. The most probable industrial application of solar and wind resources is to generate electricity that can replace combustion of fuels through the use of electro-technologies.

With respect to natural gas, the physical characteristics of wind and solar energy affect how and in which industries these resources can be viable. First, the intermittent nature of their production will most likely require some form of dispatchable back-up power in order to sustain production. Additionally, while wind turbine and solar photovoltaic technology have advanced considerably, the energy intensity of many industrial processes would require substantial amounts of land for turbines or solar cells. For example, powering production of a single medium-sized steel electric arc furnace would require solar panels covering an area of 200 square miles, roughly the size of Brooklyn, Manhattan, and Queens combined. Doing so with wind would require constructing a wind park roughly 160 times the area required for an average-sized gas-fired electric generation plant.

LAFARGE

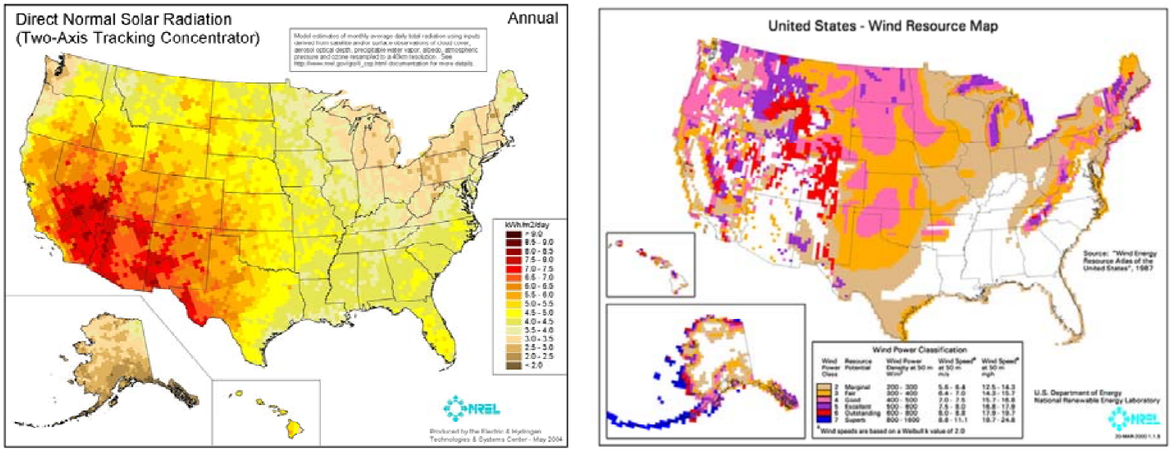
Box 1: Lafarge installs a 10 MW wind farm to power a cement plant

In May 2005 Lafarge placed into operation twelve 850 kW wind turbines that will provide 50% of the power needed to run the company's cement factory in Tetouan, Morocco. The $13 million project harnesses the site outstanding class 6 wind resource and is estimated to reduce greenhouse gas emissions from the operation by 30,000 tonnes per year. The project is registered with the Clean Development Mechanism established to support the 1997 Kyoto protocol and Lafarge has voluntarily committed to reduce gross greenhouse gas emissions from its worldwide operations 15% below 1990 levels.

Source: LaFarge 2005 Sustainability Report

The final important physical distinction between these energy sources and natural gas in terms of industrial users' perspective is that they are highly location-dependent. Whereas natural gas can be readily transported by pipeline and stored in tanks, long-distance transportation of electricity is not efficient, and electricity cannot be cost-effectively stored. As a result, the principal areas of opportunity for these resources to serve industrial needs are generally in the southeast for solar and upper plains and inter mountain states for wind (*See Figure 2-2 below*). These areas have much more limited industrial activity than the traditional manufacturing centers of the Midwest, Gulf Coast, and Northeast.

Figure 2-2: location of U.S. solar (left) and wind (right) resources



Source: National Renewable Energy Laboratory

- **Fossil Fuels (Coal)**

Domestically abundant, energy dense, and inexpensive, industry has nonetheless more than halved its coal consumption since 1949.[1] Although increases in natural gas prices have revived the relative value of coal on a cost basis, a number of operational and transactional factors constrain the supply that can be reasonably made available to users. First and foremost the Clean Air Act limits the level of pollutants that industrial sources may emit. Since coal is a dirtier fuel than natural gas, this limits the extent to which systems based on traditional coal energy can displace natural gas use. Operationally, replacing natural gas with coal, which is a solid, requires changes to fuel handling and solid waste infrastructure. Whereas natural gas is generally delivered via pipeline, coal is most often shipped via railroads or barge.[2] Although industrial users lacking access to rivers or railroads can take delivery by truck, this mode is 10 times more expensive per ton-mile than rail and 14 times more expensive than by barge.[3] As a result, truck transport significantly erodes coal's cost advantage. Additionally, investment in fuel handling facilities such as conveyor belts, pulverizers, and conversion technologies may need to be made in order to move the fuel from the point of delivery to the conversion technology and prepare it for use in later stages of the value chain. Finally, plants will need ample space to store coal as both a reserve and in between shipments.

[1] Energy Information Administration, Annual Energy Review 2005, Table 2.1d.
[2] Energy Information Administration, Coal Transportation Rate Database, Modal Shares of Utility Contract Coal Tonnage, 1979, 1987, 1995, and 1997
[3] Energy Information Administration, Coal Transportation Rate Database, Average Utility Contract Coal Transportation Rate per Ton-Mile by Transportation Mode, 1979-1997

- **Opportunity fuels**

Opportunity fuels are energy-rich wastes and waste by-products. Many opportunity fuels, such as municipal solid waste (MSW), anaerobic digester gas, landfill gas, tires, food processing wastes, and textile wastes are not conventionally used in power generation. Opportunity fuels are less abundant than traditional fuels, however, they offer several distinct advantages. They can be highly desirable from a cost perspective, as they often present a disposal burden to the waste producer. Thus, use of waste as an energy source can deeply mitigate costs to dispose of certain industrial wastes and, when sourced from third parties willing to pay disposal fees, actually result in an additional revenue stream for the user. If consumed properly, use of opportunity fuels can also protect against important environmental problems such as groundwater leaching and greenhouse gas emissions associated with more conventional disposal routes such as land filling.

As with other alternative fuels, the physical properties of many opportunity fuels differ from those of natural gas in important ways. Opportunity fuels have a range of energy densities, ranging from over 14,000 Btu/lb with petcoke, to much the lower levels of 5,000 Btu/lb associated with MSW. In addition, opportunity fuels present issues of heterogeneous composition, particularly in the case of municipal solid waste, and often bear contaminants such as sulfuric compounds in black liquor and petcoke.

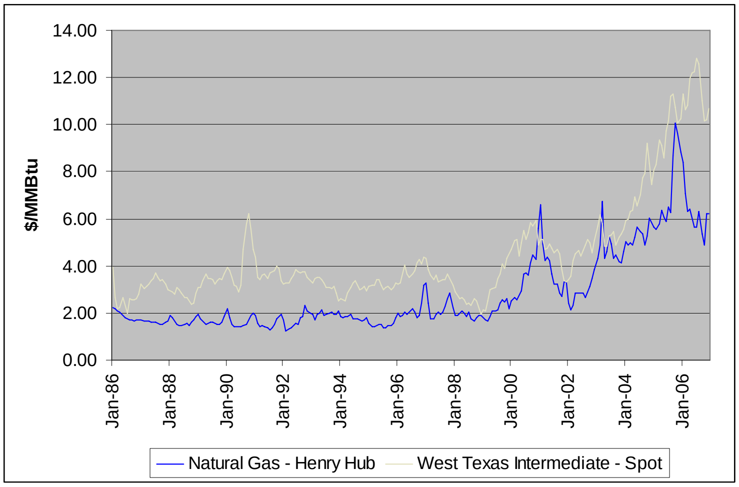
The range of opportunity fuels is quite extensive, but for purposes of industrial energy consumption only three main ones are considered here: petroleum coke, black liquor, and municipal solid waste. These represent substantial energy sources that used either at the industrial site or in electricity production. As a result the related technology has potential cross-application in industry.

- Petroleum coke: A by-product of the petroleum refining process, petcoke is inexpensive and will be increasingly abundant as petroleum refiners process lower grade crude oils.
- Black Liquor: Formed during the paper making process when wood pulp is separated into cellulose – the main constituent of paper – and lignin, its energy content is roughly half that of the original wood pulp.[4]
- Municipal Solid Waste: The MSW resource base considered as feedstock for natural gas replacement is comprised of household waste, and does not include industrial, hazardous, or construction and demolition waste.

[4] Larson, Eric D., Stefano Consoni, and Ryan Katofsky. "A Cost-Benefit Assessment of Biomass Gasification Power Generation in the Pulp and Paper Industry" 8 October, 2003, p. 6

- **Petroleum derivatives** The prevailing notion of fuel flexibility has implied the ability to switch between natural gas and crude oil distillate products. Such flexibility generally is feasible with the use of readily available fuel flexible burner tips; this type of fuel flexibility has been in use for decades and is well understood by industry and regulators.

Figure 2-3: Wholesale cost of oil and natural gas on Btu basis



Source: EIA Petroleum Navigator, EIA Natural Gas Navigator

At least three points should limit DOE interest in petroleum derivatives as a fuel flexibility source. First and foremost, crude oil is an extremely high-value energy resource that can produce products as diverse as jet fuel, home heating oil, and industrial chemicals. Coupled with its ease of transportation, these factors make crude oil a generally more expensive resource on Btu basis than natural gas (*see Figure 2-3*). Fuel switching to crude distillates thus offers limited economic value, beyond perhaps the option value available in rare instances when natural gas is more expensive than petroleum. Even so, the EIA currently projects the price difference between the fuels to increase through 2030.[5]

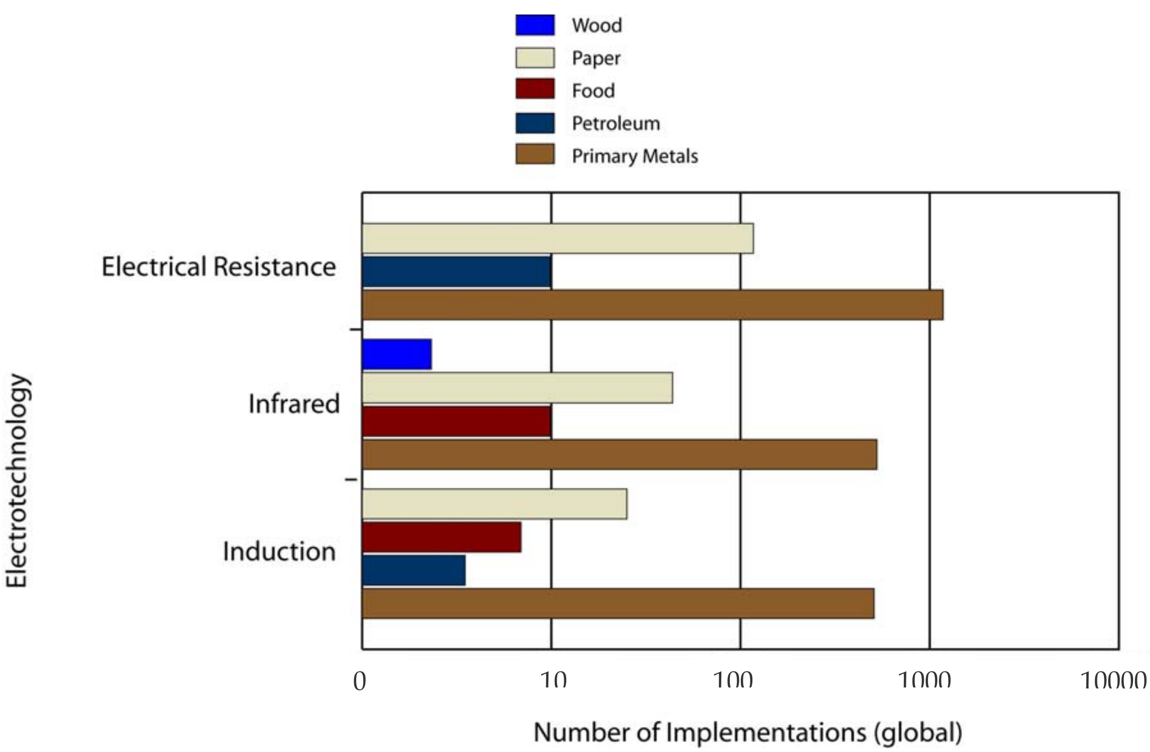
Independent of the price spread between these fuels, emphasizing use of petroleum resources will not advance national energy security interests. The U.S. already imports 65% of its petroleum consumption[6] and is set to increase this share to 70% by 2030. Thus, substituting petroleum for natural gas will entail replacing a fuel largely produced domestically with one largely produced abroad.

Finally, use of distillate fuels provides little support to environmental objectives relative to natural gas. Natural gas is superior to oil with respect to pollutants, including CO_2, NO_x, SO_x, particulate matter, producing between one-half and two-thirds the weight of each pollutant per unit of energy.[7]

[5] The 2007 Annual Energy Outlook projects prices of distallate fuels to increase from 70% more expensive than natural gas in 2004 to over 100% more expensive in 2030 (see table 3: Energy prices by sector and source).
[6] Energy Information Administration, *Annual Energy Outlook 2007* Washington: 2007. Table 11.
[7] For additional details on the specific emissions profiles associated with various combustion systems, see the US EPA, *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*, Chapter 3.

- **Electro-technologies** comprise a number of classes of technology that convert electrical energy into heat. These technologies can be a feasible alternative to provide industrial process with an environmentally sound and financially beneficial substitute to natural gas. These technologies are deployed commercially across all sectors (*see Figure 2-4 for some examples*). From the industrial users perspective these technologies offer relative simplicity compared to other fuel flexibility options in that the user only need focus on the production process-conversion and all the risks and concerns associated with energy delivery to the industrial process such as fuel supply risk, obtaining and updating regulatory permits, potential obligations to limit carbon consumption, are transferred to the electricity supplier. This enables the user to focus on the core business.

Figure 2-4: Globally electro-technologies are already widespread in the primary metals, paper, food processing, and petroleum sectors



Source: Environment Canada Innovation, Monitoring, and Industrial Sectors section, "Environment Technological Innovation" Montreal: 2005, p 5

2.1.2 Conversion technologies – are they technologically within reach?

The second distinguishing factor of the fuel flexible supply chain is that it often involves a step to convert the raw fuel into a form of energy – usually heat – useful to industrial users. Conversion technologies fall into two basic categories: the first involves chemical alteration of the feedstock, usually resulting in a liquid or gaseous fuel, which in most cases is then combusted. The second involves direct combustion of the fuel, usually after processing such as pulverization, vitrification, or formation of a solution with water to optimize the physical state of the fuel.

Technologies involving chemical alteration of alternative fuels are more complex than direct fire options, however, they are technologically with reach from the standpoint that the core technological conversion process has been developed, tested, and demonstrated in industrial applications. While barriers to their wholesale integration remain, they offer the potential to capture substantial amounts of pollutants such as heavy metals, sulfur, and carbon during the chemical conversion process. This would greatly reduce their air emissions. The principal chemical conversion pathways are gasification, liquefaction, and electro-chemical reformation.

Gasification is the conversion of hydrocarbon fuel into synthesis gas ("syngas") through the application of heat and pressure. The syngas (mainly hydrogen and carbon monoxide) can be burned directly or can be further synthesized into industrial chemicals such as methanol and ammonia, or, via shift and catalytic synthesis liquefaction processes, into liquid fuels resembling those currently derived from petroleum. While syngas is an intermediate step in coal-to-liquids production, the molecular structure of biomass allows for liquid fuel production both via the syngas pathways as well as through pyrolysis, esterfication, and hydrolysis.

Although synthesis gas can be burned in the same industrial infrastructure as natural gas, it is of a lower heat content (i.e., Btus per pound) than natural gas. This fact may require upgrades to combustion infrastructure.

The current gasification industry, though still nascent, has a handful of firms that install and operate gasifiers that consume opportunity fuels, biomass, and, to a lesser extent, coal. Gasification technology still faces considerable barriers to implementation, however the technology is available and within the realm of consideration of many industrial users.

2.2 Fuels flexibility in key energy consuming processes

The third segment of the natural gas supply chain comprises the point at which the fuel is directly applied to the manufacturing process. There are essentially two basic uses for natural gas. The larger of the two, comprising almost 90 percent of industrial natural gas consumption, is as a combustion fuel for boilers, combined heat and power, process heaters and, to a much lesser extent, machine drives and plant lighting. The remaining 10 percent of natural gas is for feedstock in the manufacture of chemicals such as hydrogen, methanol, and ammonia. These principal uses are described below; they are drawn from a much more detailed analysis provided in Appendix A.

- **Boilers** consume roughly 20% of natural gas used in industry. Over 43,000 boilers are currently operated by industrial users, the majority in energy intensive industries such as food, paper, chemicals, refining, and metals that are affected by unfavorable natural gas prices. Boilers tend to be long-lived investments, with average life expectancies of 25-30 years, though some sources estimate that nearly half the boiler capacity is more than 40 years old. This suggests that a large portion of boilers may be at or near a point where they can be economically switched. Boilers can and are run using the entire range of fuels discussed above (though many alternative fueled boilers are used to power electric generators), making them an ideal target for fuel flexibility programming.

- **Combined heat and power** (CHP) is the sequential production of electricity and heat, generally performed at the site of the customer load. These systems consume about 13% of US industrial natural gas. For users with significant heat and electrical loads CHP units offer major efficiency benefits. In contrast to traditional boilers and furnaces, which produce heat only, electricity CHP units produce electricity that can substantially decrease reliance on electricity from the electric utility, conferring to the CHP investor potential electric bill savings. At the same time, CHP greatly enhances the productivity of energy by recapturing heat normally lost during electricity production at central-station facilities that do not re-capture waste heat.

  CHP units also can be, and are, run with multiple fuel sources. CHP would appear to be a good match for fuel flexibility programs. One difficulty in terms of fuel flexibility is that CHP technology is in many ways quite mature and it is already the subject of substantial private investment. Nonetheless, many of the highest-value CHP projects are natural-gas driven turbines and reciprocating engines, and fuel flexibility resources may be usefully leveraged by linking CHP to gasification systems. Solid fuels such as biomass, coal, and petcoke may also have a role, as they can be used with high levels of efficiency when burned in steam turbines.

- **Process Heaters** consume more energy as a group than do boilers, however, they are a vastly more heterogeneous group. Process heaters include a wide range of applications, including kilns, ovens, melters, furnaces, and dryers. Industry consumes about 42% of its natural gas in these devices. Despite the fact that processes heaters are designed to heat materials under controlled conditions, as opposed to simply raise steam, the process heaters conversion technologies are similar to those of boilers. From a fuel flexibility standpoint, therefore, the opportunities and challenges of using alternative fuels in process heaters are similar to those for boilers.

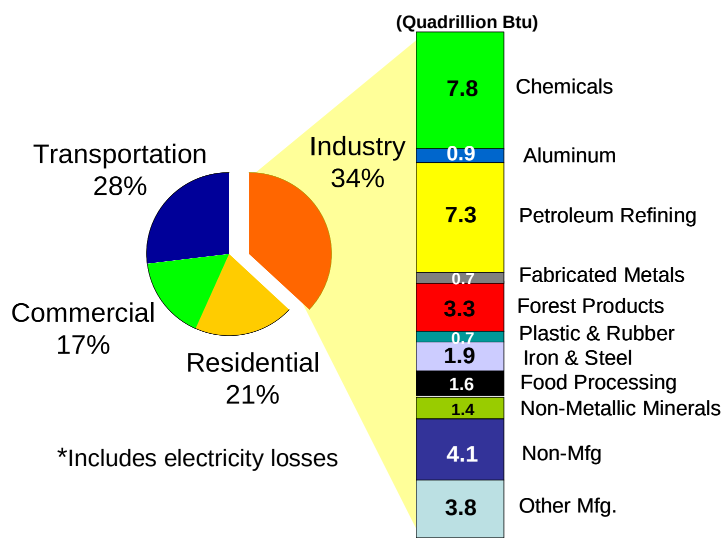
- **Feedstock** use comprises an additional 10% of natural gas consumption, focused in large part in the chemicals industry. Feedstock requirements are in some ways the most difficult to meet using alternative fuels because natural gas is used specifically for its chemical content. Alternative fuels such as coal, biomass, and petroleum that substitute for natural gas relatively easily in heat applications do not have the molecular composition to support feedstock applications in their raw state. Their value as a natural gas feedstock replacement is realized only if they are gasified and processed through a shift reaction to create a synthetic natural gas.

3.0 WHAT DRIVES – AND INHIBITS – INDUSTRY INTEREST IN FUEL FLEXIBILITY?

While DOE objectives are oriented toward national and global energy problems, industrial users are concerned with the impact of energy systems on their production cost. The market for fuel flexibility technologies can only develop when specific technologies bring value to industrial operations. For the fuel flexibility program to succeed, then, it must accurately evaluate the critical factors that can make fuel flexibility options more desirable to users. It must also anticipate and address the challenges and risks that industrial users might perceive in adopting these options. Given these parameters, early market research suggested that a near term 3% - 7% natural gas displacement potential by 2012 exists.

The industries that are most affected by high natural gas prices are concentrated largely in the chemicals, refining, metals, and food processing industries (*see Figure 3-1*). These industries are not only the largest consumers of energy, but they also often have energy as a higher fraction of total cost compared with other industries. Managers in these industries are concerned about rising and volatile natural gas prices, and have three basic options available:

Figure 3-1 Shares of natural gas consumption by economic sector and industry



Source: EIA Annual Energy Review 2006; EIA MECS 2002

1. Move operations off-shore to countries with lower energy costs;
2. Continue using natural gas, accepting high prices and volatility as a cost of doing business, and pass on higher costs to consumers, if the business allows.
3. Integrate fuel flexibility options in their energy supply chains.

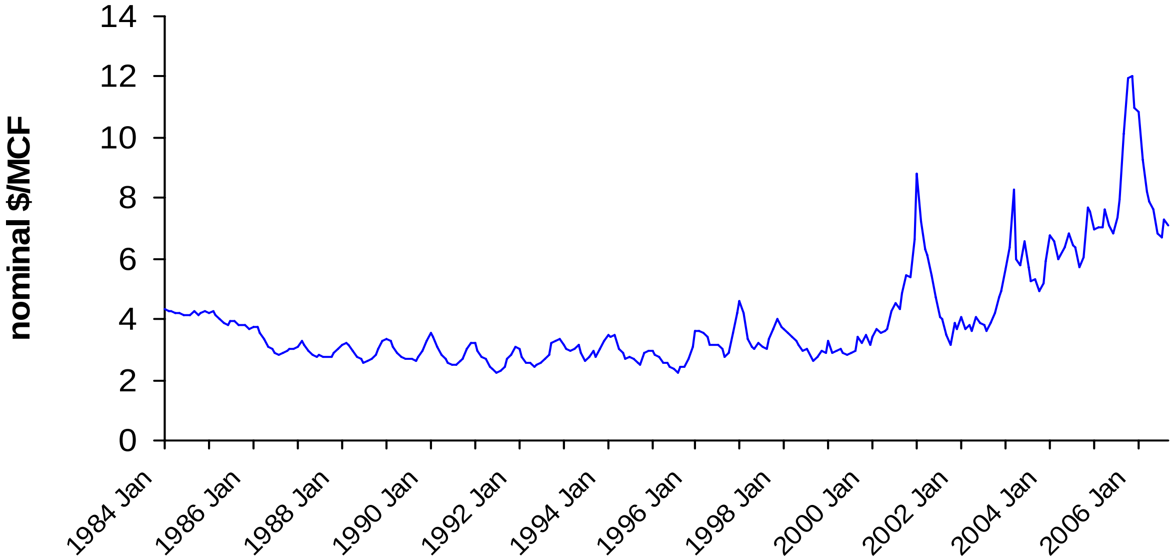
While none of these options fully resolve the natural gas cost problem, preliminary analysis suggests that fuels flexibility holds significant promise. In some respects the fuel flexible value chain could provide superior performance to that of natural gas, as it can rely entirely on domestically abundant energy sources that are often intrinsically cleaner or close waste loops. Further, the addition of conversion technologies necessary to transform alternative fuels into energy forms similar to natural gas offers the opportunity to eliminate the release of pollutants into the atmosphere. However, unlocking the potential for fuel flexibility option to advance these interests requires overcoming technical, economic, and regulatory barriers. Appendices A and B focus on the specific opportunities for fuel flexibility and identifies in greater detail these challenges.

