Novel Process for Management of Tars and Oils from Waste Gasification

June 24, 2005

Developer's NAIC: 562213 Solid Waste Combustors and Incinerators *

Science/Technology Fields: Biomass, Cogeneration, Fluidized-bed combustion

Arena NAIC: 334513 Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables; 562213 Solid Waste Combustors and Incinerators; 221119 Other Electric Power Generation *

Library of Congress Subject Heading: TK1001-1841 Electrical engineering; Production of electric energy or power

Technology Type: Product and Process

Supply Chain: Power/Design and Development; Power/Processing Tools and Techniques; & Power/Disposal and/or Recycling

International Patent Classification: Section H02: Generation, Conversion, or Distribution of Electric Power — Subsection N: Electric Machines Not Otherwise Provided For — 3/00: Generators in which Thermal or Kinetic Energy is Converted into Electrical Energy

Geographic Region: Primarily North America, with some application internationally

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1 Executive Summary

The following is a non-proprietary description of this technology.

Non-Proprietary Description of Technology
The technology generates a low to medium-btu producer gas through a novel fixed-bed gasifier that integrated entrained-flow features. This technology DOES NOT REQUIRE the tar cracking or steam reforming normally required downstream of a gasifier. The proprietary process is considerably less complex than current methods, reducing overall capital and operating costs of gasification equipment by up to 20%. It is effective with a wide variety of feedstocks — coal, biomass, waste tires, municipal waste, construction & demolition debris, etc. and can be applied to electrical power applications using steam boilers, reciprocating engines or gas turbines. The technology can also be used for NOx reburning applications in existing coal boilers. [1]

— Redacted —'s technology deals with the gasification of biomass substrates, creating a synthesis gas of moderate BTU content; such processes are increasingly being looked to, to develop alternatives to the use of petroleum and petroleum products for energy generation and for specialty chemical production. Fossil fuels presently account for 80 percent of the energy used in the US; these are finite resources which will eventually become exhausted.[2] To the extent petroleum products can be replaced by similar products generated from renewable resources, such as biomass, the negative impact on the world economy from the phasing out of petroleum can be moderated.

— Redacted —'s technology at this stage is very embryonic; moreover, the primary industry in which its technology is designed to compete — electricity generation through gasification of biomass — is itself embryonic. The bioproducts industry is newly emerging as an individual entity and is not established under a single North American Industrial Classification System (NAICS) code. Companies producing biomass feedstocks and/or bioproducts fall under food processing (NAICS 311), chemicals (NAICS 325) or under multiple classifications (see Table 1). Other materials manufactured from biomass, as well as from other sources such as petrochemicals, and products that are used for food rather than industrial purposes, are also reported. This overlap makes it difficult to aggregate statistics for the bioproducts industry.[3]

Table 1 — NAICS Characterization of the Bioproducts Industry[4]

NAICS	Major Products	% Industrial Bioproducts
825193 Ethyl alcohol fermented	Non-potable ethanol for fuel and industrial purposes	3 – 5%
825191 Gum and wood chemical manufacturing	Rosin, pine oil, turpentine, wood alcohol	100%
825221 Celluloic manmade fibers	Cellulose acetate, acetate fibers, cellulose fibers, regenerated cellulose fibers	100%
811221 Wet corn milling	Corn sweeteners, starch and dexedrin, corn oil, corn gluten	26%
811222 Soybean oil	Soybean cake and meal, soybean oil, soybean protein	4 – 6%
811223 Other oilwood processing	Cottonweed oil and binders, linseed oil, palm oil	2 – 100%
825611 Soap and other	Detergent, soap, glycerin,	11%

[1] Written description provided by — Redacted — to Norm Brown, August 2, 2005.
[2] *North American Biomass and Waste-to-Energy Markets*, Frost & Sullivan; 28 May 2003; p. 14.
[3] *Industrial Bioproducts: Today and Tomorrow*, US Department of Energy, Office of the Biomass Program, July, 2003; p.3
[4] *Ibid.*

detergents	washing compounds	
825613 Surface acting agents	Calcium and sodium salts of oils, fats or greases, soluble oils and greases	85%