3.1 Driving for industry to re-tool the energy value chain rather than business-as-usual

From an industry perspective the need for alternatives has grown increasingly with the rising importance of two chief trends: natural gas prices are both higher and more volatile than at any other time in recent history*(see Figure 3-2)* and mounting concern over the impact of global warming that will require shifts in how industry uses fuels.

Of most immediate concern, natural gas prices have risen and become substantially more volatile. After years of relatively predictable seasonal fluctuations in the range of $2.50 to $4.00 per thousand cubic feet (MCF), gas prices soared to nearly $9/MCF in the winter of 2001 and hit a peak of $12.13/MCF for industrial customers in November 2005 (caused in no small part by the devastating hurricane activity in the Gulf of Mexico). The main reason for these increases and spikes is that natural gas use has grown significantly because natural gas emerged as an ideal fuel in many respects. It is an energy-dense, readily transportable fuel that relies on mature technology; it can be implemented quickly, cheaply, and at little operational risk; and in contrast to oil and coal, it produces lower SOx, NOx, mercury, particulate matter, and CO_2 per Btu of energy delivered.

Figure 3-2: Natural gas prices and volatility have increased significantly since 2000



SOURCE: EIA, Dec. 2006 Monthly Energy Review, Table 9.11

A second issue of increasing importance is that addressing global warming and other environmental problems favor natural gas usage. While the environmental benefits of burning natural gas compared with other fossil fuels is an important driver behind energy decisions today, introduction of carbon constraining regulations in the future could dramatically increase the demand for natural gas. Natural gas releases a little more than half of the carbon per unit of energy produced as does coal. This additional pressure on natural gas supplies, especially when combined with limited alternatives, will cause added natural gas price pressures and associated economic dislocations.

At present it is not clear what form a carbon constraint might take in the U.S. or when it might be implemented. However, the political and business landscape points to an increased probability that mandatory carbon emissions restrictions will be implemented. Regardless of the outcome of efforts at the national level, California, eleven Northeastern states, and five Western states have enacted or are seriously contemplating emissions regulations. As these states together host more than one-quarter of the nation's industrial output, the impact on industry can be potentially significant.[8]

Set against these trends is the fact that over the last decade, the low lifecycle costs, environmental performance, and ease of integration with process operations helped ensconce natural gas into industrial applications. Now that industry is facing high

[8] The rule contemplated by the seven parties of the Northeastern States' Regional Greenhouse Gas Initiative (RGGI) initially apply only to the power sector but other sources of emission will be considered once the carbon cap is in place and trading has commenced.

natural gas prices in the U.S., and the unappealing prospects of long-term fixes by moving abroad, it is in the position to think creatively about re-tooling energy value chains. Developing compelling opportunities for fuel flexibility to address this problem first requires a clear assessment of current constraints. These fall into three basic categories: the simplicity of the current energy value chain, the current regulatory environment, and factors relating to how businesses make decisions.

3.2 Inhibitors for industry to re-tool the energy value chain

3.2.1 Current value chain is simple and reliable

The standard natural gas chain value chain offers an important measure of simplicity and reliability that pose a barrier to the uptake of fuel flexibility offerings.

The first area in which the fuel flexible value chain is less simple than that for natural gas is procurement of the fuel supply itself. Contracting mechanisms and delivery infrastructure for natural gas are well established. Users typically sign bi-lateral contracts with natural gas utilities who deliver the fuel through an extensive set of pipelines with high reliability. Regulations supporting these contracts are well developed and the contracts have a high degree of certainty.

Alternative fuels, which are used by industry in small volumes if at all, are not supported by such levels of regulation and infrastructure. These issues manifest themselves in different ways depending on the fuel type. Biomass feedstocks can be heterogeneous, a fact which can affect the performance of gasifiers and combustors. Third-party developers of biomass-fired plants have reported trouble obtaining reliable feedstock delivery. Coal procurement, meanwhile, is hampered by a national infrastructure designed to bring coal to large central-station electric plants by train or barge, not relatively disparate industrial users who may not have river or railroad access. Finally, opportunity fuels such as MSW, petcoke, and black liquor present varying combinations of procurement challenges, including gaining legal possession of the fuel (as in MSW), transportation to the point of consumption, and screening to eliminate dangerous substances from the fuel before they can damage the industrial infrastructure.

The intermediate conversion technology can be another inhibitor, particularly in the case of gasification technologies. Natural gas-fired systems require minimal engineering that convert natural gas to useful energy with high reliability. Energy pathways relying on gasification or liquefaction employ sophisticated equipment that requires specialized knowledge to implement, operate, and maintain the system. They also require accommodating the existing natural gas equipment to handle solid fuels having distinct physical and burn properties relative to natural gas, which may require additional amounts of capital investment and process integration to maintain product quality. Such upgrades include fuel and supply header modifications to accommodate the lower heating value of many gasified fuel alternatives, boiler modifications to maintain efficiencies, and fuel conditioning to prevent fouling of burners and boilers.

The seamless integration of these multiple potential failure points is essential to maintaining system up-time necessary to pay back the investment and meet customer requirements.

3.2.2 Environmental regulations

The Federal Clean Air Act (CAA) and its implementation under State authority will influence the potential for industry to use alternative fuels, as these fuels and the associated energy conversion pathways create emissions profiles that differ from those of traditional natural gas combustion. In addition, current regional and expected federal regulation of greenhouse gases may have impacts on industrial users.

The Clean Air Act and Fuel Flexibility

Many fuel flexibility technologies entail changes to the energy value chain that will constitute "major modifications" to pollution-emitting equipment under the CAA. This triggers an obligation by the permit holder to meet EPA's New Source Performance standards, the most stringent pollution abatement requirements in force. The standards apply to almost all industrial energy technologies, regardless of size, though large, energy intensive users such as refiners are particularly attentive to whether an investment in equipment will force them to undertake potentially substantial revisions to air permits.

An additional issue with respect to fuels flexible technologies is that current regulations are highly oriented toward the use of traditional fuels. Standards for novel application of advanced fuels in many cases have not been developed. Furthermore, state regulators responsible for implementing state implementation plans are often unfamiliar with the technologies, as many will have little or no experience with them and lack data to support permitting decisions. This presents a major problem for investors in fuel flexible technologies, as construction on the facility cannot commence until air emissions permits have been approved.

Obligations under non-air regulations are unknown

Alternative fuel use may create obligations stemming from frameworks designed to protect other aspects of human health and the environmental. The Clean Water Act, the Resource Conservation and Recovery Act, as well as various state requirements, all may affect the slate of fuel alternatives at a particular industry or plant location. Because many fuel flexibility concepts are new to the industrial sphere, the applicability of these and other laws is presently unknown or untested.

The Impact of Future Carbon Regulation Needs to be Considered

Although the form, limits, and timing of greenhouse gas regulations are not yet defined, the fuels flexibility program will most likely not deliver results to users over the longer term if it catalyzes migration to fuel flexible technologies that will perform poorly in a carbon constrained economy. This would worsen already serious concerns about the impact of such legislation on the industrial sector. Analysis of one prominent climate change policy, the McCain-Lieberman bill introduced but defeated in 2003, indicated that economic production would shift toward less intensive areas of the economy, essentially creating a recession as output and employment decline as the economy shifts to low carbon production paradigms.[9] For industry, this means loss of production, particularly in energy intensive industries, as well as more aggressive replacement of plant and equipment and utilization of alternative fuels.

In this vein it is equally important to note that the same analysis, however, indicates that early measures to improve the low-carbon technology base can assist the transition to a low-carbon industrial sector. It found that meeting many of the fundamental aims of the fuel flexibility program – earlier availability, lower costs, and higher efficiencies for advanced technologies in all sectors of the economy – could substantially reduce the legislation's adverse impacts.

3.2.3 Corporate decision-making factors

Although different combinations of the fuel flexibility value chain will create different opportunities and highlight different hurdles to large-scale deployment, several commonalities unite almost all the options, regardless of the industry, firm, or alternative fuel considered.

- **Competition with the core business for capital:** Fuel flexible technologies are often capital intensive. Managers, generally specialists in the core business but not alternative technologies, prefer to invest in direct improvements to the business. As a result, even alternative energy projects with economically rational returns may go unfunded.

- **Financial performance:** Energy from fuel flexible technologies is often more expensive than that from traditional natural gas systems, particularly in smaller

[9] Energy Information Agency, "Analysis of S.139, the Climate Stewardship Act of 2003: Highlights and Summary" Washington: 2003, p. 22

applications where economies of scale cannot be achieved. The perceived performance risk of an alternative energy system requires rates of returns significantly greater than the standard hurdle rate in many firms. In addition, financiers are often reluctant to commit to investments with limited or unproven performance records.

- **Access to supply:** The limited delivery infrastructure serving many alternative fuels limits the maximum economic transportation distance of many fuels, thus requiring that they be consumed close to where they are harvested or produced. These problems are notable with petcoke, biomass, and MSW. Electro-technologies may in some circumstances require upgrades to the local electricity distribution grid in order to accommodate the increased load.

- **Commodity price volatility:** Alternative energy technology investments are generally predicated on natural gas price forecasts. Natural gas prices, like other commodities, exhibit substantial fluctuations over time. Thus, a firm undertaking an investment that is attractive while prices are high may ultimately put itself at a competitive disadvantage in the event of a price collapse, as competitors using traditional fuels enjoy lower cost structures. Furthermore, some fuel flexible commodities such as petcoke and electricity may in fact exhibit volatility on par with that of natural gas.

- **Absence of performance/risk wraps:** An engineering, procurement, and construction "wrap" identifies to a financier who or what entity is going to be responsible for the risk of building the system, including price, construction and performance of the system.) Securing such wraps is an essential measure of the financial worthiness of the project and critical to securing project finance, however, they are not widely available for advanced technologies such as gasifiers.

- **Investment size:** The sheer size of some alternative energy technologies create an implementation hurdle. While small scale gasifiers may cost on the order of tens of millions of dollars, a petroleum coke gasifier co-located on-site at a refinery, for example, would likely cost up to $1 billion[10]. Technologies requiring smaller investments can be attractive to financiers because they can more effectively diversify risk. However, at a smaller size there is not a clear business case as to the value of the investment as often times the unit is being built inside the fence and does not provide outside revenue.

[10] Bechtel, Global Energy, and Nexant, *Gasification Plant Cost and Performance Optimization* National Energy Technology Laboratory: 2002, p. 33.

- **Equipment lifespan:** Industrial energy infrastructure often has a long lifespan. Estimates place much of the current boiler inventory, for example, at roughly 40 years old. This equipment is typically fully depreciated and can be used at little cost to the user; as a result replacing it with new equipment can erode any price differential the new equipment may offer over natural gas.

3.2.4 Summary of constraints faced by industry

The result of this analysis, including consultations with industry, has produced a condensed list of the chief constraints to fuel flexibility in industry. For purposes of program development described in the next section they have been grouped into four general groups: 1) business process, integration, and finance issues; 2) emissions and regulatory issues; 2) locational constraints; and 3) technology development and engineering economics issues.

Business process, integration, and finance issues pertain to the physical and business aspects integration of alternative fuel devices into existing industrial processes.

- Procurement of biomass is hindered by the feedstock's heterogeneity and distinct commercial terms vis-à-vis natural gas.
- Accommodating natural gas equipment to run on solid fuels that have distinct physical and burn properties requires a large amount of capital investment and process integration.
- Much of the market for fuel flexibility equipment lies in retrofitting existing plants, however, many alternative fuels, especially solids such as coal, petcoke, refuse derived fuel, or biomass, may be incompatible with these existing systems.
- Use of electro-technologies is constrained by the fact that electricity is more expensive per unit energy than natural gas and, depending upon the nature of the regional electricity market, may be as volatile or more so.
- Securing Municipal Solid Waste streams for use in industry will encounter competition from landfilling.
- Engineering, procurement, and construction "wraps" are not widely available for advanced technologies such as gasifiers.
- Financial hurdles to alternative energy projects include: capital intensity that is difficult to diversify, limited/unproven performance records, and need for rates of returns significantly greater than standard investments.

Emissions and regulatory issues arise from regulatory regimes that may penalize alternative technologies due to a lack of actual experience.

- Combustion of alternative fuels may release levels of particulates, sulfur dioxide, and nitrogen oxides that requires additional and/or novel pollution control equipment for the flue gases, however little credible data exists to support permitting decisions.

- Little is known about how fuel flexibility options will affect industrial permits for non-air resources.

Locational constraints are limitations due to the physical location of alternative fuel sources and points of consumption, often stemming for a lack of infrastructure.

- Access to biomass supply such as wood is restricted due to a maximum economic transportation distance.
- Transportation requirements will diminish the economic rationale to use petcoke.
- Electro-technologies are dependent on the localized availability of electricity delivery capacity.
- The infrastructure for biomass (growth, harvest, processing, storage, transportation) or coal handling and storage on-site for industrial gasification can be both logistically and economically impractical.

Technology development and engineering economics issues related to needed advances in the fuel flexible machinery itself of particular necessity to be considered for integration with processes.

- Energy, density, physical properties, combustion characteristics and chemical composition of biomass feedstocks vary.
- Reliability of the gasification systems will be a CHP constraint.
- Low heating value biomass and coal–based syngas affects gas flow rates requiring fuel and supply header modifications (applicable to both boilers and process heating units).
- Increased biomass and coal-based gas flow rates result in a pressure drop that causes boiler de-rating and impacts the boiler's operating limits and efficiency.
- Fuel liquids produced from solid fuels (e.g., petcoke, biomass, coal) require special handling or processing to prevent fouling of burners and boilers.
- Substituting electro-technology in most cases requires the complete replacement of the existing thermal equipment.
- Syngas contains impurities that must be removed from the gas stream in order to prevent fouling of the equipment. Additionally, use of fuels such as coal and petcoke that would normally present air quality concerns under direct fire applications may only be viable in many areas if controlled pollutants are removed prior to combustion.
- Many industrial plants are too small to obtain adequate economies of scale, particularly in the case of coal-fed gasifiers.
- Many electro-technologies do not scale well in that there are little or no economies of scale above a given module size.

4.0 WHAT ROLE SHOULD DOE PLAY?

The federal government is an agent in achieving the public benefits associated with migrating industry from reliance on natural gas system toward a more resilient system based on multiple fuels. DOE's ITP is the logical agent to marshal resources already invested in publicly funded programs at the DOE and the national laboratories in conjunction with its own dedicated resources and stakeholder base to achieve improved fuel flexibility in industry.

The principal challenge to making operational an effective fuels flexibility program lies in effectively harnessing the link between public and private spheres. Alternative technologies, even where their technical viability is well understood and agreed upon, expose users to higher levels of risk due to the fact that they are unsupported by the same level of operating experience, legal support, and infrastructure as natural gas. Government entities such as DOE can make important contributions in this area by supporting early demonstrations that provide data to support decision-making. An effective DOE program can initiate activities along these lines to help re-define the context in which energy decisions are made. These fall into a few primary areas:

Box 2: Coal gasification plant proposed in Indiana will produce pipeline quality gas; developers seek $1.2 bn EPACT loan guarantee.

Indiana Gasification, LLC is proposing a $1.5 billion coal gasification plant that would be the first to provide pipeline-quality synthetic natural gas and capture CO_2. A Carnegie-Mellon study indicates that the project would likely provide consumers with $3.7 billion in savings over 30 years. Letters of intent for off-take contracts have been initially signed by Indiana utilities, however, industrial users could add substantially to the value proposition of the facility. Users would gain access to an extremely low-carbon fuel highly compatible with existing processes at a price lower than that they currently pay for natural gas, while the developer would diversify the project's off-take, as well as additional revenue streams from co-products from the conversion process.

The project will seek a $1.2 billion loan guarantee from the DOE in 2007.

Source: Indiana Office of the Governor new release, "Southwest Indiana aims to be home to large natural gas plant," 10/27/06

- *Information gaps:* the extremely limited performance records of advanced technologies result in very limited sets of information upon which users, financiers, and regulators can make informed judgments. In the absence of credible information, they will default to traditional energy sources.

- *Convening power*: DOE has the capacity to assemble both market actors and market shapers who would not otherwise be drawn into cooperation. This includes linking energy technology vendors with potential users as well as serving as an interlocutor with regulatory agencies such as the EPA.

- ***Early stage technology R&D***: Private entities will systematically avoid supporting research and development for technologies with commercial application far off into the future or that create value in areas difficult to monetize such as environmental benefits and national security.

A second principal challenge in defining the appropriate role for government is differentiating project activities by the stakeholders the program seeks to mobilize. Broadly, the three main sets of stakeholder in the fuels flexibility sphere, and the best way for the government to catalyze innovation among them are as follows:

- **Technology developers** that research and develop and market hardware such as gasifiers, boilers, or process heaters. For these entities, the optimal DOE contribution are grants with which they can perform early-stage research in line with their corporate objectives, possibly through cost-share agreements with the government. Successful grants enable significant leveraging of public resources by enabling technological advancement that the developer can then take to the next level of production and marketing.

  Technology demonstrations may also prove valuable for technology developers. Users and investors may be unwilling to commit resources to novel technologies because their performance under the demands of normal production processes is uncertain. Demonstrations enable accretion of performance data which enables potential investors to determine the appropriateness of a technology investment for their process and risk appetite, stimulating demand for products in develops have invested.

- **Specialized energy companies** provide development and management of alternative energy technology equipment in exchange for off-take agreements. For these users development of viable bases of stable, creditworthy customers able to accept system off-take is essential to success. Their chief challenge lies in navigating air, water, and solid waste regulations using technology that, while technologically mature, has sparse track records and little institutionalized regulatory knowledge. For these users the convening power of government can be used to familiarize customers with alternative service offerings, coordinate agencies to smooth permitting processes, and identify new customer bases. They may also benefit from government programs such as loan guarantees and production tax credits that enable them to monetize any public benefits they provide as well as mitigate the risks associated with novel technologies.

- **End-users** who own, operate and manage their own equipment to support their manufacturing processes. Unlike specialized energy companies, end-users do not need to identify new customers; however, public resources that mitigate risk or improve the return of alternative energy investments are of importance. Demonstration facilities may induce these users to invest in alternative technologies by eliminating their interest in being "the first to be second," however, stakeholder interviews suggested that this concern is subordinate to improving the risk–return relationship.

Where Great Floors Begin

Box 3: Gasification raises value of Georgia carpet factory waste

Carpet has an energy content greater than coal from the Powder River Basin and carpet factories in the U.S. produce about 2.5 million tons of carpet waste annually. Faced with rising costs to dispose of excess carpet and wood flour from its wood flooring manufacturing plant, Shaw Industries of Dalton, GA and Siemens alternative energy group installed a gasifier with capacity to handle 12,000 tons per year of carpet and 6,000 tons per year of wood flour. The gas is used in a heat recovery boiler to generate 50,000 lbs of steam per hour, sufficient to meet 80% of the requirements for the plant's color-dyeing needs. Shaw estimates the plant cost at $10-$15 million, with cost reductions of $3.5 million per year. The company is looking to install additional gasifiers at its other plants, in direct response to high energy prices.

Source: Power Magazine, Global Monitor, February 2007 and Distributedenergy.com, "The Wall-to-Wall Solution," July/August

Within these parameters, a range of actions or opportunities are available to DOE to catalyze the potential for alternative technologies in industries. Working from the constraints identified in the previous section, these opportunities are as follows:

BUSINESS PROCESS, INTEGRATION, & FINANCE ISSUES

- **Procurement of biomass is hindered by the feedstock's heterogeneity and distinct commercial terms vis-à-vis natural gas**
  – *Establish simple but standard biomass feedstock standards (similar to coal characterization or natural gas parameters) supported by recognized and consistent measurements, working with ASTM/ANSI to facilitate feedstock contracting and purchases.*
  – *Establish a feedstock contracts information clearinghouse to help users negotiate contract terms associated with biomass, such as transit fees, contract duration, and remedies for contract disputes.*
- **Accommodating natural gas equipment to run on solid fuels that have distinct physical and burn properties requires a large amount of capital investment and process integration**
  – *Develop and share economic and technical assessments based on actual boiler population data to identify ageing natural gas boilers, process heaters, and CHP units that should be targeted for replacement with fuel-flexible equipment.*

  - *Demonstrate fuel switching options. Example: test the economic and technical viability of gasifying petcoke into multiple product streams, such as liquid fuels, electricity, and co-products.*
  - *Evaluate and analyze tradeoffs between a large central gasifier versus small, modular on-site gasifiers (in terms of capital and operating costs as well as ability to penetrate the market) to identify critical variables affecting gasification business models.*
- **On-site gasification of petcoke at refineries requires potentially substantial revisions to air permits**
  - *Determine the regulatory compliance costs associated with refinery-sited petcoke gasification and combustion, as well as regulatory issues associated with production and sale of co-products including syngas, liquid fuels, electricity, and industrial chemicals.*
- **Much of the market for fuel flexibility equipment lies in retrofitting existing plants, however, many alternative fuels, especially solids such as coal, petcoke, refuse derived fuel, or biomass, may be incompatible with these existing systems**
  - *Model the economic, efficiency, and emissions performance issues of combustion versus gasification as well as use of CHP versus straight steam generation using various fuel options*
  - *Develop and share economic and technical assessments based on actual boiler population data to identify ageing natural gas boilers, process heaters, and CHP units that should be targeted for replacement with fuel-flexible equipment*
  - *Establish a tested to determine how much syngas could be blended with natural gas without adversely affecting the air emissions, performance, and reliability of industrial CHP, boilers, and process heaters (potential collaboration with Fossil Energy)*
  - *Determine performance characteristics of turbines using syngas in order to support manufacturer warranties for machines originally designed for natural gas use.*
- **Use of electro-technologies is constrained by the fact that electricity is more expensive per unit energy than natural gas and, depending upon the nature of the regional electricity market, may be as volatile or more so**
  - *Support RD&D for development of a cost-competitive electric-fired boiler*
  - *Create a model industrial users could apply to their operations to determine cost savings possible through use of electro-technologies.*
- **Securing municipal solid waste streams for use in industry will encounter competition from landfilling**
  - *Convene industry-municipality-waste agency collaboratives to identify projects, agree to workable contract terms, and execute them.*
- **Engineering, procurement, and construction "wraps" are not widely available for advanced technologies such as gasifiers**
  - *Explore the use of DOE special contracting mechanisms to provide insurance or financial risk guarantees for innovative projects.*
- **Financial hurdles to alternative energy projects include: capital intensively that is difficult to diversify, limited/unproven performance records, and need for rates of returns significantly greater than standard investments**
  - *Determine applicability of EPAct loan guarantees in the industrial sphere.*

EMISSIONS AND REGULATORY ISSUES

- **Combustion of alternative fuels may release levels of particulates, sulfur dioxide, and nitrogen oxides that requires additional or novel pollution control equipment for the flue gases, however little credible data exists to support permitting decisions**
  – *Establish a tested designed to provide regulator-credible emissions profiles for gasifiers at or near market readiness using different synfuels.*
  – *If the testbed reveals that the alternative fuels produce emissions levels incompatible with prevailing standards in all areas (including non-attainment), support development and/or application of pollution control devices.*
- **Little is known about how fuel flexibility options will affect industrial permits for non-air resources**
  – *Determine whether any regulatory issues such as those for wastewater, solids handling, or feedstock harvesting will impede the use of alternative fuels in both direct fire and gasification options.*

LOCATIONAL CONSTRAINTS

- **Access to biomass supply such as wood is restricted due to a maximum economic transportation distance**
  – *Develop an analytic model for determining the cost effective use and limitations of agriculturally derived biomass for industrial applications.*
- **Transportation requirements will diminish the economic rationale to use petcoke**
  – *Evaluate and analyze optimal combinations of gasifiers, feedstock, and specific applications with a regional focus to identify opportunities to use petcoke in close proximity to where it is generated.*
- **Electro-technologies are dependent on the localized availability of electricity delivery capacity**
  – *Determine the geographic areas, applications, and load profiles that characterize the best candidates for electro-technologies, and calculate the costs necessary to upgrade the grid and plants in order to accommodate them.*
- **The infrastructure for biomass (growth, harvest, processing, storage, transportation) or coal handling and storage on-site for industrial gasification can be both logistically and economically impractical**
  – *Understanding what would be a sufficient inventory needed be kept on-site to keep a reliable inventory. Optimization based on where the biomass/coal is, where the operation, what the heat content is, how big the landmass is, and the associated increase in cost to support it.*

TECHNOLOGY DEVELOPMENT AND ENGINEERING ECONOMICS ISSUES

- **Energy, density, physical properties, combustion characteristics and chemical composition of biomass feedstocks vary**
  – *Establish simple but standard biomass feedstock standards (similar to coal characterization or natural gas parameters) supported by recognized and consistent*

measurements, working with ASTM/ANSI to facilitate feedstock contracting and purchases.