— Redacted — also considers its technology as suitable for a secondary application in industrial processing, where natural gas or liquid natural gas is currently used as a heating source, such as in metal refining, smelting and fabricating. The NAICS code for Steel Foundries, which is taken as representative of this general class, is 331513.[5]

What makes this technology a scientific/engineering innovation is primarily its ability to gasify biomass in a process which is (A) less complex than current gasification processes, due to elimination of one or more purification steps, thus reducing both capital/equipment and processing costs; and (B) capable of producing a syngas product which is cleaner than that produced by competing approaches. — Redacted —'s description of these advantages is found below:

Non-Proprietary Description of the Key Innovation(s) Underlying the Technology[6]

The — Redacted — Reactor enables the primary fuel to be pyrolyzed, and subsequently gasified in a coarse-fed, fixed-bed gasifier or a fluid-bed gasifier. The pyrolysis gases can be upgraded using less gas cleaning and gas conditioning steps. Various other gasification applications of the Reactor; include, but are not limited to the following processes:

- Gasification of various feedstocks in a coarse-fed or fluid-bed gasifier; for example, but not limited to, woods and forest products, agriculture and cultivar residual, animal manures, slaughter residue, waste tires, municipal waste, construction and demolition debris, and other forms of biomass.
- Gasification of low-BTU fuels, where the syngas quality is upgraded for high value use.
- Gasification of fuels containing hazardous constituents when it is necessary to thermally oxidize the hazardous constituents, without deference to significant feedstock materials handling costs.
- Extracting and reforming or reacting landfill gas, coal-bed gas, and chemical spill vapors emanating from a soil plume.
- Near field oil or gas steam reforming and production of hydrogen for crude sweetening and carbon dioxide for enhance oil recovery

— Redacted —'s Reactor has utility to the petrochemical industry, removing and react reactor gases at a specific location in a chemical process such as a distillation column. Specific examples and benefits of this potential application include:

- A new partial or complete reboiler that simultaneously cracks and reforms the heavy bottoms
- A new, small, custom reactor for in-situ reaction (e.g., either hydrogenation or oxygenation) of the heavy bottoms, or organic components at a specific tray gas stream.
- Disruption of azeotropic liquid mixtures by extracting, reacting, and/or rerouting a given constituent.

As is evident from the Non-Proprietary description above, there are a number of applications for — Redacted —'s technology, but these fall generally into two distinct application areas. The first set of bulleted applications deals with generation of electricity from a number of non-petrochemical feedstocks; though — Redacted — has also indicated that its process can also be directed toward coal, tar sand and oil shale processing, its primary application is in processing of biomass. Biomass gasification normally

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[5] US Census, 2002 NAICS Definitions, 331513 Steel Foundries (except Investment), from NAICS website: http://www.census.gov/epcd/naics02/def/ND331513.HTM

[6] Written description provided by — Redacted — to Norm Brown, August 2, 2005.

results in “tars” and “bottoms” which are difficult to crack and which require additional processing steps[7]; the advantage of — Redacted —’s approach is that these materials are cracked as an integral part of — Redacted —’s process and thus result in a cleaner gas which does not require additional processing steps.

The second set of bulleted applications of the — Redacted — technology shows the utility of the technology in producing clean syngas for use as a lower-cost replacement for natural gas or liquid natural gas. This secondary market application could be utilized in metals, clays and advanced materials manufacture where gas-fired kilns, boilers or smelters are used. Since the technology’s primary market — generation of electricity from biomass — is extremely embryonic, with negligible commercial capacity at present in North America,[8] — Redacted — sees the secondary market of kiln/smelter firing as offering an immediate, if somewhat smaller, initial market opportunity.

This Report will therefore address both market segments: the Primary Market of biomass energy generation, and the Secondary Market of natural gas-replacement in metals and materials processing. — Redacted — Energy Company wishes to elicit support from electric generation organizations (public utilities or equipment/refinery owners) for co-development of a scaled-up demonstration project featuring — Redacted —’s technology, offering licenses of that technology in return for such support.

The end-user is defined as the person who ultimately uses the technology. Commercialization occurs when end-users buy the technology to utilize it in a practical application. For — Redacted —’s Primary and Secondary Markets, the end users are

End-User(s)

Primary Market — Energy Generation from Biomass:

— Redacted —’s technology is infrastructural, adding capacity to a wide number of potential markets. — Redacted — will be seeking industrial intermediary partners, such as electricity generating companies and utilities; landfill and municipal waste handlers; farm, forest and livestock managers. petrochemical suppliers and refineries, and transportation entities building a “hydrogen economy” for the future.[9] The ultimate end-user (consumer) of biomass-generated electricity is the same end-user for coal-, hydro-, or nuclear-generated electricity — the residential or commercial customer using the generated electricity. But such end-users are many years away from being routinely supplied with electricity generated by — Redacted —’s process. Instead, — Redacted — must deal with interim-users — the engineers, builders and designers who will be selecting and constructing the electricity generating facilities over the next 20 years or so.

For purposes of this study, therefore. interim-users will be addressed for — Redacted —’s primary market, rather than end-users. For these applications of — Redacted —’s technology (power generation, waste handling, and petro-substitute production), the first-implementers will be engineers of various specializations. The US Bureau of Labor Statistics identifies 15 subspecialties in the engineering field, and the majority of these can have involvement with the kind of projects which — Redacted — may deal with. Of these 15, the following specialties appear relevant:

Agricultural	Biological	Chemical	Civil	Electrical
Environmental	Industrial	Materials	Mechanical	Petroleum

Engineers apply the theories and principles of science and mathematics to research and develop economical

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7 Murphy, Michael, *Repowering Options: Retrofit of Coal-Fired Power Boilers using Fluidized Bed Biomass Gasification*, Energy Products of Idaho; May, 2001, p. 4.

8 *North American Biomass and Waste-to-Energy Markets*, Frost & Sullivan; 28 May 2003; p. 5.

9 Phillips, Ben, “Strategic Analysis” *Monograph*, Emery Energy Company; May 27, 2005; pp. 3-4.

solutions to technical problems. Their work is the link between perceived social needs and commercial applications. Engineers design products, machinery to build those products, plants in which those products are made, and the systems that ensure the quality of the products and the efficiency of the workforce and manufacturing process. Engineers design, plan, and supervise the construction of buildings, highways, and transit systems. They develop and implement improved ways to extract, process, and use raw materials, such as petroleum and natural gas. They develop new materials that both improve the performance of products and take advantage of advances in technology. They harness the power of the sun, the Earth, atoms, and electricity for use in supplying the Nation's power needs, and create millions of products using power. They analyze the impact of the products they develop or the systems they design on the environment and on people using them. Engineering knowledge is applied to improving many things, including the quality of healthcare, the safety of food products, and the operation of financial systems.

Engineers consider many factors when developing a new product. For example, in developing an industrial robot, engineers determine precisely what function the robot needs to perform; design and test the robot's components; fit the components together in an integrated plan; and evaluate the design's overall effectiveness, cost, reliability, and safety. This process applies to many different products, such as chemicals, computers, gas turbines, helicopters, and toys.

In addition to design and development, many engineers work in testing, production, or maintenance. These engineers supervise production in factories, determine the causes of breakdowns, and test manufactured products to maintain quality. They also estimate the time and cost to complete projects. Some move into engineering management or into sales. In sales, an engineering background enables them to discuss technical aspects and assist in product planning, installation, and use.

Most engineers specialize. More than 25 major specialties are recognized by professional societies, and the major branches have numerous subdivisions. Some examples include structural and transportation engineering, which are subdivisions of civil engineering; and ceramic, metallurgical, and polymer engineering, which are subdivisions of materials engineering. Engineers also may specialize in one industry, such as motor vehicles, or in one field of technology, such as turbines or semiconductor materials.

This statement, which contains an overall discussion of engineering, is followed by separate statements on 14 branches of engineering: Aerospace; agricultural; biomedical; chemical; civil; computer hardware; electrical and electronics, except computer; environmental; industrial, including health and safety; materials; mechanical; mining and geological, including mining safety; nuclear; and petroleum engineering. Some branches of engineering not covered in detail in the *Handbook*, but for which there are established college programs, include architectural engineering—the design of a building's internal support structure; and marine engineering—the design and installation of ship machinery and propulsion systems.

Engineers in each branch have a base of knowledge and training that can be applied in many fields. Electronics engineers, for example, work in the medical, computer, communications, and missile guidance fields. Because there are many separate problems to solve in a large engineering project, engineers in one field often work closely with specialists in other scientific, engineering, and business occupations.