- *Establish a grant program designed to assist technology developer conduct research and develop on early-stage technologies that can then be brought to the next stage of production.*

- **Reliability of the gasification systems will be a CHP constraint**
  - *Establish a testbed facility dealing specifically with the reliability of CHP engines under a range of fuels, both syngas and direct combustion, to determine likely failure points and generate credible performance data.*
- **Low heating value biomass and coal–based syngas affects gas flow rates requiring fuel and supply header modifications (applicable to both boilers and process heating units)**
  - *Evaluate impact of low and medium Btu syngas on product quality derived from process heating operations, with particular emphasis on production processes with potentially important impacts on flame temperature and product quality. In particular, establish impact synthetic natural gas will have on industrial processes sensitive to flame properties, such as metal crafting or glassmaking.*
  - *Support RD&D to optimize existing burners and fuel supply headers to run boilers on lower Btu gas.*
- **Increased biomass and coal-based gas flow rates result in a pressure drop that causes boiler de-rating and impacts the boiler's operating limits and efficiency**
  - *Support RD&D to modify/replace existing burners and fuel supply headers to run boilers on lower Btu gas.*
- **Fuel liquids produced from solid fuels (e.g. petcoke, biomass, coal) require special handling or processing to prevent fouling of burners and boilers**
  - *Support RD&D to minimize impurities stemming from direct coal liquefaction and biomass pyrolysis technologies for modular integration.*

INTRINERGY US PIPE

Box 4: Pipe plant eases process integration challenges of syngas by buying it "over the fence" from 3rd party owner/operator

Intrinergy, a specialist marketer of synthesis gas to industrial users, has signed a long-term supply agreement to provide synthesis gas to U.S. Pipe for use at its Bessemer and North Birmingham plants.

Intrinergy will build, own and operate a gasification unit at each of two U.S. Pipe sites using wood waste, shredded plastic automotive parts and landfill waste feedstock. Additionally, Intrinergy will build, own and operate a materials processing facility at a separate location. Intrinergy expects to break ground in the second quarter of 2007 and to begin commercial operations in the fourth quarter of 2007. The Jefferson County Economic and Industrial Development Authority has agreed to provide $25 million to $25 million in bond financing for the project.

Source: Intrinergy, http://www.intrinergy.com/pdf/PR_USPipe_111006.pdf

- **Substituting electro-technology in most cases requires the complete replacement of the existing thermal equipment**
  - *Develop and share economic and technical assessments based on actual boiler population data to identify ageing natural gas boilers, process heaters, and CHP units that should be targeted for replacement with fuel-flexible equipment.*
- **Syngas contains impurities that must be removed from the gas stream in order to prevent fouling of the equipment. Additionally, use of fuels such as coal and petcoke that would normally present air quality concerns under direct fire applications may only be viable in many areas if controlled pollutants are removed prior to combustion**
  - *Support RD&D for hot gas cleanup, investigate various options for removal of impurities and controlled pollutants including, adsorbents, membranes for H_2S and CO_2 removal and improved catalysts and processes for gas conditioning.*
  - *Explore current activity with respect to carbon capture & sequestration and how it applies to industry, specifically with respect to locations where industrial CO_2 can be used to enhance oil recovery.*
  - *Establish a grant program designed to assist technology developer conduct research and develop on early-stage technologies that can then be brought to the next stage of production.*

The Hunton Group — Building Value Through Comfort | VALERO ENERGY CORPORATION

Box 5: Gasified petcoke to provide steady market for Valero petcoke and stable energy costs for local users

Hunton Energy, an independent power producer, announced plans to build the Lockwood integrated gasification combined cycle (IGCC) power generation plant to be located in Fort Bend County, Texas. The project has a unique industrial link: the $2.4 billion, 1200 MW plant will gasify petcoke from a nearby Valero Energy Corporation through a long term supply arrangement. Hunton has indicated that the plant will enable the Fort Bend County "to be the only county in the United States that will be able to offer a major company, considering expansion or relocation, inexpensive and predictable electricity prices." The company has indicated that it will sequester 10-15% of the plant's CO2 and that it "will exceed all regulatory requirements." Groundbreaking is scheduled for 2008.

Source: Hunton Energy, http://www.huntonenergy.com/projects/lockwood.htm.

- **Many industrial plants are too small to obtain adequate economies of scale, particularly in the case of coal-fed gasifiers**
  - *Evaluate and analyze tradeoffs between a large central gasifier versus small, modular on-site gasifiers (in terms of capital and operating costs as well as ability to penetrate the market) to identify critical variables affecting gasification business models.*
  - *Explore the conditions necessary for 3rd party operators to provide over-the-fence syngas, such as leading greater industrial participation in the IGCC concept.*
  - *Analyze opportunities to co-locate industrial steam users with utility power plants*
  - *Establish a grant program designed to assist technology developer conduct research and develop on early-stage technologies that can then be brought to the next stage of production.*

- **Many electro-technologies do not scale well in that there are little or no economies of scale above a given module size**
  - *Create a best practices and applications guide for electro-technologies, used to target potential industries, possibly in conjunction with utilities.*

5.0 NEAR- AND LONG-TERM DISPLACEMENT POTENTIAL MAY BE SIGNIFICANT

As previously outlined, the objective of a fuel flexibility program would be not only to protect industry from the volatility associated with natural gas prices, but also to displace significant quantities of natural gas, thus promoting future energy security.

ITP has targeted displacing 3% to 7% of natural gas in industry by 2012 and close to 30% by 2020. In looking at a near-term goal, the current profile of industry process operations (e.g., number of units, capacity, age distribution, number of companies per industry) is useful as a baseline for projecting future displacement potential. In the longer term, however, there is less certainty regarding projections, as technological changes may significantly alter the profile of industry process operations.

Table 5-1 below presents our projection of what could be achieved by 2012 in terms of natural gas displacement—predicated on moderate to significant action on the part of DOE to initiate a widespread fuel flexibility program.

Although a fuel flexibility program would be cross-cutting among all industries, for analysis it is useful to examine each industrial sector. Thus, we estimated the amount of natural gas consumption in 2012 by using the 2002 Manufacturing Energy Consumption Survey (MECS) data, specific to industry and process operation (i.e., boiler, CHP, process heating) as a baseline. Then for each sector and each type of industrial process (e.g., boiler, furnace) we assumed a percentage for a likely switching *potential* leading to natural gas displacements. These assumptions reflect best professional judgment, based on our knowledge of industrial operations and equipment, and reflect what could be achieved, with moderate efforts, by industry.

Table 5-1: Projected Industry Specific Results of a Fuel Flexibility Program – by 2012

FOOD				
Natural Gas Consumed Annually (TBtu)*		*Projection Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2002	*2012*			
480	509	There are approximately 8,400 process heating units in the food industry, mainly ovens, dryers, and heating furnaces. Electro-technologies are already in use in the food processing industry with 10 infrared and 6 induction applications implemented globally. There is potential for the infrared and induction/induction technologies to provide rapid heating, which would be applicable for dryers.	5% of smaller process units (e.g., driers, ovens) convert to electro-technology	11
		There are approximately 10,200 small industrial boiler units (capacity <100 MMBtu/hr or <30 MW) with a total capacity of 134,000 MMBtu/hr (39,400 MW) input in the food industry, resulting in an average boiler capacity of 12MMBtu/hour (4MW). 65% of the industry's total boiler capacity is attributed to small industrial boilers. There are 62,133 primary	2% of small boilers (under 30 MW) convert to gasification or biomass combustion	5

		companies in the food industry.		
PAPER				
Natural Gas Consumed Annually (TBtu)*		*Projection Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2002	*2012*			
435	461	There are approximately 3,500 industrial boiler units with a total capacity of 376,000 MMBtu/hr (111,000 MW) input in the paper industry, resulting in an average capacity of 109 MMBtu/hour (32MW). The paper industry has already taken great strides to increase their consumption of biomass by combusting their industrial by-products. Currently, 87% of the industrial boiler fuel is "other" which includes biomass consumption while natural gas only accounts for 9% of total consumption. There are 4,167 primary companies in the paper industry.	20% of boilers switch from natural gas consumption to biomass combustion	30
		CHP units have already been adapted to a number of alternative fuels and these opportunities continue to increase. In the paper industry there are approximately 185 large CHP units (10 MW+ capacity) with a total capacity of 12,000 MW, resulting in an average capacity of 65MW. The paper industry also produces 500 billion pounds of black liquor (waste) annually, therefore converting to biomass CHP is feasible.	20% of large CHP units switch from natural gas to biomass gasification	34
		Electro-technologies are widespread in paper industry and with global applications including electrical resistance (100 units), infrared (70 units) and induction (40 units). Dryers and kilns are technologies directly applicable to the paper industry. Also, lime kilns are capable of burning many kinds of fuel including, biomass, wood, or coal.	10% of process heating units (e.g., kilns) switch from gas to biomass or electro-technologies	14
CHEMICALS				
Natural Gas Consumed Annually (TBtu)*		*Projection Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2002	*2012*			
1,515	1,606	Boiler capacity in the chemicals industry lies heavily within the large industrial boilers (>250MMBtu/hr capacity or >83MW) with 350 large units producing 151,000 MMBtu/hr (44,000MW), resulting in an average capacity of 430 MMBtu/hr (127MW). 45% of the industry's total boiler capacity is attributed to large industrial boilers. There is a general trend emerging in boiler inventory distribution across industries showing sales of large boilers are quite mature (30+ years) with combined capacity of approximately 1,560,000 MMBtu/hour (460,000MW). Therefore, there is a potential market for boiler refurbishment with solid, liquid or gas fired boiler technologies. There are 2,940 primary companies in the bulk chemicals industry.	10% of boilers replaced/refurbished because of age, switch for non-natural gas usage	48
		CHP units have already been adapted to a number of alternative fuels and these opportunities continue to increase. In the chemicals industry there are approximately 150 large CHP units (10MW+ capacity) with a total capacity of 25,000 MW, resulting in an average capacity of 167MW.	5% of CHP units switch from natural gas to biomass gasification	25
PETROLEUM REFINING				
Natural Gas Consumed Annually (TBtu)*		*Projection Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2002	*012*			
768	814	Boiler capacity in the refining industry lies heavily within the large industrial boilers (>250 MMBtu/hr or >74 MW) with 220 large units producing 115,000	10% of boilers replaced/refurbished because of age, switch for non-natural gas usage	15

		MMBtu/hr (520 MW), resulting in an average capacity of 521 MMBtu/hr (153MW). 67% of the industry's total boiler capacity is attributed to large boilers. As mentioned for the chemical industry, there is a general trend emerging in boiler inventory distribution across industries showing sales of large boilers are quite mature (30+ years). Therefore, there is a potential market for boiler refurbishment with solid, liquid or gas fired boiler technologies.		
		The utilization of petcoke as a fuel is most applicable to the refinery industry because it is an inexpensive and increasingly abundant byproduct of the refining process. In 2005, refinery net production of petcoke reached approximately 305 million barrels/yr. (A recent example of this opportunity is exemplified by Hunton Energy, a gasification power plant that plans to build a $2.4 billion power plant that will gasify petroleum coke and is scheduled to begin next year.)	10% of the increased short-term petcoke capacity (3.8 million tons, annually) used for fuel	50
PRIMARY METALS				
Natural Gas Consumed Annually (TBtu)*		*Projection Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2002	*2012*			
601	637	There are approximately 5,400 process heating units in the metal casting industry alone with the majority being furnaces, ovens, and melters. Electro-technologies are already well developed for certain process functions. Electro-technologies are already in use in this industry sector more than 1,000 electrical resistance, 800 infrared and 800 induction applications implemented globally. There are 2,693 primary companies in the metal casting industry.	2% of process heating (e.g., furnaces) convert to electro-technologies	11
OTHER MANUFACTURING				
Natural Gas Consumed Annually (TBtu)*		*Projection Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2002	*2012*			
1,106	1,172	Boiler capacity in the other manufacturing industry lies heavily within the small industrial boilers (<50 MMBtu/hr or <14MW) with 11,000 small units producing 110,000 MMBtu/hr (32,440 MW), resulting in an average capacity of 10 MMBtu/hr (3MW). 39% of the industry's total boiler capacity is attributed to small boilers. Less than half of the industry consumption is natural gas based, therefore there is an opportunity to continue the trend of utilizing non-natural gas fuels such as biomass/coal.	1% of boilers switch from natural gas consumption to biomass/coal	3
		There are approximately 122,000 process heating units in the other manufacturing industry with the majority being ovens and heating furnaces. Electro-technologies are already well developed for certain process functions such as melting and curing. Processes such as heat treating, smelting and drying are also emerging candidates for the application of electro-technology. This opportunity will be driven by applications in which electro-technologies enable manufacturers to reduce their production cost, increase their productivity and improve product quality.	2% of small scale process heating convert to electro-technology	17
TOTAL				
Natural Gas Consumed Annually (TBtu)*				*Quantity of Natural Gas Displaced (TBtu/yr)*
2012				
5,199				263

* Includes natural gas consumption attributed to conventional boiler use, CHP and/or cogeneration and process heating only.

In summary, for 2012, the estimated potential displacement is 263 TBtu/yr or 5 percent of the expected amount of natural gas consumption (absent a fuel flexibility program) of 5,200 TBtu/yr. The largest impact is a result of biomass gasification and consumption, followed by the industry specific application of petcoke fuel/syngas. While widespread globally, the application of electro-technology will be evolving among various industry, therefore, it is of lower impact in the short term.

To put these results in context, a savings of 263 TBtu/yr is roughly equivalent to one mid-sized LNG import terminal (i.e., 0.8 to 1.0 billion cubic feet/day, or BCFD, at 70-85% operating capacity—similar in scope to the Cove Point, Maryland, import facility).

Using the same method as for the short-term projections, we present in Table 5-2 below the potential long-term results of an aggressive fuel flexibility program, associated with 2020:

Table 5-2: Projected Industry-Specific Results of an Aggressive Program – by 2020

Natural Gas Consumed Annually (TBtu) 2012	Natural Gas Consumed Annually (TBtu) 2020	Displacement Rationale	Specific Results	Quantity of Natural Gas Displaced (TBtu/yr)
FOOD				
509	533	Widespread global implementation of electro-technology	30-40% of smaller process units (e.g., driers, ovens) convert to electro-technology	68 - 91
		Technical advances in gasification due to testbed facilities and other demonstration lead to industry adaptation and implementation. Increased exploration of 3rd party operators to provide over-the-fence syngas leads greater industrial participation in the IGCC concept.	15-20% of small boilers (under 30 MW) convert to gasification or biomass combustion	39 - 53
PAPER				
461	483	Demonstrations of the fuel switching options (testing of economic and technical viability) results in increased industry implementation	50-60% of boilers switching from natural gas consumption to biomass combustion	80 - 95
		Technical advances in gasification due to testbed facilities and other demonstration lead to industry adaptation and implementation	30-40% of large CHP units switch from natural gas to biomass gasification	54 - 72
		Widespread global implementation of electro-technology	30-40% of process heating units (e.g., kilns) switch from gas to biomass or electro-technologies	43 - 58
CHEMICALS				
1,606	1,682	Boilers continue to age increasing the opportunity for modification/replacement	20-25% of boilers replaced/refurbished because of age, adapted for non-natural gas usage	100 - 125
		Technical advances in gasification due to testbed facilities and other demonstration lead to industry adaptation and implementation	20-25% of CHP units switch from natural gas to biomass or coal gasification	106 - 132
PETROLEUM REFINING				
Natural Gas		Displacement Rationale	Specific Results	Quantity of

Consumed Annually (TBtu) 2012	2020			*Natural Gas Displaced (TBtu/yr)*
814	852	Boilers continue to age increasing the opportunity for modification/replacement	20-25% of boilers replaced/refurbished because of age, adapted for non-natural gas usage	32 - 40
		Increased utilization of petcoke resource and regulatory compliance costs are as well as other regulatory issues are resolved	25-50% of the estimated 8.4 million tons of increased annual petcoke capacity used for fuel	59 - 118
PRIMARY METALS				
Natural Gas Consumed Annually (TBtu)		*Displacement Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2012	*2020*			
637	667	Widespread global implementation of electro-technology, Evaluations of the impact of low and medium Btu syngas on product quality and flame temperature leading to advancements in industrial processes sensitive to flame properties, such as metal crafting or glassmaking	15-20% of process heating (e.g., furnaces) converted to electro-technologies or coal gasification	88 - 118
OTHER MANUFACTURING				
Natural Gas Consumed Annually (TBtu)		*Displacement Rationale*	*Specific Results*	*Quantity of Natural Gas Displaced (TBtu/yr)*
2012	*2020*			
1,172	1,228	Emissions/pollutant control devices are optimized and regulatory barriers are address making direct combustion of biomass or coal gasification a more viable option	10-15% of boilers switching from natural gas consumption to the direct combustion of biomass or coal gasification	32 - 49
		Widespread global implementation of electro-technology	5-10% of small scale process heating converted to electro-technology	44 - 88
TOTAL				
Natural Gas Consumed Annually (TBtu)				*Quantity of Natural Gas Displaced (TBtu/yr)*
2020				
5,445				745 – 1,039

For 2020, the estimated potential displacement ranges from 745 to 1,039 TBtu/yr. This would correspond to 14% to 19% of the projected amount of natural gas consumption (absent a fuel flexibility program) of 5,445 TBtu/yr. It is important to note that this estimate is more speculative because changes in the profile of industrial process operations are unknown. Also, this estimate depends heavily on the success of an aggressive fuel flexibility program under DOE's leadership. As with the short-term estimate, to put this in context of avoided LNG imports, this quantity of natural gas displacement would be equivalent to 2½ to 3½ mid-sized LNG import terminals (again, assuming., 0.8 to 1.0 billion cubic feet/day, or BCFD, at 70-85% operating capacity—similar in scope to the Cove Point, Maryland, import facility) or 1 to 2 of the larger LNG terminals currently under construction in the U.S.

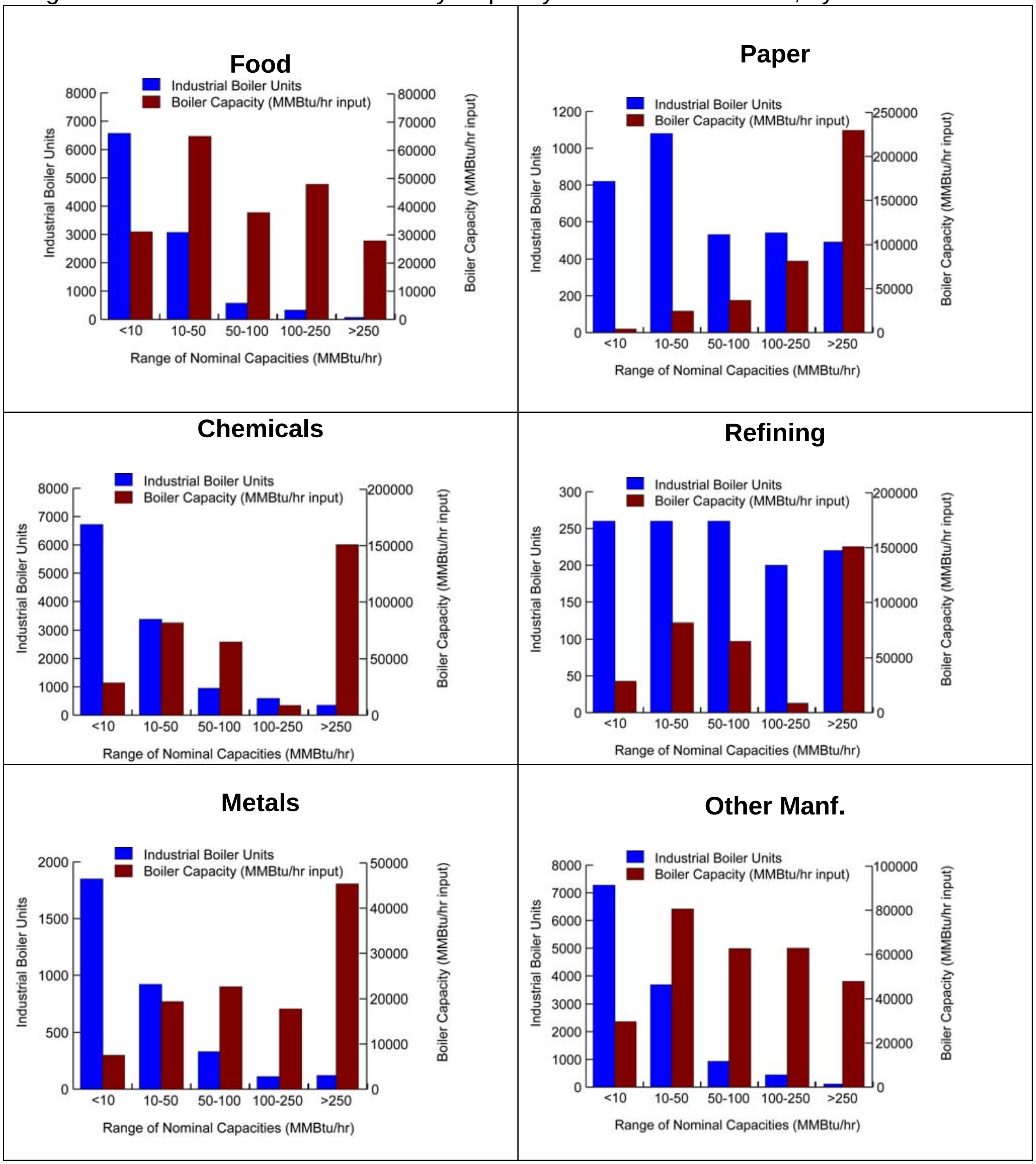
APPENDIX A: DESCRIPTION OF INDUSTRIAL PROCESS EQUIPMENT SUITABLE FOR FUEL FLEXIBILITY

A.1. Boilers

Boiler Size and Capacity Distribution

Industrial boilers are a critical component of industrial operations and are used throughout the manufacturing sector to generate steam and hot water. There are approximately 43,000 industrial boilers in the U.S. with an aggregate capacity of 1.5 million Btu/hr (MMBtu/hr) (*see Figure A-1*). More than half of these boilers are less than 10 MMBtu/hr capacity, however these small boilers account for less than seven percent of the total capacity. The majority (71%) and the largest boilers (82%) are found within energy intensive industries such as food, paper, chemicals, refining, and metals. Therefore, when considering the scale of opportunities for fuel substitution, the decision should be made by industry, based on boiler capacity, not necessarily the number of units.

Figure A-1: Industrial Boiler Inventory Capacity and Number of Units, by Sector

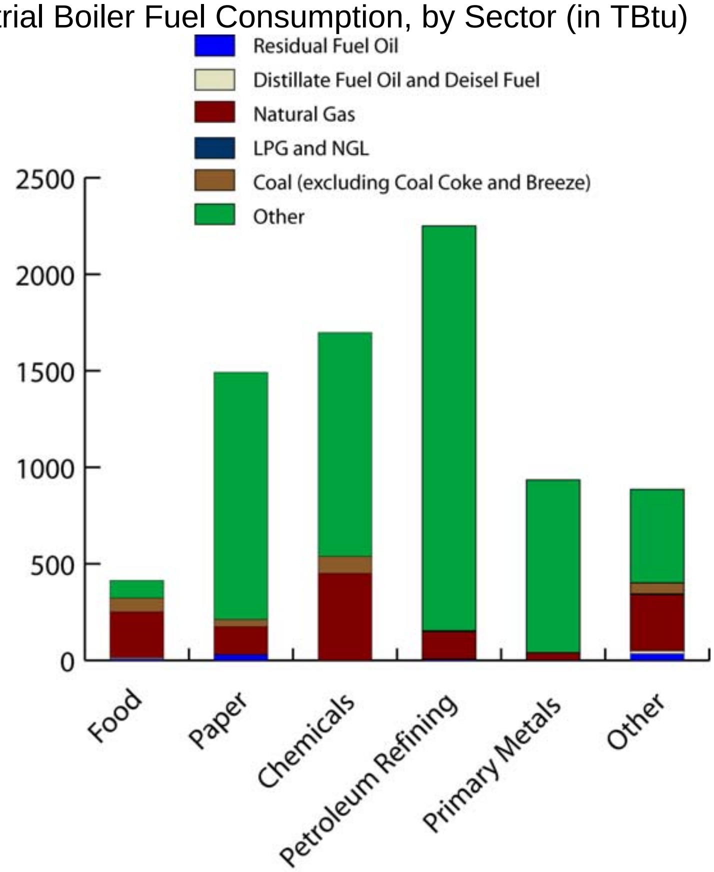


Source: Energy and Environmental Analysis, Inc., *Characterization of the U.S. Industrial Commercial Boiler Population*, May 2005.