Engineers use computers to produce and analyze designs; to simulate and test how a machine, structure, or system operates; and to generate specifications for parts. Using the Internet or related communications systems, engineers can collaborate on designs with other engineers around the country or even abroad. Many engineers also use computers to monitor product quality and control process efficiency. They spend a great deal of time writing reports and consulting with other engineers, as complex projects often require an interdisciplinary team of engineers. Supervisory engineers are responsible for major components or entire projects.[10]

Secondary Market — Kilns, Smelters & Boilers:

The secondary market for — Redacted —'s technology consists of industrial concerns currently using natural gas as part of manufacturing, especially metals, clays, and advanced materials requiring a high-heat phase. Taking steel

[10] Bureau of Labor Statistics, US Department of Labor, Career Guide to Industries, 2004-05 Edition, Engineering, on the Internet at http://bls.gov/oco/ocos027.htm (visited July 1, 2005).
[11] Bureau of Labor Statistics, US Department of Labor, Career Guide to Industries, 2004-05 Edition, Engineering, on the Internet at http://bls.gov/oco/cg/cgs014.htm (visited August 1, 2005).

manufacturing as illustrative, the Bureau of Labor Statistics shows a competitive and declining market. Faced with international competition and a worldwide glut of steel, the U.S. steel industry continues to respond by modernizing its manufacturing processes and consolidating businesses to increase productivity. Despite successful efforts to reduce costs and an improving competitive position, steel manufacturing firms still face stiff competition, and employment is expected to continue to decline. However, investment in modern equipment and worker training has transformed the U.S. steel industry from one of the Nation's most moribund to one of the world's leaders in worker productivity and the lowest cost producer for some types of steel.

Establishments in this industry produce steel by melting iron ore, scrap metal, and other additives in furnaces. The molten metal output is then solidified into semifinished shapes before it is rolled, drawn, cast, and extruded to make sheet, rod, bar, tubing, and wire. Other establishments in the industry make finished steel products directly from purchased steel.

The least costly method of making steel uses scrap metal as its base. Steel scrap from many sources—such as old bridges, refrigerators, and automobiles—and other additives are placed in an electric arc furnace, where the intense heat produced by carbon electrodes melts the scrap, converting it into molten steel. Establishments that use this method of producing steel are called electric arc furnace (EAF) mills, or minimills. The smaller initial capital investment required to start and operate an EAF mill has helped drive the growth of this production method. Moreover, scrap metal is found in all parts of the country, so EAFs are not tied as closely to raw material deposits as are integrated mills and can be placed closer to consumers. EAFs now account for about half of American steel production, and their share is expected to continue to grow in coming years.

The growth of EAFs comes partly at the expense of integrated mills. Integrated mills reduce iron ore to molten pig iron in blast furnaces. The iron is then sent to the oxygen furnace, where it is combined with scrap to make molten steel. The steel produced by integrated mills generally is considered to be of higher quality than steel from EAFs but, because more steps are involved in the production process, it also is more costly. The initial step in the integrated mill process is to prepare coal for use in a blast furnace by converting it to coke. Coal is heated in coke ovens to remove impurities and to reduce it to nearly pure carbon.

At the other end of the steel manufacturing process, semifinished steel from either EAFs or integrated mills is converted into finished products. Some of the goods produced in finishing mills are steel wire, pipe, bars, rods, and sheets. Products also may be coated with chemicals, paints, or other metals that give the steel desired characteristics for various industries and consumers. Also involved in steel manufacturing are firms that produce alloys by adding materials such as silicon and manganese to the steel. Varying the amounts of carbon and other elements contained in the final product can yield thousands of different types of steel, each with specific properties suited for a particular use.

Steel companies, like most businesses, have entered the era of sophisticated technology. Taking several forms, this technology has improved both product quality and worker productivity. Computers are essential to most technological advances in steel production, from production scheduling and machine control to metallurgical analysis. Computerized systems change the nature of many jobs, while they eliminate or reduce the demand for others.