Note: The scale of the boiler capacity differs among industrial sectors.

Fuel Consumption
As reported by the Environmental Information Administration *Manufacturing Energy Consumption Survey* (MECS), industrial boilers consume 1,670 TBtu (12% of all energy at industrial facilities including renewable energy sources) excluding electricity[11]. Almost 78 percent of the industrial boiler units (excluding renewable fuel-fired boilers) are identified as natural gas-fired consuming 1,306 TBtu annually, resulting in natural gas remaining the highest purchased energy source for boilers. Alternatively, certain industries—refining, paper, and primary metals—have large portions of boiler capacity that are fired with by-product fuel (e.g., wood, by-product gases) which fall under the "other" fuel source category. Coal and residual fuel are also energy sources that are often utilized to fuel industrial processes. Figure A-2 is an industry specific summary of industrial boiler fuel consumption of various fuel sources (excluding net electricity):

Figure A-2: Industrial Boiler Fuel Consumption, by Sector (in TBtu)



Source: Energy Information Administration *Manufacturing Energy Consumption Survey*. Table 5.2: End Uses of Fuel Consumption, 2002.
Note: Other fuels includes net steam (the sum of purchases, generation from renewables, and net transfers), and other energy that respondents indicated as used to produce heat and power. It also includes unspecified end use consumption.

As shown in Figure A-2, the potential for fuel flexibility in industrial operations is promising, as the largest boiler fuel input is by-product or other fuels at a total of 6,006

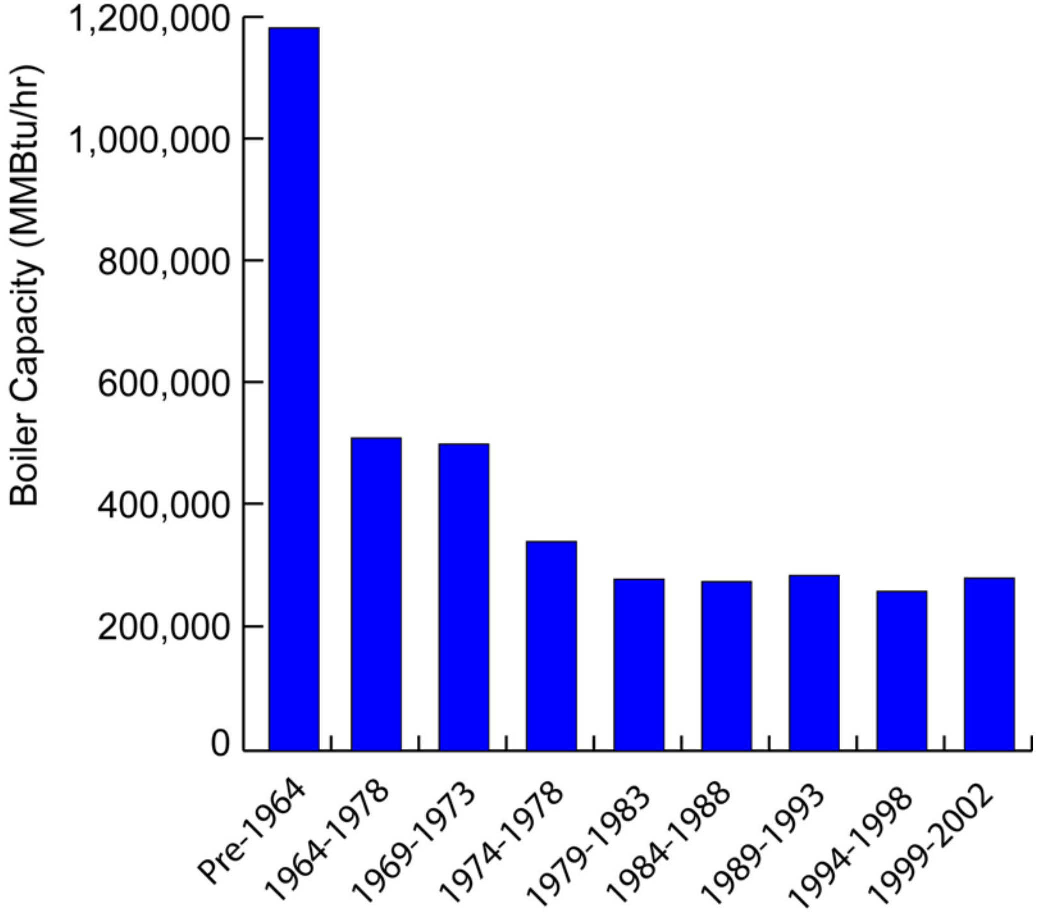
[11] Energy Information Administration, *Manufacturing Energy Consumption Survey - Table 5.2: End Uses of Fuel Consumption*, 2002.

TBtu/yr. This is due to industry incentives to recycle by-products on-site as process fuel, utilizing an abundant and convenient resource. The paper industry, for example, has already begun to take great strides by consuming more by-products (e.g., black liquor) for fuel than natural gas. Chemicals is the largest single consumer of natural gas, mostly consumed during organic chemical manufacturing.

Age Distribution

The general trend in boiler inventory distribution shows that sales of large boilers have moderated over the past 30 years. A majority of the boilers currently in industry are now quite mature and have either been retired, replaced, or refurbished to extend their operational life. The average life expectancy of the boilers is approximately 25-30 years depending on operating conditions (It is unclear to what extent refurbishment extends this figure). Therefore, there is not only an opportunity for boiler modification, there is a potential market for boiler refurbishment or replacement with solid, gas fired, or tri-fuel burner technologies. The sales data for units larger than 10 MMBtu/hr suggests that 47 percent of boiler capacity is at least 40 years old and 76 percent is at least 30 years old (*see Figure A-3*).

Figure A-3: Age Distribution of Boilers Greater than 10 MMBtu/hr



Source: Energy and Environmental Analysis, Inc., *Characterization of the U.S. Industrial Commercial Boiler Population*, May 2005.

Industrial boilers are readily adapted for fuel supply alternatives

There are a number of potential alternatives for substituting natural gas applicable to the industrial boilers and process pathways:

Coal

Coal has many important uses worldwide including electricity generation, steel production, cement manufacturing and other industrial processes, and as a liquid fuel. Primary uses of coal include large boilers and cogeneration facilities. Coal is often directly fired in the form of pulverized coal using a fluidized bed or stoker boiler. However, due to its high emissions and difficulty of use regarding material handling, few new coal-fired boilers or cement kilns have been built. Alternatively, interest in coal gasification has increased in popularity due to its lower emissions output.

Biomass

In 2003, biomass contributed nearly 2.9 quads to the nations energy supply (nearly 3%), making biomass the single largest renewable resource in the U.S., recently surpassing hydropower [12]. Biomass is used for power generation and large combined heat and power units. The biomass resource base considered as feedstock for natural gas replacement is comprised of both forest resources (including forest products industry processing residues, and timberland and other forest land fuel treatment thinnings) and agricultural resources (major crop residues including corn stover and grain straw, corn and soy grain by-products, and perennial grasses and woody crops). These resources are not as energy dense as conventional fossil resources, however, that they are renewable resources with no "net" carbon emissions make them compelling natural gas alternatives. Biomass is often directly fired in a pulverized or fluidized bed boiler. Direct combustion techniques for biomass results in the production of steam, which in turn is used to drive a turbine to generate electricity, or as process heat. Biomass can also be gasified, resulting in a combustible gas, composed of nitrogen, carbon monoxide and hydrogen , that can be used as a natural gas substitute.

Petroleum Coke

Petroleum coke (petcoke) is a by-product of the petroleum refining process. It is formed when heavy residual oils co-produced with gasoline and other high-value energy products are heated to high temperatures in special coking drums. Petroleum coke can take several forms, which are then sold for use as raw materials for industrial products or energy. Delayed petcoke, the form most commonly used for heat (and thus of greatest applicability to industrial processes), is typically composed of 75-80 percent carbon, 3 – 3.6 percent hydrogen, 3.4 – 5.3 percent sulfur, and 5.5 – 15 percent moisture content[13]. Petcoke is low in volatile matter, resulting in the potential for ignition problems, and has a low ash content, which results in lower handling cost. Petcoke has a high energy content and can substitute for natural gas through two primary pathways: gasification and direct firing.

Municipal Solid Waste

The municipal solid waste (MSW) resource base considered as feedstock for natural gas replacement is composed mainly of household waste and does not include industrial, hazardous, or construction and demolition waste. The energy content of MSW is highly unpredictable, varying by region and time of year. The energy content of a representative composition (containing an evenly distributed mixture of rubbish and garbage, 50 percent moisture content, and 7 percent non-combustible solids by weight – including plastics) is approximately 5,000 Btu/lb on a higher heating value basis[14].

[12] DOE- ORNL, DOE/GO-102995-2135: *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005.

[13] Narula, Ram, *Challenges and Economics of Using Petroleum Coke for Power Generation*, World Energy Council, (accessed January 2007); available from http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/1_2_26.asp .

[14] Georgia Department of Natural Resources, Environmental Protection Division, Air Protection Branch, *Waste Classification Guide* (accessed January 2007); available at www.georgiaair.org/airpermit/.

Both incineration and gasification are acceptable methods of MSW disposal, due to a significant reduction in material volume (about 85%) as well as elimination of groundwater contamination and methane generation concerns.

In addition to its physical properties, MSW has a bi-directional supply chain that is unusual among traditional fuels. Traditional fuel supply chains are built only upon a supplier providing the customer with a fuel. The unusual aspect of MSW is that the MSW fuel supplier is also, in effect, a customer, as the holder of the MSW (generally a municipal government) is essentially relying on the industrial user for waste disposal services. While the interaction seems appealing in concept, in practice it means that use of MSW by industry must recognize that municipalities and other waste owners have a vested need to dispose of their waste in a proper, appropriate, and continuous way. This confers upon industry an obligation not associated with other fuels.

Black- Liquor

Black liquor represents the fifth largest source of energy in the country and is formed during the paper making process when wood pulp is separated into cellulose – the main constituent of paper – and lignin. Black-liquor is the mixture of lignin with water and chemicals from the separation process. Its energy content is roughly half that of the original wood pulp, representing a substantial fuel opportunity[15]. Black-liquor is burned in a recovery boiler which produces steam and electricity and recovers the inorganic chemicals for recycling throughout the process. From 1972 to 1994, the pulp and paper industry dramatically increased its energy self-sufficiency from 36% to 57%[16], in large part by making use of black liquor. Although this provides most of the electricity for the mill and allows for recovery of the original pulping chemicals through the application of heat and lime, it is not an optimal process. Gasification of the black liquor, however, could substantially improve the efficiency of the process by optimizing process electricity and steam generation.

Industrial boilers can utilize different fuel conversion technologies

Given the various fuel supply options for alternative fuel for the boiler, the next step in the value chain to consider is conversion technology. While all of the fuel supply options listed are available, directly combusting these fuels is not always feasible. Additionally, converting from natural gas to solid fuel burning boilers would require mandatory boiler replacement regardless of condition or age of the boiler.

Direct Combustion

[15] Larson, Eric D., Stefano Consoni, and Ryan Katofsky. *A Cost-Benefit Assessment of Biomass Gasification Power Generation in the Pulp and Paper Industry*, October 8, 2003.

[16] American Forest & Paper Association, *AGENDA 2020: A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry*, November 1994.

Direct combustion is commonly used to convert biomass into useful energy. It involves the oxidation of biomass with excess air, producing hot flue gases used to generate hot air, hot water, steam or electricity. Direct combustion of biomass is most conveniently applicable to the forest products industry. Materials often used for energy purposes include: wood, agricultural residues, wood pulping liquor, municipal solid waste (MSW) and refuse-derived fuel.

Biomass has a lower energy content than coal, however its use for energy production can significantly contribute to the decline of net CO_2 emissions[17]. Also, atmospheric emissions of wood systems are lower in sulfur dioxide than those of coal systems, but emissions of particulate matter are potentially higher. Therefore, scrubbers and other air pollution control technologies are necessary to reduce these emissions to levels produced by coal systems.

Gasification

Gaseous fuel can be manufactured from coal, biomass, petroleum coke, or any other carbonaceous substance. Gasification is the partial oxidation of a solid or liquid feedstock to manufacture a gaseous product (synthesis gas or "syngas") made predominately of hydrogen and carbon monoxide. Impurities (sulfur, nitrogen, mercury, etc.) are removed from the syngas to produce a fuel which is used similarly to natural gas but has a lower heating value.

For example, coal can be gasified in either dry or slurried form, where it reacts with oxygen and steam under pressure to yield syngas. This gas can be combusted directly, or converted via catalytic processes to synthetic natural gas, liquid fuels, and other chemical products useful in industry. The by-product of the process is slag, a vitrified compound of inorganic substances including metals and ash, thus limiting emission of these substances into the air. Likewise, sulfur and carbon dioxide can be recovered and potentially marketed, minimizing plant emissions and possibly providing additional revenue.

While coal is used in several commercial gasification processes, biomass is more reactive and gasified at lower temperatures and pressures than coal. Also, biomass is often gasified with an air stream input rather than an oxygen stream input; this is a significantly cheaper process. However, unlike mined coal, biomass resources are dispersed and heterogeneous in nature. Biomass' elemental composition, energy content and conversion to useful energy forms and products varies. Therefore, special handling and feeding systems must adapted to accommodate heterogeneous, lower bulk density forms of biomass and should be considered when considering fuel switching[18].

[17] Overend, Ralph P., Stanford University: Global Climate and Energy Project (GCEP), *Thermochemical Biomass Gasification Technologies and Products*, April, 27, 2004.
[18] Babu, Suresh, PhD, *Observations on the Current Status of Biomass Gasification*, May 2, 2005.

Coal/Biomass-to-liquids

Syngas can be directly combusted in conventional natural gas boilers. The gas can also be converted through the Fischer-Tropsch or similar method to ultra-clean liquid hydrocarbons and upgraded to synthetic fuels (e.g., alcohols, diesel, and gasoline), or other shift reactions to chemicals, fertilizers, and hydrogen for fuel cells. Of special interest is the diesel fuel fraction because it requires little processing from the Fischer-Tropsch oil and it has desirable characteristics including low sulfur and aromatic content.

Existing gas and oil boilers may be switched to coal-based liquids without significant modification. Converting an existing gas-fired industrial boiler to coal liquids is not significantly different from converting a gas-fired unit to residual fuel oil. The Fischer-Tropsch fuel alternative is favorable due factors including environmental issues and resulting interest in clean-burning liquid fuels, a desire for fuels derived from secure, domestic feedstock, interest in exploiting stranded or associated gas resources and heavy oil residues[19].

Fuel Supply Availability

The U.S. alone produced 1,028 million tonnes of coal in 2005 and has 247 billion tonnes of coal reserves. In fact, if the United States were to continue at its current rate of production, it would have 245 years of coal supply remaining[20]. Most coal is used domestically suggesting that domestic coal supply will play an important role in the US energy security[21].

In general, bituminous coal with a low sulfur content is the best option for gasification use. It has a high heating value and therefore provides more energy. In the U.S., coal is primarily found in four regions; Appalachia, Powder River, the Illinois Basin, and Colorado. The composition of the coal available in the U.S. varies significantly by region[22]. Coal from the Appalachian basin, for example, has a fairly high energy content and high sulfur content. For a single stage entrained flow gasifier, high sulfur bituminous coal may offer the best coal value for gasification, which takes advantage of high energy content by utilizing syngas cleaning technologies to remove undesired sulfur.

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[19] Mark S. Bohn and Charles B. Beham, *A Comparative Study of Alternative Flowsheets Using Orimulsion™ as Feedstock*, October 1999.

[20] *BP Statistical Review of World Energy*, June 2005 (accessed January 2007); available from: http://www.bp.com/sectiongenericarticle.do?categoryId=9010933&contentId=7021561 .

[21] The World Coal Institute, *The Coal Resource – A Comprehensive Overview of Coal* (accessed January 2007); available from: http://www.worldcoal.org/pages/content/index.asp?PageID=37 .

[22] Bloomberg- financial data provider.

Unless biomass resources are readily available near industry, transportation costs of raw biomass become prohibitive at distances in excess of 50 miles. The biomass resource base currently contains the following energy availability:

- Forest resources[23]
    - Forest products industry processing residue – 152 Trillion Btu
    - Timberland fuel treatment thinnings resource – 774 Trillion Btu
    - Other forest land fuel treatment thinnings resource – 174 Trillion Btu
- Agricultural resources
    - Agricultural residues – 2,824 trillion Btu

Petcoke is a significant opportunity fuel for industry, particularly the refining sector, because it is inexpensive and increasingly abundant. In 2005, refinery net production of petcoke reached approximately 305 million barrels/yr[24]. It has been estimated that there will be a 4 million ton annual increase in coker capacity in the U.S. over the next three years[25].

The MSW resource base contains 1,350 TBtu of energy in annual land filled material. For every 1 million tons of MSW, 432,000 scf/day of landfill gas (LFG) are produced. There are currently 600 candidate landfills in the U.S. with a total LFG generation potential of 725 million scf/day (about 15,000 MMBtu/hour)[26]. The available MSW resource base is a viable feedstock option for natural gas replacement. The large size of the resource base is appealing, and the collection, transportation, storage, and processing infrastructure is well established. Additionally, as land filling of MSW becomes more costly and available landfill volumes continue to decline, the economics of alternative disposal methods will change. As opposed to paying for biomass, there is actually a tipping fee for MSW. This means that for every ton of MSW that is received for incineration or gasification, the facility is paid on a per ton basis for receiving the material. As an example, average tipping fees for Florida range from $40-$60 per ton, depending on location[27].

A.2. Combined Heat and Power

Combined heat and power (CHP) is the sequential production of electricity and heat, generally performed at the site of the customer load. For users with significant heat and electrical loads CHP units offer major efficiency benefits. In contrast to traditional

[23] DOE- ORNL, DOE/GO-102995-2135: *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005.
[24] Energy Information Administration, *Petroleum Navigator – Refinery Net Production*, 2005.
[25] Booz Allen, *The Industrial Fuel Flexibility Workshop: Initial Stakeholder Feedback*, October 2006.
[26] USEPA, Landfill Methane Outreach Program (LMOP), *An Overview of Landfill Gas Energy in the U.S.*, April 2006.
[27] Solid Waste Management in Florida, *Solid Waste Management 1999 Annual Report*, Chapter 4: Landfill Disposal, August 1999.

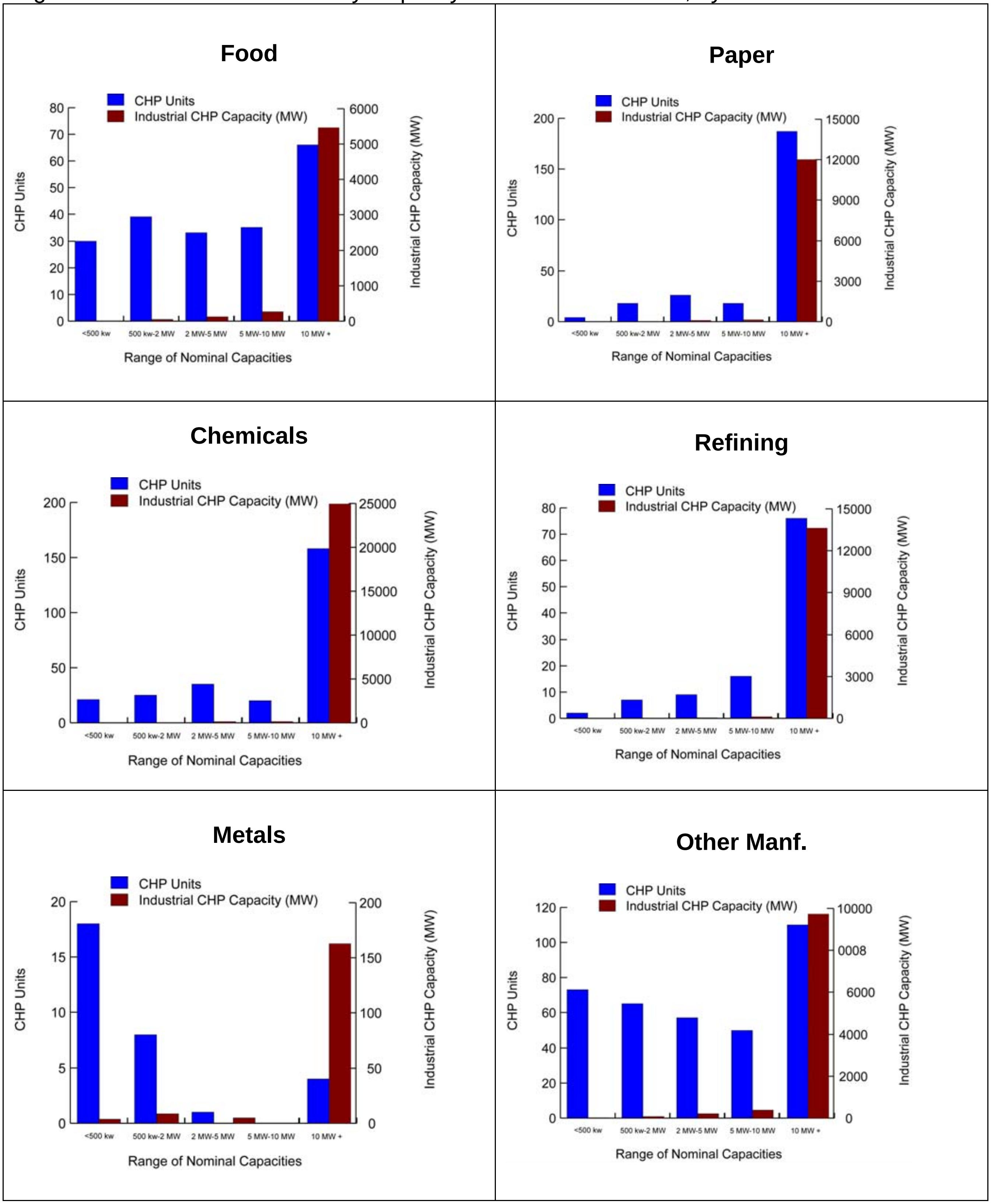
boilers and furnaces, which produce heat only, electricity produced by CHP units can substantially decrease reliance on electricity from the electric utility, conferring to the CHP investor potential electric bill savings. At the same time, CHP greatly enhances the productivity of energy by recapturing heat normally lost during the production electric generation central-station facilities.

CHP systems represent a significant long-term fuel flexibility option because they can be, and are, run with multiple fuel sources. CHP would appear to be a good match for fuel flexibility programs. One difficulty in terms of fuel flexibility is that CHP technology is in many ways quite mature and it is already the subject of substantial private investment and marketing. Nonetheless, many of the highest-value projects are natural-gas driven, and fuel flexibility resources may be usefully leveraged by linking CHP to gasification systems.

Size and Capacity Distribution

Combined Heat and Power units constitute the third-largest natural gas consuming industrial manufacturing process, using roughly 12 percent of all natural gas consumed by industry. CHP capacity is heavily centralized in the chemical sector, which runs close to 40 percent of all current installed CHP capacity. The pulp & paper and refining industries are also major users, while penetration of CHP among fabricated metal manufacturers is comparatively small (see Figure A-4).

Figure A-4: CHP Boiler Inventory Capacity and Number of Units, by Sector



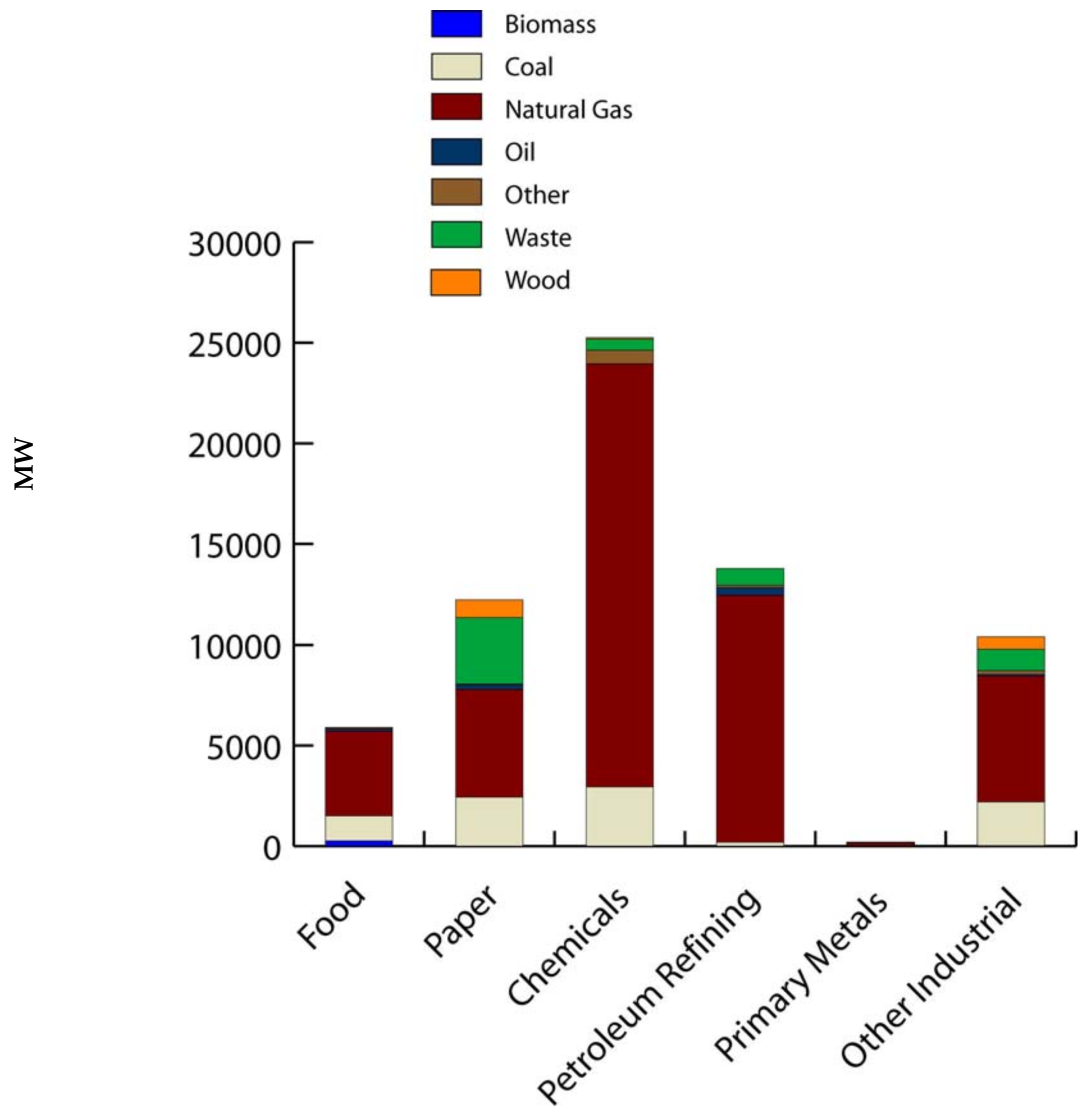
Source: EEA Combined Heat and Power Installation Database.

The refining and chemicals sectors have the largest amount CHP by capacity in part because almost all of their capacity is concentrated in large systems; the average unit size in these sectors is well over 100 MW. By comparison average size in the paper industry is roughly half that number. Among all other industries, the vast majority of units are less than 10 MW.

Natural gas is currently the preferred fuel for CHP units, as it powers 3 out of every 4 MW of CHP. A significant portion of coal CHP have been added, including in the post-Clean Air Act/Public Utilities Regulatory Policy Act era, however, these additions have not kept pace with overall CHP capacity growth, and coal-fired units account for only some 12 percent of CHP capacity, down from nearly 25 percent in 1984. Oil, usually burned in the form of distillate products and diesel, comprises a modest share of the nation's CHP inventory.

CHP units have been adapted to a number of alternative fuels, and this has increased over the past two decades (see Figure A-5). For many of these alternatives, CHP represents a productive way of eliminating waste streams more than it represents a fuel *per se*. The food industry, led by sugar manufacturing, has become a leader in the use of biomass CHP, a category which includes bagasse, digester gas from waste-water treatment facilities and farms, and landfill gas. This is the case also with industrial by-products such as petroleum coke and black liquor.

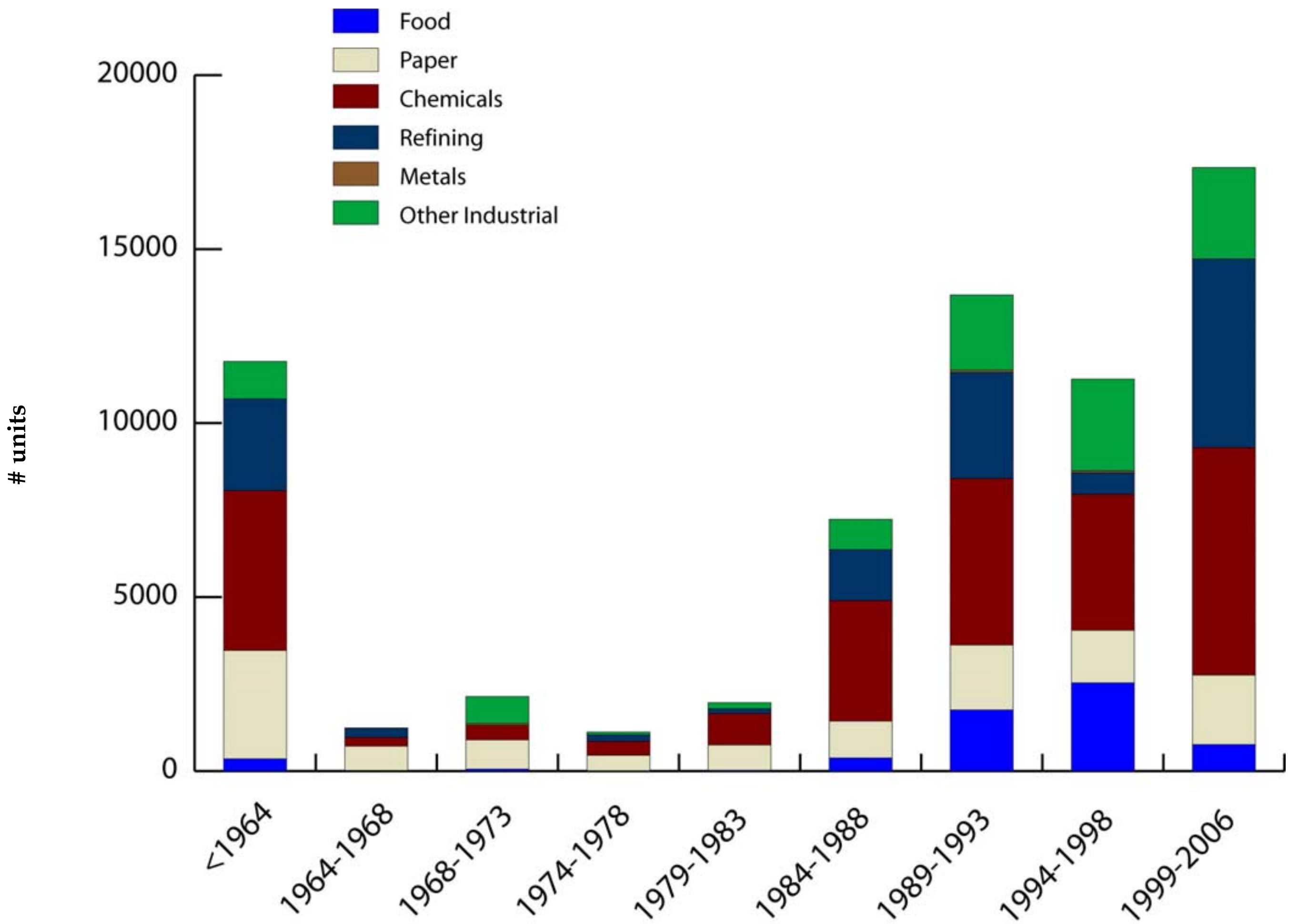
Figure A-5: CHP Capacity by Fuel and Industry



Source: EEA CHP Installation Database

The age distribution of installed CHP unit is "book-ended" with a substantial pre-1964 component, followed by a lull in activity, then continued investment corresponding to the enactment of PURPA and deregulation of gas prices that began in earnest in the early 1980s (*Figure A-6*). As with boilers, a significant portion of the US CHP inventory is at least 40 years old; 16 CHP units date to 1900 and a full 2 GW of capacity pre-date World War II. In contrast, to boilers, however, CHP development in industry began a renaissance in the early 1980s, most probably as a result of PURPA, which enabled user to sell excess electricity back to the electric utilities. Natural gas-fired CHP entered into a sustained phase of relatively intensive development, which tapered off precipitously in 2001 as a result of increases in natural gas prices which greatly reduced spark spreads.

Figure A-6: CHP Capacity by Age and Sector



Source: EEA CHP Installation Database

Existing options in CHP Fuel Supply Provide for additional fuel flexibility options

The range of fuel supply conversion technologies available for use in CHP applications is quite wide. Technologies based on fuel combustion (as opposed to chemical reactions) form the vast majority of CHP units in the U.S. and virtually all the units in service in industry. A variety of prime movers convert fuel energy into heat and mechanical energy useful for generating electricity:

- **Turbines** generate heat and power through one of two distinct processes. A *steam* turbine generates electricity by burning fuel in a boiler or heat recovery steam generator (HRSG) to raise steam and apply the resulting steam to turn the turbines. This is the same process used to generate most of the electricity used in the U.S., and virtually any combustible fuel can be used. In contrast to standard electricity generators, however, CHP units recapture the "waste" steam for use as process heat or, through the use of absorption chillers, cooling.

  A *combustion* turbine, by contrast, burns a liquid or gaseous fuel directly in a combustion chamber, creating compressed gasses that, when channeled at high pressure through turbine blades, create the mechanical motion necessary to generate electricity. In combined cycle units, the heat resulting from combustion can be recaptured to make steam for production of additional electricity. In cogeneration units, the steam can be used for process heat, hot water, or raising steam, as well as to power absorption chillers for cooling. In addition to achieving high efficiencies, emissions from turbines can be reduced to very low levels and maintenance costs per unit of output are low. Practical sizes range from a few kilowatts to hundreds of megawatts.

  Micro turbines provide power at scales much smaller than combustion turbines – generally in the range of tens to hundreds of kilowatts. Their smaller size presents efficiency challenges which result in these systems' lower level of technical maturity. However, electrical efficiencies of 23-26 percent have been achieved, and the potential for low NOx emissions, design simplicity, and reduced maintenance gives this technology great potential in smaller applications.[28]

- **Reciprocating engines** are internal combustion engines in which a piston is used to compress an air-fuel mixture, which is then ignited with spark plug or high compression, driving the piston and turning a shaft which generates electricity. Natural gas, distillate fuels, and heavy oil are useful in reciprocating engines. In larger systems the waste heat is sufficient to raise low-pressure steam, while smaller ones produce hot water. The primary advantage of reciprocating engines is that up-front costs are relatively low. However, the emissions profiles are not as good as those of turbines, the engines are noisier, and require regular maintenance in order to maintain reliability.

- **Fuel cells** generate electricity electrochemically when a hydrogen atom is passed through an anode, where a catalyst splits the atom into a proton and an electron. Concurrently, oxygen from the air enters at the cathode. The electron from the anode passes through an electrolyte, creating the electric current, before the

[28] NREL, Gas-Fired Distributed Energy Resource Technology Characterizations, 1-7.

hydrogen, oxygen, and electron recombine with oxygen from the cathode to produces a molecule of water and exit the system. The hydrogen may come from a variety of sources, but early applications extract the fuel from fossil fuel feedstock, including natural gas.

Proton Exchange Membranes (PEM) are the most energy dense fuel cells; they have quick start and stop capability, and have outputs up to 75 kw. These characteristics make their greatest potential value in transportation applications, though the modest heat they produce (~80°C) make them useful in small commercial and residential applications. By the same token, these qualities make them less suited to industrial applications whose the heat and power needs can be more effectively met using other fuel cells.[29]

Solid oxide fuel cells use a solid ceramic electrolyte and operate at temperatures up to 1,000°C. The high heat they produce makes them amenable to on-site feedstock reformation, eliminating the need for an external reformer and boosting overall efficiency. Efficiency can be further raised by hybridizing the system with a turbine to burn residual feedstocks.[30] Their relatively large size and significant heat output makes them amenable to medium- and large-scale industrial facilities with large process heat or steam requirements.

Molten Carbonate fuel cells use a molten alkali carbonate electrolyte, but perform in many respects similarly to solid oxide fuel cells. They operate at a lower temperature, around 600°C, but this is still high enough for on-board reformation and are also expected to be useful in medium and large industrial facilities.[31] Cells have been tested using a variety of fuels, including hydrogen, carbon monoxide, natural gas, propane, landfill gas, marine diesel, and simulated coal gasification products in the 10 kW to 2 MW range.[32]

A.3. Process heat equipment

Types and Distribution

Process heating is another prime target for fuel flexibility. There are an estimated 200,000 process heaters used domestically in energy intensive manufacturing processes across the U.S.[33] Process heating is used across many energy intensive industries for a wide range of applications to heat materials under controlled conditions. Equipment

[29] UNDP World Energy Assessment (2000), 287
[30] National Academies of Science, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs (2004)*, 33
[31] From UNDP World Energy Assessment (2000), 287
[32] Fuel Cells 2000, Fuel Cell Basics – Types. Viewed online at http://www.fuelcells.org/basics/types.html on 1/10/2007.
[33] BNP Media, *Furnace Demographic Survey*, April 2005.

includes ovens, heating furnaces, process fluid heaters, dryers, heat treating furnaces, reactors, kilns and melters (*see Figures A-7a and b*).

Figure A-7a: Estimated Number of Process Heaters by Primary Industry

	Dryer	Heating Furnace	Heat Treating Furnace	Kiln	Melter	Oven	Process Fluid Heater	Other	Total
Iron & Steel	--	112	72	--	--	--	--	--	**184**
Aluminum	4	--	12	--	28	4	8	36	**92**
Petroleum Refining	28	16	--	--	--	--	--	--	**44**
Chemical	7,040	1,144	--	44	528	528	18,656	484	**28,424**
Cement	--	16	--	--	--	2	2	--	**20**
Food Processing	1,408	1,376	320	96	--	2,432	1,216	1,504	**8,352**
Glass	176	224	224	192	608	880	38	192	**2,534**
Heat Treating	648	1,728	5,184	72	24	1,224	72	120	**9,072**
Metal Casting	264	1,272	936	193	1,080	1,152	360	120	**5,377**
Powder Metal	264	456	744	48	--	312	--	--	**1,824**
Forging	--	576	360	12	12	12	--	--	**972**
Mining	1,776	1,392	24	960	--	96	192	24	**4,462**
Electronics	3,852	3,708	2.952	2,412	648	6,228	540	144	**20,484**
Other Materials Production Process	3,560	1,720	1,360	3,920	80	3,320	1,000	1,240	**16,200**
Other Mfg.	14,688	27,064	16,864	2,040	9,656	26,928	13,872	11,152	**122,264**
Grand Total	**33,708**	**40,804**	**29,052**	**9,989**	**12,664**	**43,118**	**35,956**	**15,016**	**220,307**

BNP Media, *Furnace Demographic Survey*, April 2005.

Figure A-7b: Typical Applications for Process Heaters

Process Heater	Typical Applications	Typical Materials Produced	Applicable Industries
Dryers	Product drying, crystallizing, cleaning, coating	Metal parts, food, beverages, ceramics, clay, paper, air, coatings	Metals, Food & Beverage, Ceramics, chemical, pulp and paper
Kilns	Calcining, sintering	Ceramics, limestone, iron ore	Chemicals, mining, metal glass, ceramics
Heating Furnace	Preheating, electrical process heating, part warming, pasteurizing	Aluminum, steel, other metals, ceramic, graphite, ceramics, mineral products	Mining, metals, food processing, chemicals
Heat Treating Furnace	Annealing, carburizing, hardening, austenitizing, stress relieving	Steel, iron, copper, brass, other metals and alloys, glass ceramics	Heat treating, metals, glass, ceramics
Melters	Melting, re-melting, reducing	Aluminum, glass, other metals, minerals	Metals, glass chemicals

Source: Jain, Ramesh, Industrial Technologies Program, *Identifying Opportunities and Impacts of Fuel Switching in the Industrial Sector*, June 2006.

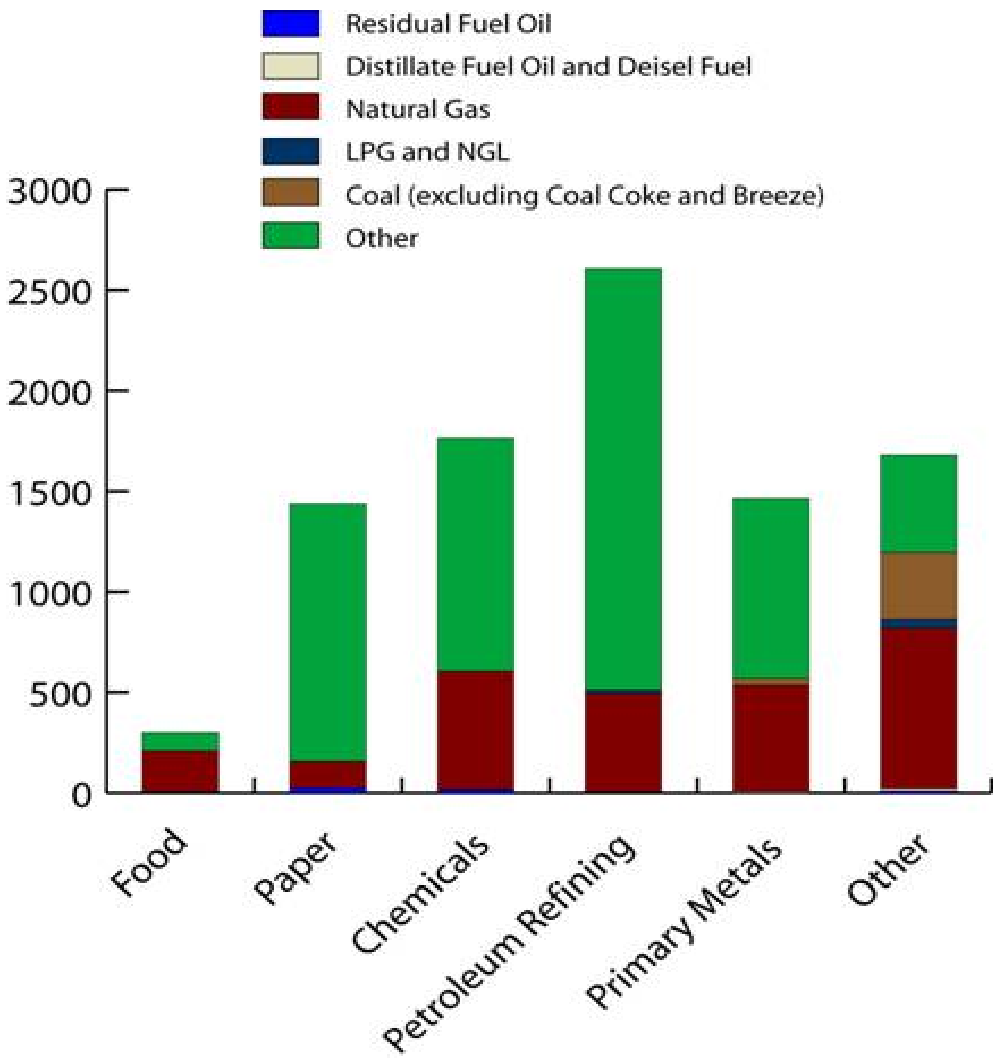
Besides "other manufacturing," the largest number of furnaces (heat and heat treating) are found in the heat treating, electronics, metal casting and mining industries as shown in Figure A-7a. Additionally, manufacturing industries, including chemical and petroleum refining industries, use process heating equipment such as dryers and reactors while the food industry utilizes ovens and kilns. This breakdown of industry applications set the stage for various natural gas substitution opportunities discussed in this section of the report.

Fuel Consumption

Industry consumes 3,597 TBtu/yr of fuel and more than three quarters of consumption is attributed to natural gas fuel as shown in Figure A-8[34]. For example, the iron and steel industry's energy input is consumed by heating and heat treating furnaces while the forest products industry utilizes its heaters and dryers for its manufacturing process. The cement industry uses a majority of its energy for fired heaters while the food and beverage industry uses its energy to fuel ovens, dryers, heating furnaces and fluid heaters.

[34] Energy Information Administration, *Manufacturing Energy Consumption Survey - Table 5.2: End Uses of Fuel Consumption*, 2002.

Figure A-8: Fuel Consumption By Fuel Type For Direct Fired Process Heaters in the U.S. Manufacturing Sector (All Industries, in TBtu/yr)

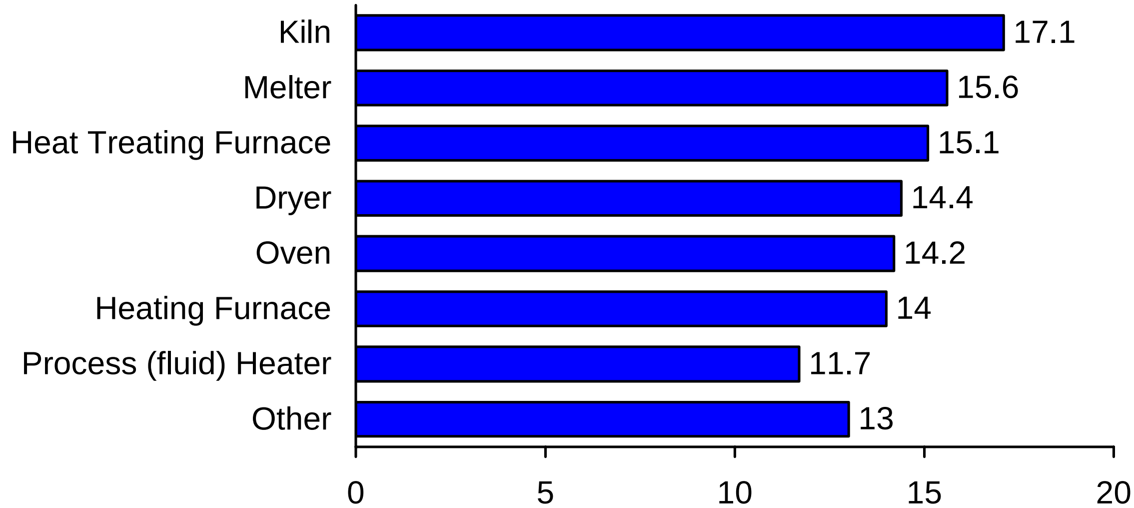


Energy Information Administration, *Manufacturing Energy Consumption Survey - Table 5.2: End Uses of Fuel Consumption*, 2002.

Age Distribution

As a process heater ages the cost of maintaining the unit increases and the unit runs less efficiently. Refurbishment or replacement provides an economically sound alternative. Sometimes it makes sense to repair or refurbish. New parts can replace older parts and increase the peak capacity of the unit extending its life expectancy. However, it may be time for process heater replacement after numerous refurbishments, or after the plant incurs high maintenance costs dependent on the equipment's age and condition. Average ages of various industrial process heaters are shown in Figure A-9.

Figure A-9: While not as old as boilers, the average age of process heating equipment is also high (in Years)



BNP Media, *Furnace Demographic Survey*, April 2005.