For workers, modernization of integrated and EAF steel mills often has meant learning new skills to operate sophisticated equipment. Competition also has resulted in increasing specialization of steel production, as various producers attempt to capture different niches in the market. With these changes has come a growing emphasis on flexibility and adaptability for both workers and production technology. As international and domestic competition continue for U.S. steel producers, the nature of the industry and the jobs of its workers are expected to continue to change.

The expense of plant and machinery and significant production startup costs force most mills to operate around the clock, 7 days a week. Workers averaged 43 hours per week in 2002, and only about 2 percent of workers are employed part time. Workers typically work varying shifts, switching between working days one week and nights the next. Some mills operate two 12-hour shifts, while others operate three 8-hour shifts. Overtime work during peak production periods is common.

Employment in the steel industry declined to about 170,000 wage and salary jobs in 2002, 80,000 fewer than in 1992. The steel industry traditionally has been located in the eastern and midwestern regions of the country, where iron ore, coal, or one of the other natural resources required for steel are found. Even today, about 46 percent of all steelworkers are employed in Pennsylvania, Ohio, and Indiana. The growth of EAFs has allowed steelmaking to spread to virtually all parts of the country, although many firms find lower cost rural areas the most attractive. Large firms employ most workers in the steel industry. More than 65 percent of the jobs in 2002 were in establishments employing at least 250 workers.

Employment in the steel industry is expected to decline 20 percent over the 2002-12 period, primarily due to increasing consolidation in the industry as companies go out of business or are bought by other companies in the industry and their operations merge. A worldwide glut of steel and production overcapacity domestically, unless checked, will cause prices to decline to unprofitable levels and require mills to either become more productive or go out of business. As mills either consolidate or close, the result will be fewer workers, but a more productive industry that will be better able to meet foreign competition.

EAF mills, with their leaner workforce and lower cost structure, are expected to benefit from the industry's transformation and will continue to gain market share. They now produce nearly 50 percent of the country's steel, up from 25 percent two decades ago. They are also attempting to improve the quality of the steel they make by melting pig iron along with the scrap. In this way, they can more effectively compete with integrated mills in markets that demand higher quality steel. Thus, as EAFs continue to grow in relation to integrated mills, job opportunities will be better at these mills. [11]

The above-cited description of steel foundry processes highlights a possible problem for — Redacted — in targeting such businesses for its secondary market. The reliance by steel furnaces on electric arc heating makes them less ideal as prospects for syngas burning. Natural gas is no longer seen as the most efficient process for small- to medium-sized foundries, so the issue of syngas replacement of natural gas is no longer relevant.[12] Natural gas is still in use in many such foundries, but for pre-warming and post-casting applications; since these applications use much less energy than the core melting processes, the advantage of reduced-cost biomass is reduced and the "hassle" of setting up biomass processors is proportionately greater.[13]

An application is a potential use for a technology that is based on end-user needs and could provide a feasible market opportunity for the technology. The following table presents our choice for an initial market entry application.

Recommended Application
Primary: Waste Biomass-to-Energy Conversion for Generation of Electricity.
Secondary: Production of Syngas to Supplement/Replace Natural Gas at Foundries, Smelters and the like.

— Redacted —'s technology addresses the heart of what's been called the "bioproducts revolution," a movement to reduce the world's economic dependence on petroleum. The Biomass Research and Development Board has suggested that we are currently "witnessing the beginning of revolutionary developments in biosciences and engineering that during this century will transform life as we know it."[14] Key among the anticipated advantages of this revolution are: economically competitive alternatives to fossil fuel and reduced dependence on foreign oil; vastly expanded and lower cost consumer and industrial products; improved environmental quality; increased economic opportunities, especially in rural, farm and forest areas; and increased exports.[15]

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[12] Michael Williams (Senior VP of Power Operations, Progress Energy Carolinas, Inc.), 919.546.6640, in a telecon with N. Brown, August 5, 2005.

[13] *Ibid.*

[14] Gonzales, Miley and Reicher, Dan, "Message from the Board Co-Chairs," in *Fostering the Bioeconomic Revolution in Biobased Products and Bioenergy*, Biomass Research and Development Board (US Department of Agreiculture and US Department of Energy); January, 2001, p.2.