Fuel supply alternatives for process heating units are similar to industrial boilers

In a process heating system, heat is generated by the combustion of solid, liquid or gaseous fuels, and transferred either directly or indirectly to the material. Similar natural gas substitution options are available for process heat equipment as for boilers. As discussed in the sections above, applicable fuel supply alternatives include:

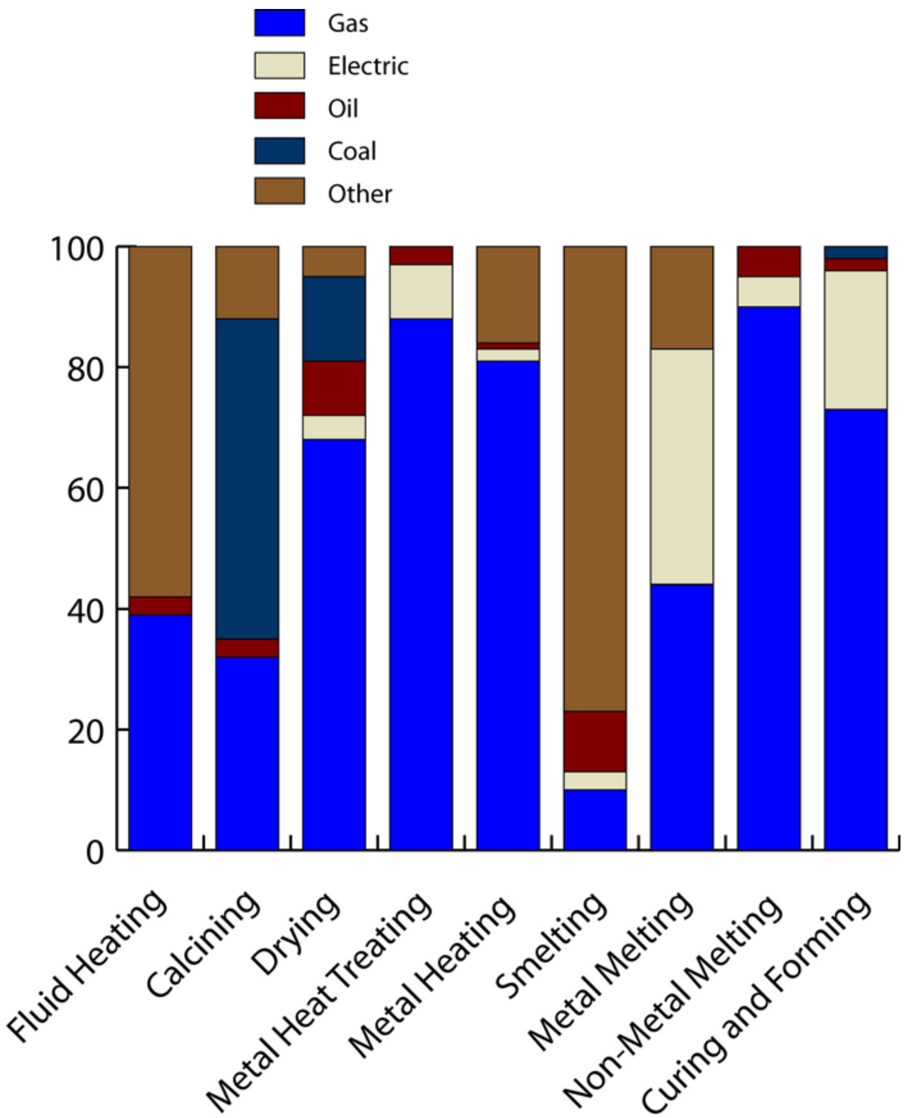
- Coal
- Biomass
- Petroleum Coke
- MSW
- Black Liquor

APPENDIX B: ELECTRO-TECHNOLOGIES AS APPLIED TO INDUSTRIAL PROCESSES

Electro-technologies are quite different in technical form from the types of processes described above, but since they are used for many of the same purposes—such as drying or smelting—and perhaps more important, because they represent in themselves a way to displace natural gas usage within industry, they are highlighted in this section. Electro-technologies consist of a variety of technology systems that use electricity to produce and process products. They enable electricity to replace natural gas and other fossil fuels in industrial processes. As can be seen in Figure B-1, they are employed in various industrial processes such as heating, drying, heat treatment and smelting. Although electro-technology can also be used in boilers; electric-fired boilers account for less than 1% of all boiler-related energy.

Market penetration to date has been driven by applications in which electro-technologies enable manufacturers to reduce their production costs, increase their productivity and improve product quality as well as working conditions and job safety. In many applications, a key advantage is faster start-up/shut-down cycles and smaller efficiency penalties when operating off optimal load.

Figure B-1: Electro-Technologies Are Well Developed For Certain Process Functions

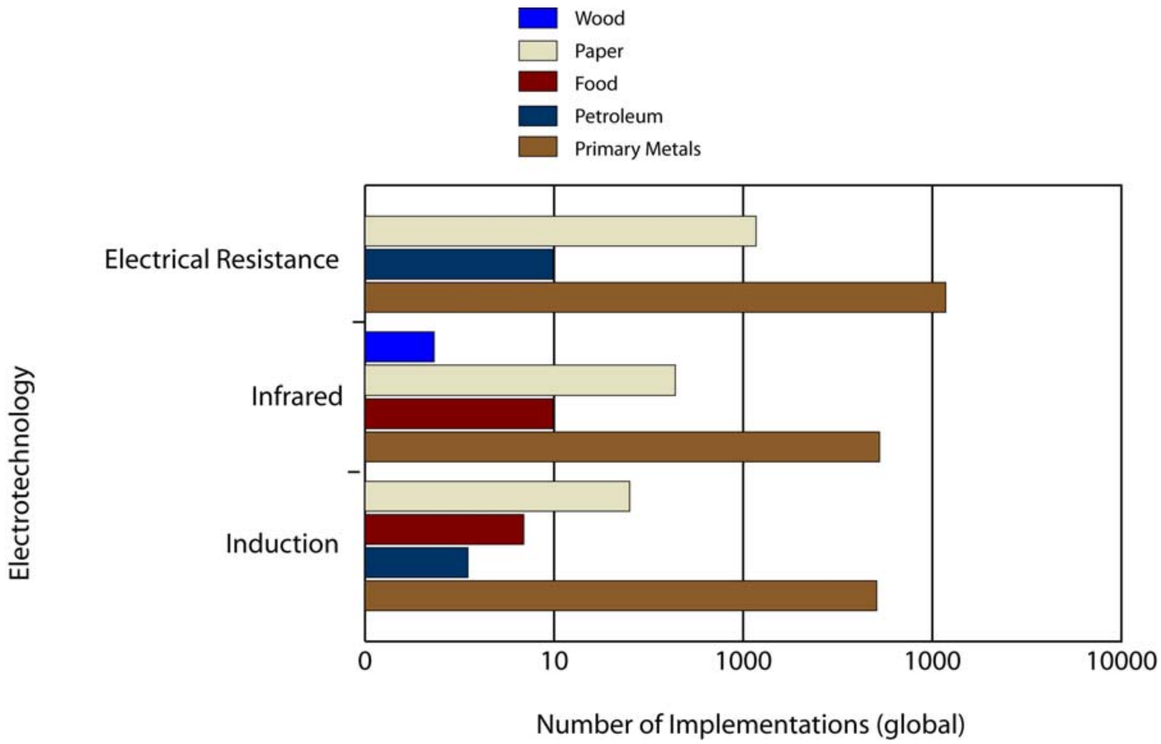


Source: *Improving Process Heating System Performance: A Sourcebook for Industry, DOE EERE ITP*

B.1. Electro-technology conversion technologies are quite different than for industrial boilers or process heating

There are a number of classes of technology that convert electrical energy into heat. These technologies can be a feasible alternative to provide industrial process with an environmentally sound and financially beneficial substitute to natural gas. These technologies are deployed commercially across all sectors (*see Figure B-2 for some examples*). From the industrial users perspective these technologies offer relative simplicity compared to other fuel flexibility options in that the user only need focus on the production process-conversion and all the risks and concerns associated with energy delivery to the industrial process are transferred to the electricity supplier.

Figure B-2: Electro-Technologies Are Already Widespread In the Primary Metals, Paper, Food Processing, and Petroleum Sectors



Source: Environment Canada Innovation, Monitoring, and Industrial Sectors section, "Environment Technological Innovation" Montreal: 2005, p 5

Electro-technologies

Indirect resistance heating consists of passing an electric current through a heating element. The heat that is generated is confined in an insulated enclosure such as a furnace. The heat can be used by direct contact or through an intermediate material. Conduction, also called direct resistance heating, involves heating a material by passing an electric current through it. These technologies require a electrically conductive workpiece. The key advantage of these technologies over gas-fired systems is efficiency. Typical heating efficiency of a gas furnace averages 15 to 20 percent. Optimal efficiency of a gas furnace can amount to 40 to 80 percent. This means that 40 to 80 percent of the heat that is generated can be used, while the rest (20 to 60 percent) goes out through the exhaust system. Optimal efficiency of an electric oven can reach up to 95 percent.

There are several electro-technologies designed for extremely high temperature applications. Plasma is a gas that has been ionized and has become electrically conductive. Plasma generators can heat gases to temperatures as high as 10,000°C. Electric arc heating is a specific kind of plasma heating that uses an electric arc created by the flow of current through ionized gas between two electrodes. Temperatures of up to 4,000°C can be reached in furnaces using electric arcs or submerged arcs as radiant heat sources. The key advantage of these technologies is the high operating temperature, since they can achieve temperature well-above the maximum achievable by combustion processes. They also allow for careful control of the heating environment, creating a controlled environment for melting reactive metals such as titanium.

Infrared heating uses radiation (short, medium, and long wavelengths) emitted by electrical resistors heated to relatively high temperatures. Key advantages are rapid heating. It also boasts high efficiency with 88 percent of the electricity supplied going to heat application where it can delivery faster drying with higher efficiency over conventional ovens.

Laser heating uses an extremely intense and coherent beam of light generated by the laser to heat the workpiece. Very high power densities can be attained, and the beam can be concentrated within a very small area. It is used in surface treatment processes. It can result in more efficient processing its high resolution minimizes treatment of unnecessary surface area and depth.

In microwave heating, a non-conductive material is subjected to an ultra-high frequency electric field. The vibrations associated with the electric charges result in homogeneous heating of the material. For microwave heating, the frequency lies between 300 and 30,000 MHz, typical at 2,450 MHz. Induction heating involves placing an electrically conductive object in a low frequency electromagnetic field. The induced current causes the object to heat up.

In all these technologies, heating is very fast compared to conventional technology. This coupled with lower losses results in higher efficiencies than conventional processes. These processes also allow better process control and result in higher quality yields with fewer rejects.

B.2. Electro-technologies present constraints to fuel flexibility that are qualitatively different than for other process operations

Equipment Replacement

Substituting electro-technology in most cases require the complete replacement of the existing thermal equipment. While the capital cost of electro-technology is typically less than or equal to conventional equipment for many applications, it is still a major capital item and most companies would only likely make such an investment at the end of the useful life of their existing equipment.

Suitability and Economies of Scale

Many electro-technologies do not scale well in that there are little or no economies of scale above a given module size. In addition, some technologies have scale limitations, i.e., microwave technology has difficulty in scale up due to short penetration depths. In addition, for many applications they just are not competitive, e.g., large boilers.

Also, in some applications conventional systems may provide better performance. For instance, precise control of part temperature is more difficult with infrared than it is with convection ovens, requiring more precise sensors and controls. Also, because infrared only directly heats the areas it "sees," infrared heating of complex parts is less uniform.

Technology Maturity and Uncertainty over Operating Performance

Electricity is more expensive per unit energy than natural gas and, depending upon the nature of the regional electricity market, may be as volatile or more so. This requires that the promised efficiency improvements over conventional systems be realized in order to achieve target returns. In many applications electro-technologies are relatively immature and many users do not want the risks around performance and reliability associated with a relatively new application.

An additional constraint is the localized availability of capacity within the electricity grid. Grid congestion and seasonal capacity constraints are already associated with certain regions; to the extent large scale electro-technologies are adapted in concentrated locations, these problems may be aggravated, with attendant fluctuations in the price of electricity.

There is also the question of actually how much natural gas is replaced when electro-technology replaces a conventional natural gas system. The answer depends upon the relative efficiency of the two processes, the amount of natural gas in the regional electricity generation mix, and the efficiency of generating technology in converting natural gas to electricity (*See Table B-1 for an example comparison*).

Table B-1: Potential Energy Savings In Drying And Sintering Applications

Parameters	Glue Drying Application		Sintering Application	
	Hot air oven	RF Oven	Natural Gas Furnace	Microwave Furnace
Daily Gross Process Energy Requirement (kW-hr)	8640	120	3000 (80% eff.)	3429 (70% eff.)
Electricity Transmission and Distribution Losses	NA	10%	NA	10%
Generated Daily Energy (kW-hr)	NA	132	NA	3771
Total Energy Use (kW-hr)	8640	132	3000	3771
Electricity Supply Mix (% NG)	NA	18%	NA	18%
Natural Gas Generating Efficiency	NA	37%	NA	37%
Total Natural Gas Used (Btu/day)	29,479,680	212,584	10,236,000	6,073,833

Source: Booz Allen analysis, based on U.S. electricity mix and average generating efficiency derived from International Energy Agency World Energy Outlook 2006.

For applications that result in large improvements in efficiency the natural gas substitution potential is quite high. Even in those cases where the overall energy usage is equivalent, the potential for natural gas savings is still quite good if natural gas is not a major source of electricity.

APPENDIX C

The Industrial Fuel Flexibility Workshop: Initial Stakeholder Feedback

Prepared for U.S. Department of Energy Industrial Technologies Program

January 22, 2007

C.1. Executive Summary

It has been widely recognized that high natural gas prices are threatening the competitiveness of U.S. industry. This recognition has resulted in a surge of interest in exploring the opportunities that exist for a near-term reduction in industrial natural gas usage. U.S. industry, the largest user of energy domestically, is principally dependent on natural gas as a single major source of fuel or feedstock. Over the past several years, there has been a rapid increase in natural gas prices that has adversely impacted the industrial sector and has significantly threatened its competitiveness.

Booz Allen Hamilton was commissioned to provide preliminary analysis of potential activities for near-term natural gas substitution in industrial processes. According to the analysis conducted by Booz Allen Hamilton, the most realistic natural gas reduction level in the near term (5-7 years) is 3-7% by 2012 and 25%-30% substitution by 2020. The analysis further suggested that initial efforts should be focused on removing the technical and market barriers of nearly-mature technologies. For example, the development of process integration specifications and broad industrial applications of fuel flexibility and alternate feedstock options for major strategic energy intensive industrial sectors such as chemicals and steel could be investigated.

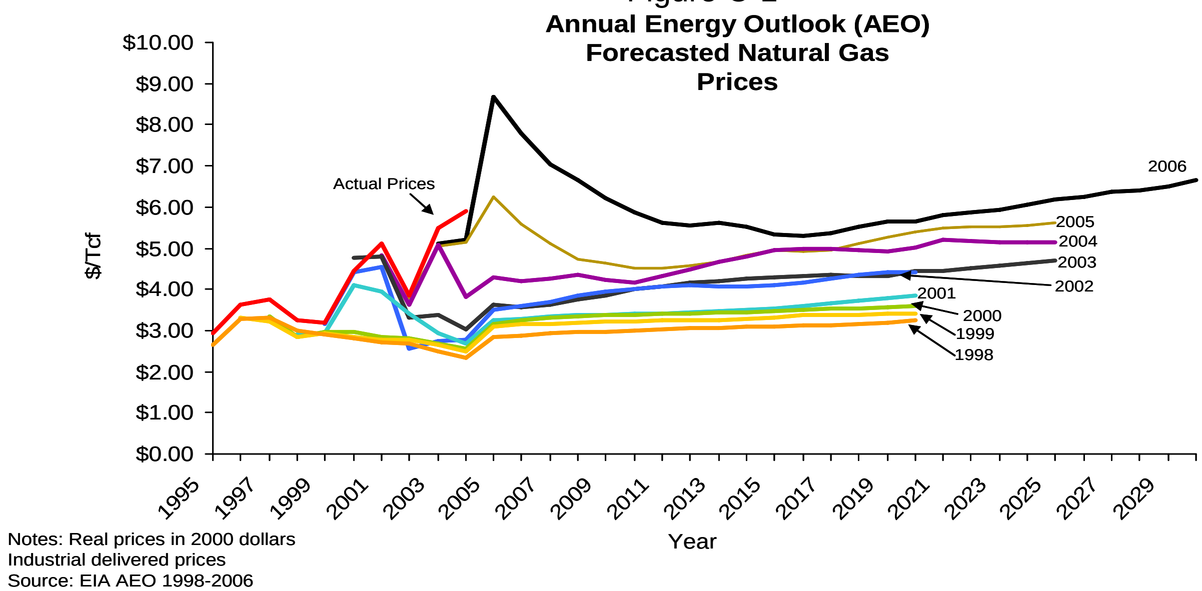
Development of a successful initiative, which would spur fuel flexibility in U.S. industry, had to be vetted with stakeholders from all ends of the spectrum, including technologists, fuel suppliers, industrial end-users, R&D specialists and national laboratories, to determine if there was a plausible role DOE could play in reducing industry's reliance on natural gas. Also, opportunities and activities supplied by these stakeholders should be considered in the mix of potential activities. As a result, on September 28, 2006, in Washington, DC, Booz Allen Hamilton sponsored the Industrial Fuel Flexibility Workshop which brought together carefully chosen participants and panelists from the various stakeholder groups. The workshop provided insights into a number of the working hypotheses formed prior to the workshop about the constraints and opportunities associated with increasing the range of fuels available to industrial users, as well as introduced new and potentially significant ideas as suggested by participants.

This document serves a synopsis of the insights provided at the Industrial Fuel Flexibility Workshop. The identification and confirmation of both the broad, commonly-shared impediments to implementation of fuel flexible technologies, as well as those faced by specific industries or alternative energy technologies provide an essential platform upon which solutions can be developed.

C.2. The Need For Fuel Flexibility In Industry

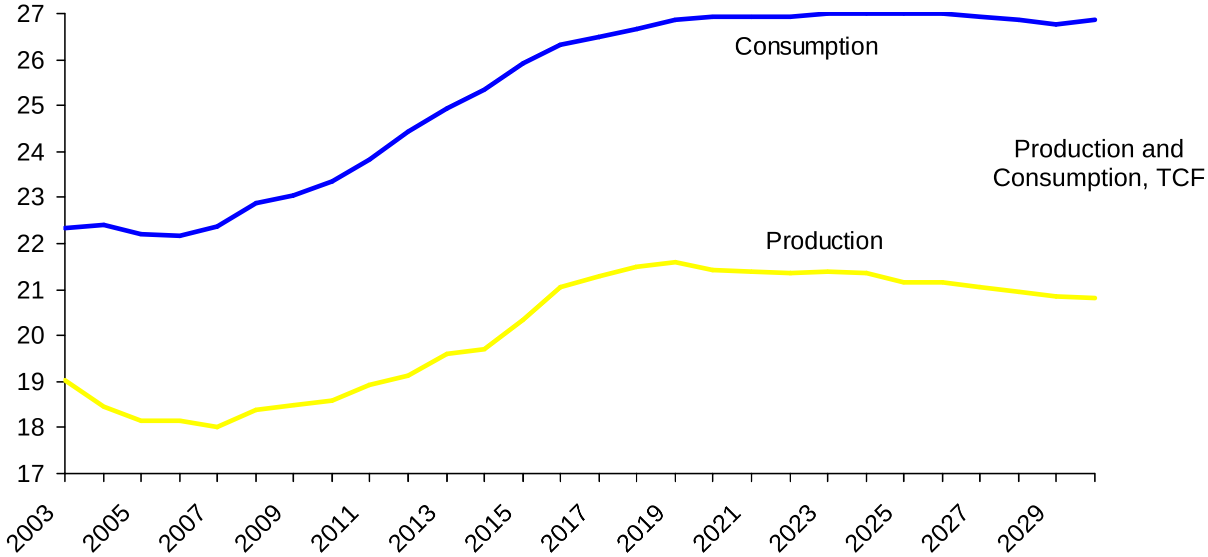
U.S. industry, the largest user of energy domestically, is principally dependent on natural gas as a single major source of fuel or feedstock. Over the past several years, there has been a rapid increase in natural gas prices that has adversely impacted the industrial sector and has significantly threatened its competitiveness. For example, during 2000 – 2004, natural gas price increases resulted in reduced civilian employment in the U.S. manufacturing sector by 70,000 jobs per year (ESA 2005). This dependence on natural gas has created a national problem in scope and scale. The drastic price increases of natural gas (100%-300%), coupled with very abrupt changes in price (from 2001), have amplified the level of urgency needed to relieve industry of this problem. As global economic growths persists, natural gas prices are forecasted to continue to rise. However, prices have been consistently underestimated as the EIA Annual Energy Outlook has been revising its forecasted natural gas prices upwards every year since 1998 (*See Figure C-1*)

Figure C-1



In addition, over the last four years, natural gas prices in North America have been extremely volatile. As the natural gas market is deregulated, prices are mainly determined by the interplay of supply and demand. The North American market has proven vulnerable to unexpected interruptions in supply and increases in demand, such as those experienced after Hurricane Katrina. It has been projected that U.S. domestic production will not satisfy the anticipated demand for natural gas in the coming years (*See Figure C-2*).

Figure C-2
U.S. Natural Gas Production & Consumption



While it was initially thought that Canada would be able to make up for the shortfall in U.S. production (as currently much of the U.S. supply of natural gas comes from Canada) Canada's natural gas production has been on the decline. Satisfying the nation's need for natural gas will therefore require a shift to LNG imports. This option, however, proves significantly complicated for three reasons. First, 75% of natural gas reserves are in unstable regions and supply disruptions in those areas will have global consequences (*See Figure C-3*). Second, US LNG terminals may reach capacity, implying a further supply-demand imbalance and increased volatility. While new terminals have been cleared in the U.S. government permitting system and more are planned in Mexico and Canada, stakeholder concerns and local requirements can delay or cancel projects. As a result, lead times can be long and project implementation is uncertain. As currently estimated, all planned capacity additions in the United States (four terminals) will handle 1.69 Tcf/year of natural gas; however eight are needed to meet the projected imports of LNG (*See Figure C-4*). Third, global demand for natural gas from developing countries like India and China has put a further strain on the availability of this non-renewable resource.

Figure C-3

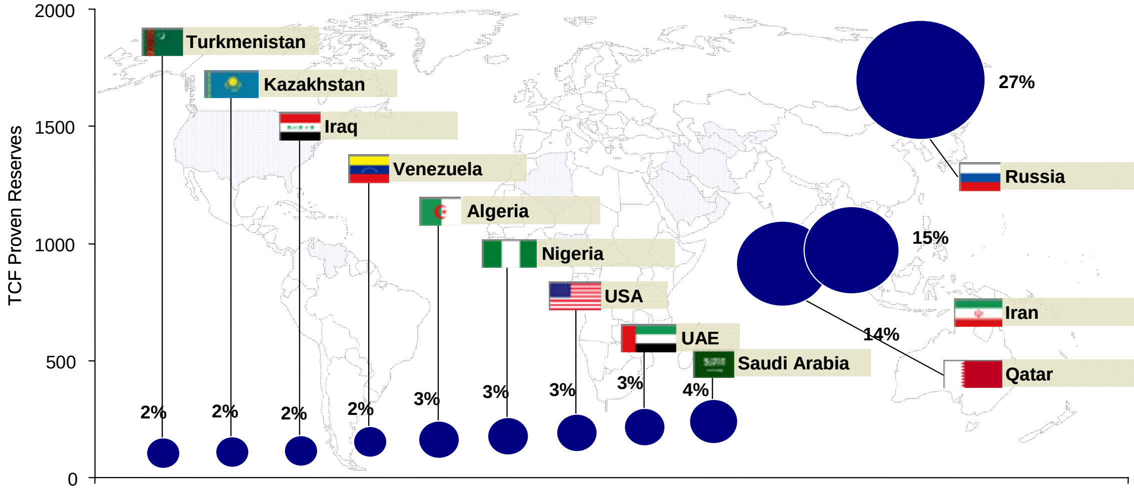
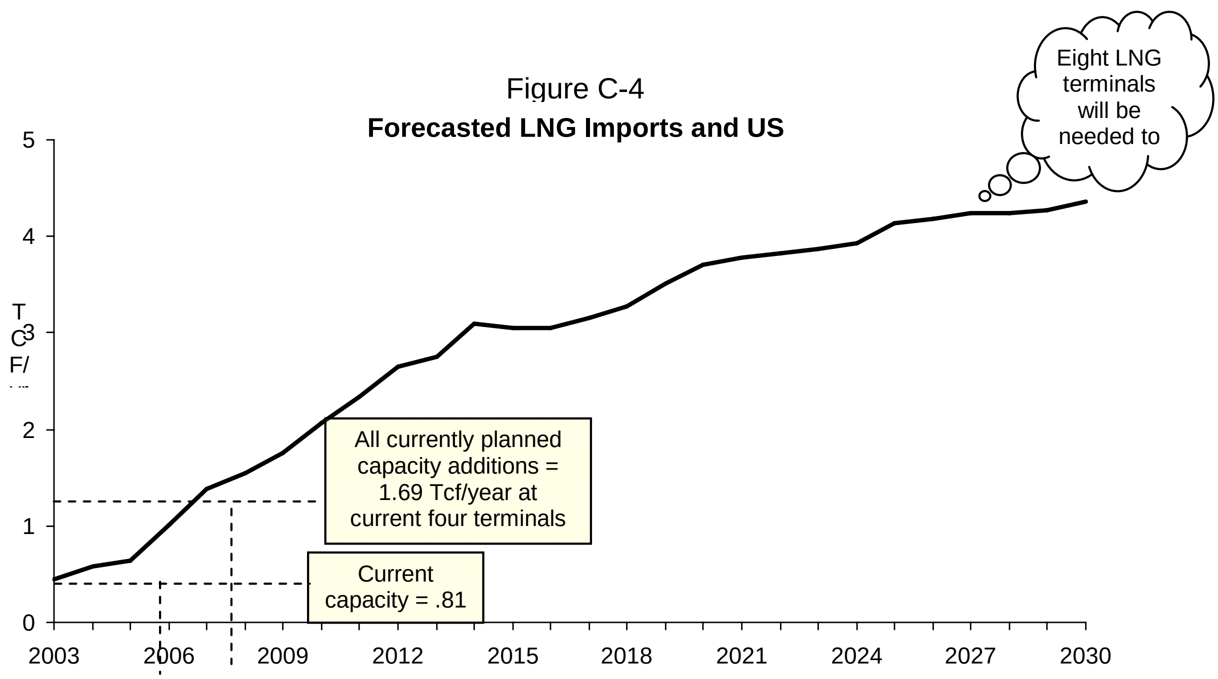


Figure C-4

Forecasted LNG Imports and US



* One bcf/day is the current capacity at Cove Point, MD and Lake Charles, LA.

Industry's cost structure is also significantly dependent on cheap natural gas. It currently has limited fuel switching capabilities in machines, process and infrastructure. Re-evaluating fundamental processes and then changing them, is risky and expensive for industry. Efficiency improvements can only play a very marginal role, if at all, in alleviating some of the stresses industry faces as efficiency gains are, by their nature, incremental, and alone are simply not of sufficient magnitude to offset the price pressure of natural gas. Because of the severe impact on their sectors, firms are unable and unwilling to divert capital toward more ambitious or long-term solutions to this problem.

C.3. The Industrial Fuel Flexibility Workshop

It has been widely recognized that high natural gas prices are threatening the competitiveness of U.S. industry. Booz Allen Hamilton was commissioned to provide preliminary analysis of potential activities for near term gas substitution. According to the analysis conducted by Booz Allen Hamilton, the most realistic natural gas reduction level in the near term (5-7 years) is 3-7% by 2012 and 25%-30% substitution by 2020. At 7% substitution, a $1 price difference between natural gas and the substitute would yield approximately $588M of direct annual cost savings. Achieving this level of substitution could also reduce enough demand to support a 2% to 4% reduction in gas prices for the entire US economy (LBNL 2005).

The analysis further suggested initial efforts should be focused on removing the technical and market barriers of nearly-mature technologies. For example, the development of process integration specifications and broad industrial applications of fuel flexibility and alternate feedstock options for major strategic energy intensive industrial sectors such as chemicals and steel could be investigated. Furthermore, analysis suggested that work should be done to catalyze the development of high potential technology platforms and address infrastructure modernization to enable large-scale migration from natural gas to other, less scarce fuels. This is a necessary measure to complement energy efficiency initiatives that cannot solely mitigate price volatility.

In order to create a successful initiative, which would spur fuel flexibility in U.S. industry, the list of proposed activities had to be vetted with stakeholders from all ends of the spectrum, including technologists, fuel suppliers, industrial end-users, R&D specialists or national laboratories, to determine if there was a plausible role DOE could play in reducing industry's reliance on natural gas. Also, opportunities and activities supplied by these stakeholders should be considered in the mix of potential activities. As a result, on September 28, 2006, in Washington, DC, Booz Allen Hamilton sponsored the Industrial Fuel Flexibility Workshop which brought together carefully chosen participants and panelists from the various stakeholder groups. The workshop was structured in the form of four workshop sessions based on various topics: opportunity fuels, industrial gasification, petroleum coke and biomass. Each panel began with the presentation of a case study followed by panelist comments which framed the discussion. This was followed by moderated discussion among panelists and workshop participants.

The initial presentation case study highlighted current applications of a technology, while subsequent panelists illuminated barriers, opportunities, and provided independent perspectives. The moderated discussion probed barriers and the potential government role in overcoming them.

Workshop participants include end-users, technology providers, technical experts, national lab representatives, financiers, and government staff for a total of approximately 75 participants.

C.3.1. Objectives of the Workshop

The purpose of the workshop was to garner expert perspectives on key barriers and solutions to alternative fuel use, verify and validate key issues Booz Allen Hamilton had identified with regards to opportunities and barriers to fuel flexibility in the industrial sector, and receive feedback from stakeholders on additional opportunities and barriers. The feedback was used to develop this report outlining specific fuel flexibility opportunities and related barriers.

The fuel flexibility workshop provided additional insights into a number of the working hypotheses formed prior to the workshop about the barriers and opportunities associated with increasing the range of fuels available to industrial users. The identification and confirmation of both the broad, commonly-shared impediments to implementation of fuel flexible technologies, as well as those that are industry or fuel-specific provide an essential platform upon which solutions can be developed. Indeed, higher acuity in perceiving barriers to alternative technologies – as expressed by users, developers, and financiers – enables DOE to more effectively facilitate solutions.

C.3.2. Panel Discussions: Key Themes and Messages

C.3.2.1. Opportunity Fuels

The opportunity fuels panel set about discussing the significant challenges of the direct combustion of solid waste, enabling the production of steam. Several topics were probed, including regulatory policy, economies of waste transfer, solid waste availability, competitive tipping fees, and the proximity of WTE facilities to municipalities. Opportunity fuel advantages discussed included net negative emission of greenhouse gases and regulatory incentives/ tax credits.

The first opportunity fuels panelist, Covanta representative Kent Burton, introduced a case study regarding the Niagara Resource Recovery Facility. In 1993, American Ref-Fuel retrofitted the facility with mass burn boilers and air quality control equipment enabling it to meet stringent environmental standards and commitments. Integrated Waste Services Association President Ted Michaels also discussed the status of WTE operating facilities while Eileen Berenyi, Ph.D, of Governmental Advisory Associates, Inc. discussed the future of opportunity fuels. Finally, Bill Chrisman from Grain Processing Corporation discussed the potential for using corn fiber or steep syrup as an energy fuel.

There are currently 89 WTE facilities operating in 27 states with the heaviest concentration (three quarters of plants) in the Northeast and Southern regions. These facilities combust MSW to reduce its volume, produce energy as steam or electricity and recover ferrous and sometimes non-ferrous metals for recycling. There has been recent consideration of new facilities in a number of locations including Florida, Connecticut, Maryland, Hawaii and California.

According to the Integrated Waste Services Association, this growth is due to the following factors: 1) Renewable status (i.e., EPACT 2005, Section 45 Production Tax Credits) 2) Advances in emissions controls and 3) Recognition of greenhouse gas benefits.

In some regions, the alternative to waste disposal is landfilling, which has become increasingly expensive. Even after a steady waste flow is secured, tipping fees for the waste must continue to be competitive in order for the waste to be used for energy rather than being landfilled. Two basic models for customer/plant cooperation that might be applicable to a more cost effective future of opportunity fuels were discussed: 1) An industrial user located within reasonable proximity of an existing plant and 2) An industrial user that secures the waste stream and combusts the waste in a dedicated boiler (e.g., Boilers at Dupont Chemical and Fibers in Kinston and Fayette, NC) to use on-site. Making WTE work also involves three types of customers: 1) Those on the fuel-producing end- those that supply the waste (nearby municipalities, which sign long-term multiyear agreements) 2) "Special waste" customers, which are those that must have assured destruction (i.e. banks, mint) and 3) Customers on back-end who buy the steam produced

The importance of regulatory policy in regards to WTE was discussed amongst panelists. The Public Utilities Regulatory Policies Act (PURPA) of 1978 incentives helped define a new class of energy producers called a qualifying facility, or small-scale producers of commercial energy who normally self-generated energy for their own needs. Although PURPA stimulated significant development of facilities, over the past 12 years the industry has experienced a dramatic decrease due to court cases affecting the economics of waste transfer, lowering the cost of landfills. Additionally, in 1990 the Clean Air Act Section 129 imposed the Maximum Attainable Control Technology Requirement, driving retrofits of large combustion units to meet the standards by 2000. Availability of the solid waste also discussed. A reported 15% of solid waste is heading to combustors, 30% is recovered and 55% goes to landfills. Although waste may be available, it is often committed on a contractual basis for terms that vary from 3-5 years to up to 20 years, and 70% of the U.S. landfill capacity is controlled by three national firms. Finally, the management of solid waste is under the purview of local governments; therefore, in order for users to be able to use the waste, they must get involved in the community and recognize that they will be providing a service to the municipalities who desire to dispose of the waste in a proper, appropriate and continuous way.

C.3.2.2. Industrial Gasification

The industrial gasification panel set about discussing the significant challenges of gasification use for industry end users. Several topics were probed, including the need for technical gasification expertise in industry, coal handling facilities, how conservative decision making has plagued industry, how changes to process are viewed as threats, and how downtime and reliability are significant concerns. Advantages of gasification which were discussed included price stability and emissions advantages.

The initial case study surrounding the EPIC gasifier, a small–scale gasifier designed for industrial use, was presented by Bill Douglas, a senior-vice president at EPIC. Bill Douglas highlighted several challenges to the use of gasification systems in industry including, 1) Complexity: even with the relative simplicity of this system, those customers that are looking at coal handling facilities additions are problematic. 2) CO_2: sequestration presents the problem of what to do with the CO_2 once it has been captured 3) Pricing: would an indifferent customer trade price certainty for the possibility that cheap natural gas returns? 4) Financing: how do you provide a guarantee to finance a gasification unit that is inside the fence?

Brian Oakley of Scully Capital identified several key issues financiers look at when determining if a gasification project should be funded. He identified two major issues: the need for a gasification plan to have an anchor tenant (i.e. a firm who will be a primary user) and a financier's need to recognize who or what entity is going to be responsible for the risk of building the system. Other key issues from a financing perspective were identified, including: 1) Smaller plants are more attractive because they are not "bet-the-company" type risks. 2) Transportation is a huge issue. For example, mine mouth coal is $36/short ton but transportation costs add $15/short ton. 3) Technology risk – will it work? 4) Market risk- who is going to buy your product? 4) Is there liquidity in the market for deals this big? Deals that are smaller can be done for a smaller price. Finally, Mr. Oakley felt that for in order for loan guarantees to work, they need to cover 80% to 100% of the project cost. Government is the "patient investor" but equity investors are looking for nearer term returns.

David Denton of Eastman Gasification Services provided comments regarding the reality of an industrial gasification market and the best way to make the technology available to industrial customers. He felt that economies of scale were the largest hurdle in making gasification an everyday reality in industry. Many industrial plants are too small to obtain adequate economies of scale, particularly in the case of coal-fed gasifiers. Mr. Denton highlighted four tangible ways in which U.S. industry could viably utilize gasification:

- Share syngas output from large-scale nearby gasification facilities (poly-generation or shared- facility concept)
- Use advantageous feedstocks and/or technologies that may enable economic operation at smaller gasification scale (i.e. biomass or wastes as feedstocks)
- Invest in a large central SNG plant located in a remote location and trade natural gas at the industrial plant location

Michael Greenman of the Glass Manufacturing Industry Council provided perspective on the concerns and advantages of gasification for industry end users. He argued that in order for gasification to be viable in the glass industry, the downtime of a plant would have to be dealt with. Glass manufacturing requires a continuous stream of power and any disruption can cause huge financial losses to glass manufacturers. He also emphasized the reality that very few industrial users want to be the "first mover" when it came to using a relatively un-tested technology, and that conservative decision making is a reality for several energy-intensive industries. Opportunities around exploring oxyfiring were also discussed as it makes the combustion process more straightforward (less air is necessary). Finally, he also supported the idea of the industrial park concept (along with David Denton) and felt that the price stability gasification provided versus natural gas was appealing.

C.3.2.3. Biomass

The biomass panel provided key insights into the use of biomass as a fuel alternative to natural gas. Panelists emphasized the availability of biomass- capturing all the heating value of biomass would meet 20% of US needs (ORNL billion-ton assessment) - but also highlighted that the transportation and variability of biomass were significant barriers. Several technologies are currently available which take advantage of energy from biomass, but the question remains as to which technology is the best option. In addition, panelists noted that most industrial energy users do not produce a steady source of biomass feedstock internally, so in several instances biomass use requires getting into the feedstock business. Several panelists emphasized that DOE can help accelerate the use of biomass by providing assistance to "first movers." Finally, all panelists saw the need for the development of air emissions data for the wide variety of biomass feeds.

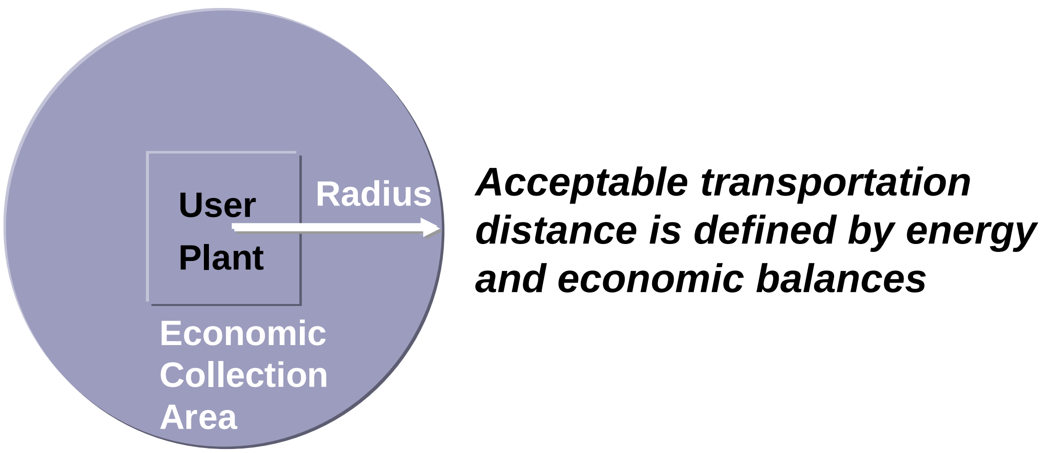
A biomass gasification case study was presented by *SilvaGas (FERCO)* representative Milton Farris. Farris discussed some of the typical barriers associated with the gasification of biomass (which includes MSW, energy crops, agricultural residues and residue fuels). "Everyone wants to be first to be second" is a common theme amongst industry, reinforcing the need for more sound demonstrations. *SilvaGas* is supported by DOE and industrial sources, but the need for DOE to provide additional assistance to move the technology into the marketplace was also expressed. Implementation issues that occur during industrial process integration were also a common concern.

Financing projects such as biomass gasification was discussed by panelist Thomas Meth of *Intrinergy*. Meth discussed three core criteria for a biomass project – feedstock, equipment and off take. Homogeneity, price stability, price, reliability and enforceability are some of the key components of a successful feedstock. In regards to biomass gasification equipment, proven technology (i.e. successful demonstrations), high efficiencies, low capital and maintenance cost and a good emissions profile are desirable. Off-take (or long term outcome/product) must maintain price certainty, credit quality and capacity utilization.

Patrick Hirl of Stanley Consulting also stressed availability and consistency issues (i.e. ash and moisture content) as key concerns in the direct fire of biomass. He emphasized that direct fire of agra-industry biomass comes down to what's available in the vicinity. In addition, seasonality of fuel presents an issue with crop residues. In the corn belt there are a significant amount of co-products (e.g., distiller's grains, whet mill feed.) that will need to be dealt with. Finally, a key concern is the permitting aspect of getting systems on the ground which can be onerous. There are also issues concerning biogas produced from anaerobic digesters and used for combined heat and power systems. Higher conversion rates for various co-products, ammonia recovery for fertilizer and anaerobic digesters designed for energy production are all desirable.

Gerald Nix of the National Renewable Energy Laboratory (NREL), stressed that biomass can only be one part of the solution to displacing natural gas use in industry. He felt that a value analysis of biomass is needed as well as an evaluation of emissions of the various types of biomass. He highlighted several barriers and opportunities including: 1)Variability: energy density, physical properties (e.g. moisture), combustion characteristics and, chemical composition of different biomass stocks. 2) Handling/conversion can be a challenge- Specific systems can be designed, i.e. to allow the user to process specific biomass stock on-site. 3) Transportation is a challenge, but can be overcome via co-location or through the use of higher energy density biomass stock (*See Figure C-5*). For a higher-energy biomass such as wood, the economic transportation distance is probably on the order of 50 miles. The acceptable distance becomes much lower for lower energy biomass stocks. For local gasification and pipeline transport of gas, distance is a factor only for biomass collection, not for use of the product gas – same for production of liquid fuels.

Figure C-5



C.3.2.4. Petroleum Coke

The petroleum coke panel set about discussing the significant challenges of producing steam from petroleum coke (petcoke). Several topics were probed including a comparison of petcoke versus coal, the petcoke pulverization market, and petcoke financial realities. Petcoke fuel advantages discussed included very small amounts of fluxant or emissions, widespread availability and cost competitiveness.

The first petcoke fuel panelist, Coffeyville Resources, LLC plant manager Neal Barkley, introduced a nitrogen fertilizer case study. Coffeyville Resources is a petroleum refiner that also uses petroleum coke gasification to produce nitrogenous fertilizer. Its Coffeyville Nitrogen Plant remains one of two fertilizer plants in North America not reliant on natural gas as a raw material. Other panelist included Everett Zilinger from the Fertilizer Institute and Jeff Hazle of the National Petrochemicals & Refiners Association. Vice President of DTE Energy Steve Hudolin was the final petcoke panelist who discussed the future of petcoke market and pulverization facilities.

Table C-1
A Comparison of Petcoke to Coal

Petcoke versus Coal		
Petcoke		**Coal**
+	Cost	+
+	Availability	+
-	Contract Term	+
+	Consistent Quality	-
-	Transportation	+
+	Mercury	-
+	Halogens	-
+	Ash/Fluxant	-

Panelists discussed the financial realties that petcoke must overcome in order for customers to choose the petcoke alternative fuel option instead of natural gas/oil. First, customers need to experience demonstrations that show significant fuel savings (~$2.50/MMBtu). Second, customers need to feel confident that the fuel switch results in profitable savings before introducing a new technology/installation into a plant's environment. For example, the capital investment for a lime kiln to fire petcoke is $1-2 million; therefore, the fuel savings must overcome the initial inertia (i.e. impacts to process, operator "hassle" and cost). Third, customers also seek a 1-3 year payback period once the capital is invested. Finally, customer permitting is also important and varies by state. States are not always familiar with burning petcoke; therefore, as experienced during the case study, regulators must be trained accordingly.

Improvements the firing of pulverized petcoke making it more economically feasible and as easy (or convenient) as firing natural gas is also a goal of DTE Petcoke company which includes several pulverizing facilities across the U.S. (centrally located to serve multiple customers) which distribute pulverized petcoke to industrial customers via pneumatic truck or rail. DTE is also seeking niche markets to substitute petroleum coke for natural gas or oil. An initial target market includes lime kilns at pulp and paper mills, which mitigate petcoke's negative attributes (i.e. sulfur) and convert limestone to lime with the addition of heat. Additional potential markets for petcoke include black liquor recovery boilers (BLRB), brick kilns, steel and glass.

When comparing petcoke to coal (*See Table C-1*) petcoke is cost competitive. According to the Argus Petroleum Coke Report (Feb. 06S-002), "attractive points for new coke buyers will be a ready supply, and the likelihood of cheap process- compared to competing fuels such as coal." It has been estimated that there will be a 4.3 million ton increase in Coker capacity in the U.S. over the next three years with a displacement potential of 117.5 Bcf of natural gas. Petcoke is disadvantaged in regards to contract terms as the fuel is generally sold on shorter-term contracts (as compared to coal) and in shipments significantly smaller than a unit train. Petcoke has an advantage over coal where fluxant and emissions are concerned. While coal produces 10-15% ash/fluxant, petcoke produces almost none. Additionally, petcoke gasification only produces a very small amount of mercury and halogens.

C.4. Our Findings

The findings that follow provide a synopsis of our understanding of what participants believed were key opportunities and constraints to industrial fuel flexibility. In general, it was felt that while certain technological innovations would spur fuel flexibility, the main obstacles to wider use of fuel flexibility options relate to actualizing the opportunities already available. Unlocking these opportunities has as much to do with business, technical, and regulatory constraints as it does additional technology-focused R&D.

- ***Compatibility of alternative fuels with plant operations is essential to securing plant manager support***

From a manufacturer's perspective, using natural gas is relatively simple and straightforward; alternative technologies, by contrast, may introduce added risk – real and perceived – to system reliability that may diminish the nominal gains achieved through use of lower cost and/or less volatile fuels. The best fuel flexibility options do not draw exclusively from the option value of fuel switching technology; they must offer minimal impact on the manufacturing process or even enhanced manufacturing process performance. Thus, options that minimize need for novel and/or risky engineering solutions are likely to greatly increase the appeal of any fuel cost enhancements. Conversely, options requiring overly sophisticated engineering may not merit consideration, even if they draw from inexpensive and stable-priced fuels such as petroleum coke. This is because many manufacturing processes are complex operations whose inherent reliability is essential to company financial performance and customer needs.

One benefit of the fuel flexibility program is that certain options can actually diminish the complexity of managing an industrial process. This is particularly the case where relatively proven technologies owned and operated by third parties eliminate the need for a manufacturing facility to own and operate certain types of equipment. Covanta cited an instance in which it acquired a customer for its Niagara plant because purchasing steam from Covanta enabled it to avoid the capital expenditure and O&M costs associated with purchase of a new boiler.

Another significant opportunity for introducing fuel flexibility may lie in the redesign and expansion of plant facilities. By engineering the plant specifically to run from the alternative fuel, plant owners can minimize augmenting overall plant complexity potentially associated with retrofits. In especially complex processes, such as those for petrochemical production and petroleum refining, redesign and expansion projects may offer the only window for integrating fuel flexibility concepts. The Coffeyville Resources plant best exemplifies this logic, as the plant's fertilizer production was optimized specifically to use petcoke as a feedstock.

- ***Perception of risks and financial instruments to manage risk dampen investor appetite for new technologies***

Although many of the technologies examined at the workshop have achieved a reasonable level of technological maturity (the EPIC gasifier, for example, has been available in China for 40 years) the business risks associated with these technologies is a major reason they do not enter the market. Participants identified at least three such risks:

1. Commodity price volatility: Alternative energy technology investments are generally predicated on natural gas price forecasts. Natural gas prices, like other commodities, exhibit substantial fluctuations over time. Thus, a firm undertaking an investment that is attractive while prices are high may ultimately put itself at a competitive disadvantage in the event of a price collapse, as competitors using traditional fuels enjoy leaner cost structures.

2. Absence of performance/risk wraps: Simply stated, a risk/ performance wrap is a guarantee provided to a financier that identifies who or what entity is going to be responsible for the risk of building the system, including price, construction and performance of the system. Engineering, procurement, and construction "wraps" are not widely available for advanced technologies such as gasifiers. Securing such wraps is an essential measure of the financial worthiness of the project and critical to securing project finance.

3. Investment size: The sheer size of some alternative energy technologies – particularly gasification – renders them "bet the company" risks. A petroleum coke gasifier co-located on-site at a refinery, for example, would likely cost up to or in excess of $1 billion. Technologies requiring smaller investments can be attractive to financiers because they can more effectively diversify risk. However, at a smaller size there is not a clear business case as to the value of the investment as often times the unit is being built inside the fence and does not provide outside revenue.

- ***Reliable feedstock supply is a key concern and major challenge to achieving fuel flexibility solutions***

Workshop participants noted that the question of bringing new technologies online is not merely a technical or financial issue; the ability to actually source feedstocks and fuels for use in the alternative energy facility is often a critically limiting factor. These barriers may be geographic or institutional.

1. Geographic supply barriers stem from the marginal cost of transportation of the fuel from its source to the point of consumption and affect all fuels. Each additional mile of feedstock transport erodes the fuel alternative's economics and supply chain logistics. Prospective users of coal-based technologies must be located near a rail spur very near waterways served by barge in order to access that resource. Even where a facility has such access, coal transport has grown increasingly congested, and large, established power plants have faced increasing difficulty sourcing this fuel from railroads. Notwithstanding these challenges, however, DTE Petcoke has succeeded in transporting petcoke via barge (whose physical properties are similar to those of coal) to users seeking alternatives to natural gas.

   Because biomass and solid waste are generally transported by truck, panelists felt that close proximity to the feedstock is essential. Transport of MSW seldom makes sense beyond 50 miles. Likewise, the SilvaGas gasifier tested in Vermont under the FERCO name was located close to its woodchip feedstock. Intrinergy found that logistical problems associated with feedstock delivery from a recycling plant became so complicated that it resorted to purchasing a recycling facility and the trucking fleet necessary to source and deliver feedstock to its industrial customer.