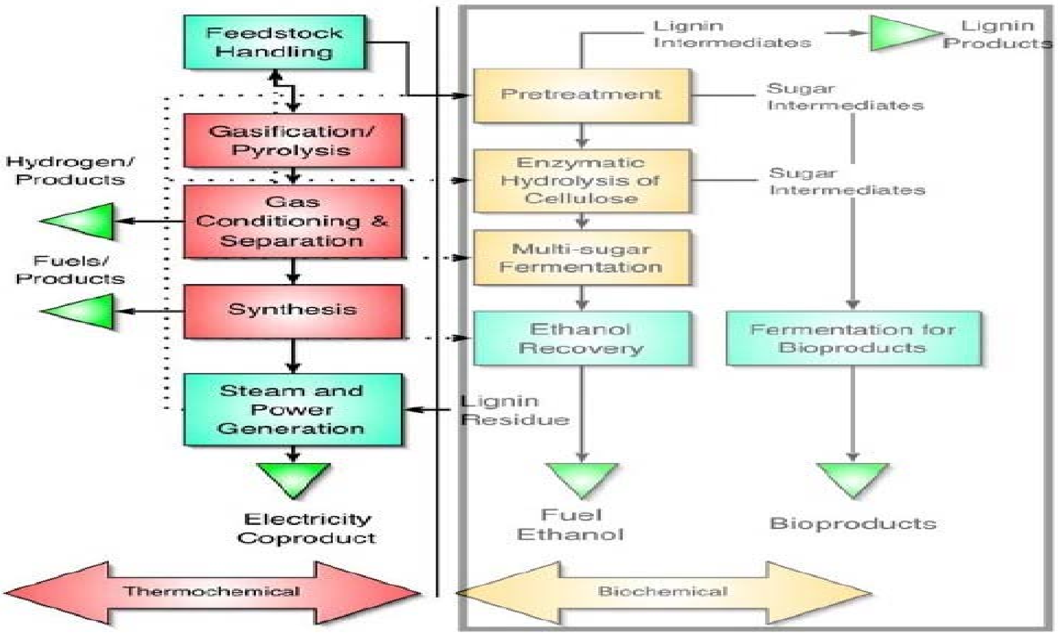
[15] *Ibid.*

So the scope of the markets — Redacted — addresses is extremely broad; this is understandable since petroleum is the core of such a large part of the world economy. Petroleum provides fuels for transportation, heating, generation of electricity, and the like; and petroleum is the basis for a galaxy of industrial and consumer products such as lubricants, fertilizers, cosmetics, pharmaceuticals, and a multitude of others. But petroleum is a finite resource, irreplaceable within any reasonable time span. So it is obvious that alternatives to petroleum must be found or civilization as we know it is likely to undergo profound change.

— Redacted —'s technology addresses the possibility of utilizing biomass to replace a number of these applications currently served by petroleum. Specifically, — Redacted —'s technology facilitates the production of synthetic, or "producer" gas (called "syngas" throughout this report) from biomass; the syngas can then be burned for heat. A primary use of such heat can be to drive turbines which generate electricity; a secondary use of such heat can be to melt clays, metals and the like in industrial processes of many kinds. In addition, this same process can be made to chemically treat the biomass to produce physical products made from the biomass' chemical constituents; these constituents are very similar to those found in petrochemical substrates such as coal and oil[16], which gives rise to the prospect of replacing a number of products currently available only from petroleum. A key one of those products is transportation fuel; — Redacted —'s syngas can be further processed into gasoline or diesel fuel substitutes.

Description of Use in Practice
The — Redacted — technology's primary use is as part of a complex process which receives organic matter, called "biomass," and combusts this material in a tightly-controlled fashion and with limited oxygen. The resulting reactions generate heat, which can be diverted through steam or gas turbines for the production of electricity. As a further result of the reactions, part of the biomass is converted to syngas capable of powering transportation vehicles. The process also produces small amounts of ash or char, which can either be disposed of or, in some cases, converted to industrial uses. Each plant built to incorporate biomass is somewhat unique, depending on purpose, process, feedstock and environment; however, a generalized schematic of the biorefinery process is shown below Figure 1: Biomass Conversion Schematic[17]:

[16] Bain, Richard, "Biomass Gasification Overview," National Renewable Energy Laboratory; January 28, 2004, p. 3.