2. Institutional supply barriers arise from the business, regulatory and policy environments governing feedstock management. These may be of greatest concern with respect to MSW and similar wastes. Although about 55% of waste is disposed in landfills, presenting an ostensibly large potential feedstock, the rights to this waste are generally locked up in long-term contracts with waste management companies for whom operating landfills is a core business. In addition, municipalities are strongly driven by the need for responsible, enduring waste management solutions; although waste-to-industrial energy can fulfill these objectives, the model is relatively untested and does not command wide awareness.

   Institutional barriers may also manifest themselves in the various commercial arrangements considered for the provision of energy from a non-traditional supplier. Models involving a non-traditional fuel supplier (e.g., waste from a municipality, petcoke from a refiner, synthesis gas from an industrial park gasifier) may not be adequately supported by conventional commercial practices. As such they may require development of unique frameworks to govern commodity pricing, credit assessments, and bankruptcy by one or more of the parties resulting in disruption of energy supplies to buyers.

- ***Energy investments are less attractive than investments in the core business***

The deployment of alternative technologies requires a highly compelling business case for the acquisition and installation of new equipment. In addition to meeting process integration requirements, plant managers must also acquire additional skills, knowledge, staff, and, in some cases, contracting arrangements necessary to ensure reliable and safe operation of the facility. Even where companies can identify investments expected to deliver strong financial performance, the opportunity cost of not investing in the core business process often prevents implementation of otherwise compelling projects. Furthermore, core business investments are often better understood by managers and executives and thus more easily justified to them.

- ***Assisting regulators with reliable data plays an important role in speeding the permitting process***

Air permits are an essential component to any fuel flexibility option. However, regulators in some cases lack credible emissions profiles and other knowledge about the various fuels and the available technologies. As emissions issues continue to be pushed further into the limelight, analyzing emissions profiles of the various fuel options is essential. There remains a tremendous amount of work in understanding the emissions make-up and combustion of the varying biomass feedstocks in particular. A delay in the permitting process may render projects unviable. For example, one workshop participant reported that a regulator permitting a gasification facility wrongly assumed that the higher capacity of the facility necessarily meant it would produce additional emissions.

- ***Recognizing the emerging global trend towards carbon regulation is of increasing importance to help achieve fuel flexibility***

The trend towards CO_2 regulation, as evidenced by the recent California regulation, the proposed rule in several Northeastern states, the EU carbon trading scheme and recent international interest, suggests that any fuel flexibility opportunity needs to be devised with the possibility of carbon constraints in mind. In particular, if the trend towards using coal and petroleum coke in industrial processes is the predominant choice, CO_2 regulation will be of significant importance.

- ***Overcoming technical barriers, particularly with respect to gasification technologies, will speed deployment***

Although non-technical barriers play a significant role in impeding the deployment of alternative technologies, resolving key technical obstacles will reduce the impact of these non-technical barriers. The panel discussions highlighted a number of technical initiatives, largely information-based, that would fill technical information gaps and enable more informed decision-making by managers. These included:

- Assessing the impact of low- and medium-Btu syngas on the operation of existing natural gas boilers. Creating data and operating guidelines on performance issues such as boiler de-rating, efficiency, emissions, and impact on performance by boiler age and type are first-order areas for inquiry.
- Low- and medium-Btu syngas may also affect natural gas-fired process heating operation. Data and operating guidelines will be needed on the impact of syngas on key process heating operations. These include product quality impacts, controllability, productivity, and emissions.
- Conducting analysis on the technical performance, cost, and operating economics of various gasification options. These may, include characterization of applicable gasification options, differences in syngas produced by various gasifier technologies and feedstocks, optimal combinations of gasifiers, feedstocks, and specific applications (perhaps with a regional focus), and the tradeoffs between a large central gasifier versus small, modular on-site gasifiers (in terms of capital and operating costs as well as ability to penetrate the market).
- Understanding the impact of impurities to gas composition and investigating various options for removal including, adsorbents (for contaminants), membranes for H_2S and CO_2 removal and improved catalysts and processes for gas conditioning operations such as shift reactors.

- ***Investing in electro-technology may prove to be financially and environmentally beneficial to industry***

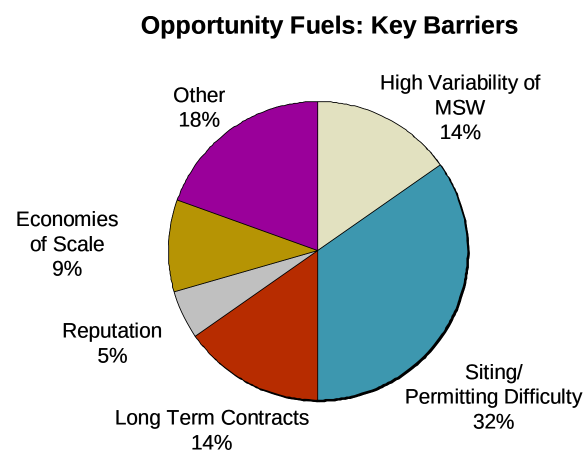
While substantial analysis needs to be completed to understand the full range of benefits of electro-technology (using electricity to provide process heating), at the outset there do seem to be particular advantages. For example, investing in electro-technology allows industry to allocate the financial and permitting risk back to utilities which have the know-how and scale to design carbon portfolios (thereby mitigating permitting risks) and the access to capital so that financial risk is shifted to the utilities.

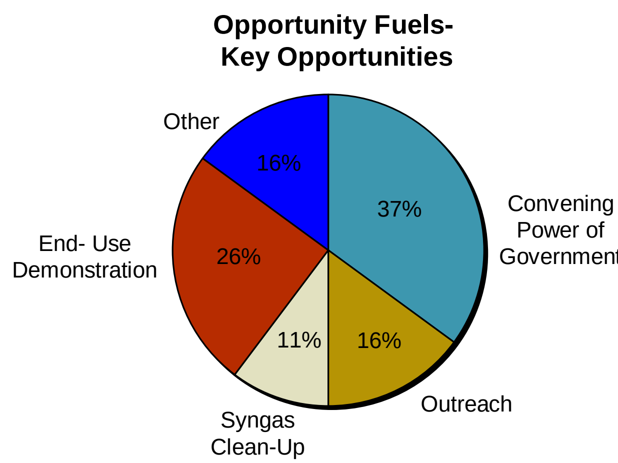
C.5. Survey Results

In a survey conducted at the conclusion of the workshop, participants were asked to prioritize potential activities identified during the workshop and prior to the workshop. Respondents emphasized using the convening power of government and outreach as key opportunities to improve fuel flexibility. The convening power of government refers to the ability to assemble representatives from disparate fields for the purpose of developing innovative solutions. Outreach in this context is considered to refer to development and dissemination of information to catalyze decision making. Outreach is particularly relevant when information gaps prevent parties from making fully informed decisions regarding technology.

<u>*Opportunity Fuels*</u>

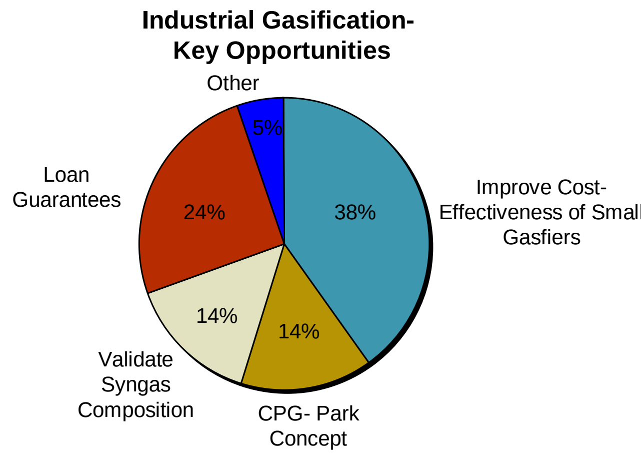
Many respondents indicated that the greatest opportunity for government to influence use of opportunity fuels lies in assembling the stakeholders necessary to catalyze collaboration between industrial users, waste-to-energy plant operators, municipalities, and other key stakeholders. Thirty-seven per cent of respondents ranked this as the primary area for impact. Supporting demonstration facilities ranked second with 26% of the vote, with outreach activities trailing at just 16%. Perhaps reflecting the enhanced performance of direct fire applications, only 11% of participants ranked development of adequate clean-up systems for medium-Btu gas as the most important opportunity.



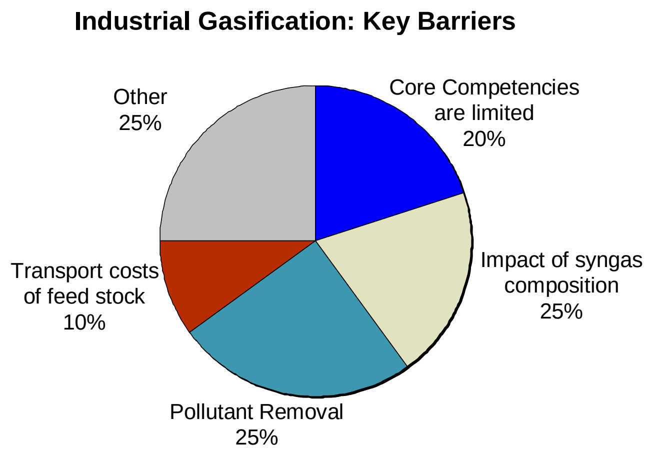


Respondents provided more varied responses to the most prominent barrier to opportunity fuels deployment. Most indicated that difficulty siting and permitting MSW facilities would provide the greatest challenge. A related category, the negative environmental reputation of the technology polled an additional 5%. However, many also cited the high variability of MSW, which would increase the technical challenges of integrating MSW with some industrial processes. Securing waste already governed by long-term contracts with waste disposal companies also ranked high. The heterogeneity of responses in this area was underscored by the high number of responses in the "other" category. In this area participants cited issues such as high capital investment and excessive transactional costs stemming from the number of parties necessary to bring MSW projects on-line.

Industrial Gasification



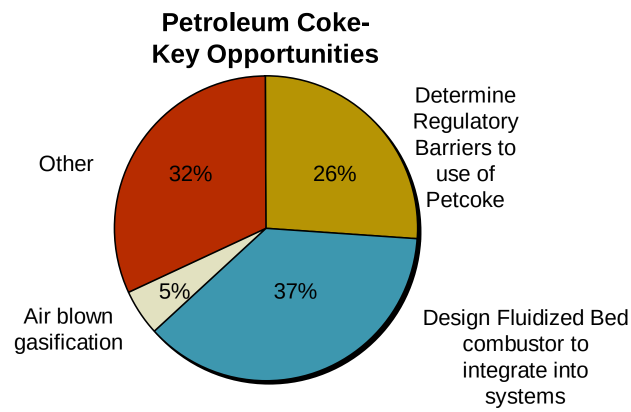
Participants indicated a strong opportunity to enhance the technical capabilities of gasification, with more than half ranking such activities as the number one priority for ITP action. Addressing the cost-effectiveness of small-scale gasifiers so that gasification can be more widely used in industry rated highest, with 38% ranking it as the number one priority. Validating the impact of syngas composition and impurities on process and environmental performance brought 14%. The financial uncertainties described earlier may have played a significant role in securing nearly one quarter of the vote for loan guarantees.

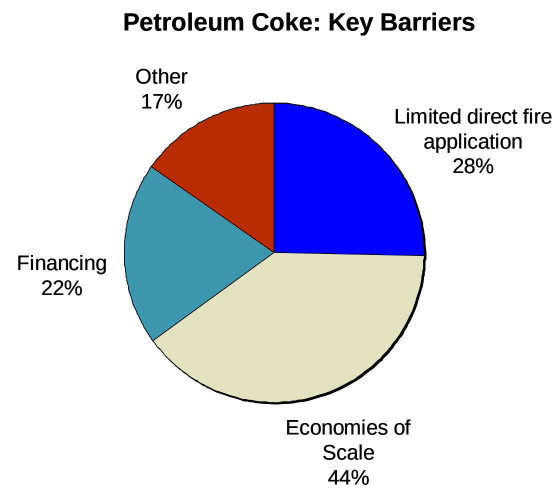


Participants expressed far less consensus on the primary barriers to industrial gasification, as suggested by the far more even distribution of respondents ranking a particular barrier as number one. One-quarter expressed that the most major problem is that syngas from coal would likely require a higher level of pollutant/contaminant removal in order to meet process specifications and environmental permit requirements than natural gas. Another quarter believed that the impact of syngas composition (specifically, its lower Btu content) would prove problematic because it would cause de-rating of equipment, decrease plant availability, and/or negatively impact product quality. One in five respondents indicated that difficulty acquiring the core competencies necessary for gasifier operation would prove to be the primary limiting factor. As with opportunity fuels, the lack of consensus around a single barrier is evidenced by the high number of “other” responses. Specific barriers cited in these responses included sub-optimal system economics and the need for regulator outreach.

Petroleum Coke

Participants expressed a relatively high degree of consensus on the need to design fluidized bed combustors that can integrate with systems now served by natural gas boilers. Unsurprising given the fuel's high metal and sulfur content relative to natural gas, more than a quarter responded that determining regulatory barriers to use of petcoke in fluidized bed combustors represented the greatest opportunity to advance the use of this fuel. A great number cited other opportunities, such as identifying additional market applications (such as the lime calcining).

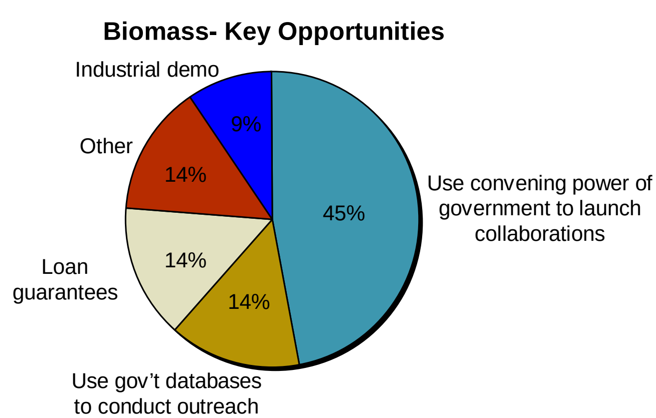




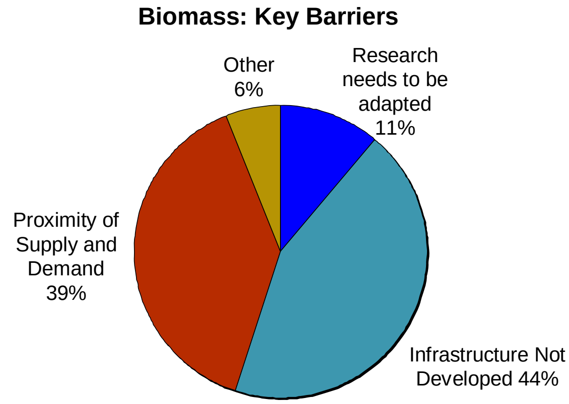
While the participant responses indicated that direct-fire applications offer the greatest opportunities, gasification issues generally dominated the barriers responses. Nearly half reported that achieving economies at smaller scale will prove the single largest barrier to petcoke use. Another 22% indicated that securing financing given the large size (~$1 billion) of potential new facilities will constitute the primary challenge. Only one-quarter felt that the high sulfur, hazardous metals, and carbon content of petcoke will seriously handicap direct fire applications over the longer term.

Biomass

Participants also showed a relatively high degree of consensus on the substantial opportunity offered by using the convening power of government to launch collaborations between government entities (DOE, Department of Agriculture), biomass producers, and industry to identify and execute viable industrial biomass projects. Participants also expressed optimism over leveraging existing government-funded resources for industrial demonstrations and outreach, as well as providing loan guarantees. The 14% of "other" responses included suggestions to provide of market and economic analyses for potential applications as well as building a solid case for a distributed manufacturing model.



Views on barriers to use of biomass split primarily on two key and related issues. The fact that infrastructure to collect, store, and distribute biomass is not developed ranked first among 44% of respondents. An additional 39% cited the high transportation costs of biomass relative to its energy content, making proximity between centers of supply and demand determinate factors in its viability. Only 11% indicated great concern that the primary barrier to biomass is that existing research needs to be adapted for industrial use.



C.6. Next Steps

During the workshop, several fuel specific and cross cutting activities were presented by the speakers and the participants, many of which have been articulated above. Table C-2 below represents the cumulative result of recommended actions made during the workshop.

Using this base of information, as well as additional research and analysis, Booz Allen Hamilton will publish an opportunity and constraints study articulating the opportunities to effectively construct an initiative aimed at reducing industry's use of natural gas.

Table C-2: Recommended DOE Actions Resulting From Workshop

Alternative Fuel(ITP Impact Potential)	Representative ITP Fuel Specific Activities
Petcoke **(90-184 TBTU)**	‣ Improve cost-effectiveness of small gasifiers through development of air blown gasification or other cost reduction approaches for industrial applications *(Process Integration Sub-element)* ‣ Determine regulatory barriers to use of pet coke in fluidized bed combustors and industrial boilers/heaters *(Tech. Analysis & Education Sub-element)*
Coal **(143-358 TBTU)**	‣ Improve cost-effectiveness of small gasifiers through development of air blown gasification or other cost reduction approaches for industrial applications *(Tech. Analysis & Education Sub-element)*
MSW **(10-20 TBTU)**	‣ Convene industry-municipality-waste agency collaboratives to identify & execute projects. *(Tech. Analysis & Education Sub-element)* ‣ Characterize displacement opportunities for NG by direct combustion of opportunity fuels including development of emission profiles for industrial combustion of various opportunity fuels
Biomass **(6-12 TBTU)**	‣ Convene industry-agriculture collaboratives to identify & execute projects. *(Tech. Analysis & Education Sub-element)* ‣ Evaluate and analyze the relative economics, energy efficiency, emissions impacts and deployment issues of biomass in industrial boilers and gasifiers *(Tech. Analysis & Education Sub-element)*
Black Liquor **(16-32 TBTU)**	‣ Develop adequate clean-up systems for the medium Btu gas *(Process Integration Sub-element)* ‣ Demonstrate higher reliability gasification islands; Prove MTCI reforming for kraft liquor *(Tech. Validation Sub-element)*
Gas By-products **(20-40 TBTU)**	‣ Conduct detailed assessment of energy contained in gas by-products, in terms of gas type, heating value, process/industry, and geographical distribution. *(Tech. Analysis & Education Sub-element)*

Representative ITP Cross-Cutting Activities
‣ Explore the potential of regulatory reform for exporting electricity (or other forms of energy) from industrial facilities, such as black liquor gasifiers to nearby users. (Tech. Analysis & Education Sub-element)
‣ Conduct stakeholder outreach (Tech. Analysis & Education Sub-element)
‣ Optimize existing burners and fuel supply headers to run boilers on lower Btu gas (150 – 200 Btu/scf) Process Integration Sub-element)
‣ Model cost and efficiency effects of alternative fuels on refining equipment. (Tech. Analysis & Education Sub-element)
‣ Deploy EPACT loan guarantees, possibly in concert with the ITP commercialization program. (Tech. Validation Sub-element)
‣ Evaluate impact of low and medium BTU syngas on process heating- product quality, controllability, throughput, emissions Tech. Analysis & Education Sub-element)
‣ Evaluate and analyze the comparative performance, cost and operating economics of various gasification operations (Tech. Analysis & Education Sub-element)
‣ Evaluate tradeoffs between large, central gasifiers versus small, on-site modular gasifiers- i.e. capex and opex, market penetration (Tech. Analysis & Education Sub-element)
‣ Evaluate and analyze the relative economics, energy efficiency, emissions impacts and deployment issues of: combustion versus gasification, centralized gasification versus modular on-site units, low Btu gas versus medium Btu gas, use in CHP versus straight steam generation (Tech. Analysis & Education Sub-element)
‣ Explore opportunities to displace natural gas by electricity in process heating and identify key areas in which electro-technology can be beneficial (Tech. Analysis & Education Sub-element)
‣ Understand opportunities to co-locate industrial steam users with utility powerplants; understand key decision making factors (Tech. Analysis & Education Sub-element)

REFERENCES

American Forest & Paper Association, *AGENDA 2020: A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry*, November 1994.

Babu, Suresh, PhD, *Observations on the Current Status of Biomass Gasification*, May 2, 2005.

Bechtel, Global Energy, and Nexant, *Gasification Plant Cost and Performance Optimization* National Energy Technology Laboratory: 2002, p. 33.

Bloomberg- financial data provider.

BNP Media, *Furnace Demographic Survey*, April 2005.

Booz Allen, *The Industrial Fuel Flexibility Workshop: Initial Stakeholder Feedback*, October 2006.

BP Statistical Review of World Energy, June 2005 (accessed January 2007); available from: http://www.bp.com/sectiongenericarticle.do?categoryId=9010933&contentId=7021561 .

DOE- ORNL, DOE/GO-102995-2135: *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005.

Energy and Environmental Analysis, Inc., *Characterization of the U.S. Industrial Commercial Boiler Population*, May 2005.

Energy and Environmental Analysis, Inc., *CHP Installation Database*.

Energy and Environmental Analysis, Inc., *Assessment of Near-Term Large CHP Market* April, 2004, p. 14-15.

Energy Information Administration, *Analysis of S.139, the Climate Stewardship Act of 2003: Highlights and Summary*, Washington: 2003, p. 22.

Energy Information Administration, *Annual Energy Review 2005*, Table 2.1d.

Energy Information Administration, *Annual Energy Review* 2006; EIA MECS 2002.

Energy Information Administration, *Annual Energy Outlook 2007* Washington: 2007. Table 11.

Energy Information Administration, *Coal Transportation Rate Database, Average Utility Contract Coal Transportation Rate per Ton-Mile by Transportation Mode*, 1979-1997.

Energy Information Administration, *Coal Transportation Rate Database*, *Modal Shares of Utility Contract Coal Tonnage*, 1979, 1987, 1995, and 1997.

Energy Information Administration, *Manufacturing Energy Consumption Survey - Table 5.2: End Uses of Fuel Consumption*, 2002.

Energy Information Administration, *Monthly Energy Review Dec. 2006*, Table 9.11.

Energy Information Administration, *Petroleum Navigator – Refinery Net Production*, 2005.

Energy Publishing, LLC. *Domestic and International Petcoke Report*, January 2006.

Environment Canada Innovation, Monitoring, and Industrial Sectors section, *Environment Technological Innovation* Montreal: 2005, p 5.

Fuel Cells 2000, *Fuel Cell Basics – Types*. Viewed online at http://www.fuelcells.org/basics/types.html on 1/10/2007.

Georgia Department of Natural Resources, Environmental Protection Division, Air Protection Branch*, Waste Classification Guide* (accessed January 2007); available at www.georgiaair.org/airpermit/.

Improving Process Heating System Performance: A Sourcebook for Industry, DOE EERE ITP.

Jain, Ramesh, Industrial Technologies Program, *Identifying Opportunities and Impacts of Fuel Switching in the Industrial Sector*, June 2006.

Larson, Eric D., Stefano Consoni, and Ryan Katofsky. *A Cost-Benefit Assessment of Biomass Gasification Power Generation in the Pulp and Paper Industry*, October 8, 2003.

Mark S. Bohn and Charles B. Beham, *A Comparative Study of Alternative Flowsheets Using Orimulsion™ as Feedstock*, October 1999.

Narula, Ram, *Challenges and Economics of Using Petroleum Coke for Power Generation*, World Energy Council, (accessed January 2007); available from http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/1_2_26.asp .

National Academies of Science, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs (2004)*, 33.

National Renewable Energy Laboratory, *United States National Solar Radiation and Wind Resources Maps*.

National Renewable Energy Laboratory, EL, *Gas-Fired Distributed Energy Resource Technology Characterizations*, 1-7.

NREL/ORNL, NREL/TP-510-33502: *Highlights of Biopower Technical Assessment: State of the Industry and Technology*, April 2003.

Overend, Ralph P., Stanford University: Global Climate and Energy Project (GCEP), *Thermochemical Biomass Gasification Technologies and Products*, April, 27, 2004.

Solid Waste Management in Florida, *Solid Waste Management 1999 Annual Report*, Chapter 4: Landfill Disposal, August 1999.

The World Coal Institute, *The Coal Resource – A Comprehensive Overview of Coal* (accessed January 2007); available from: http://www.worldcoal.org/pages/content/index.asp?PageID=37 .

United Nations Development Programme *World Energy Assessment* (2000), 287.

U.S. Department of Energy – Gas Technologies Council, *2004 World Gasification Survey,* September 2005 (accessed January 2007); available from: http://www.netl.doe.gov/publications/brochures/pdfs/Gasification_Brochure.pdf .

USEPA, Landfill Methane Outreach Program (LMOP), *An Overview of Landfill Gas Energy in the U.S.*, April 2006.