There are two principal avenues for converting biomass. The unshaded process at the left represents the generic thermochemical approach, in which family the Emery process is represented. A competitive biochemical approach is shown in the shaded portion to the right.

Gasification is any chemical or heat process which converts a substance to a gas.[18] In the gasification of biomass, heat is used in a chamber with limited oxygen, about one-third the amount needed for full combustion. In such an environment, the biomass gasifies into a "syngas" composed mostly of hydrogen and carbon monoxide.[19] This syngas can be further processed to produce hydrogen. The syngas can also be converted to sulfur-free fuels for transportation, using a catalytic process known as the Fischer-Tropsch Process, or provide base chemicals for producing biobased products.[20] Meanwhile, the heat generated even by this partial combustion of the biomass is sufficient to make steam which can drive turbines and generate electricity. Thus, in one complex process, biomaterials can be made to generate electricity, fuels and carbon-based products. Since irreplaceable petroleum is currently being employed for all these uses, it's clear to see the potential advantages of a biomass-based energy and production infrastructure.

Furthermore, the biomass used as raw material for this process has two significant advantages: [1] biomass is by definition renewable, since its origin is living organisms which can reproduce; and [2] an additional advantage of the process is that it can use biomass which otherwise would be expensive to dispose of in some other fashion. For example, over 255 million tons of trash are generated per year in North America, and the number of landfills available to receive this waste is declining.[21] A significant portion of this waste is biomass, in various forms of paper, wood and food waste; not only is there a cost to processing this waste in existing landfills, but if not treated, this biomass portion of Municipal Solid

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[17] Office of the Biomass Program, *Biomass Program Multi-Year Technical Plan*, US Department of Energy; September 30, 2005, p. 11
[18] Access Science, McGraw Hill Companies, http://www.accessscience.com/search/asearch?location=titlestext&newSearch=1&pubpriv=private&categories=dictionary&categval=dictionary&text=gasification (accessed July 1, 2005).
[19] "The Biomass Economy," NREL Journal/JA-810-31967, National Renewable Energy Laboratory, US Department of Energy,; July, 2002, p. 3.
[20] *Ibid.*
[21] *North American Biomass and Waste-to-Energy Markets*, Frost & Sullivan; 28 May 2003; p. 16.

Waste (“MSW”) decomposes and produces methane, a greenhouse gas 23 times more potent than carbon dioxide.[22] The — Redacted — technology thus has the prospect of solving two significant economic problems simultaneously — alleviating the problem of biowaste disposal, while at the same time producing much-needed energy and organic compounds, all with reduced negative impact on the environment. As one person in the electric generation business commented, “This sounds too good to be true.”[23]

These end-users work in a segment of the economy. Forces in the arena can support or threaten commercialization.

Arena Dynamics
The arena dynamics impacting — Redacted —’s technology are significant and plentiful. The most important of these are: 1. Rising worldwide demand for energy for electricity and transportation 2. Rising demand for non-energy petroleum derivatives 3. Rising worldwide demand for more efficient waste management 4. Decreasing supply of irreplaceable hydrocarbon resources (petroleum, coal, natural gas) 5. Worldwide concern for the environment, including greenhouse gases, global warming and pollution 6. Politico-economic need for greater independence from foreign petroleum resources

1. Rising world wide demand for energy for electricity and transportation

Total energy consumption is projected by the US Department of Energy (”DOE”) to rise from 98.2 quadrillion British thermal units in 2003 to 133.2 quadrillion in 2025, an average annual growth rate of 1.4%[24] This growth can be shown by Sector or by Fuel:

Figure 2: Delivered energy consumption by sector, 1970 – 2025 (quadrillion Btu)[25]

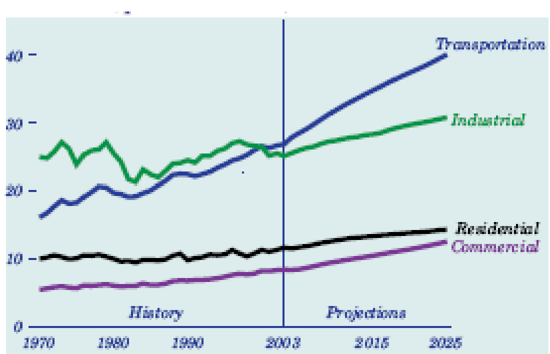
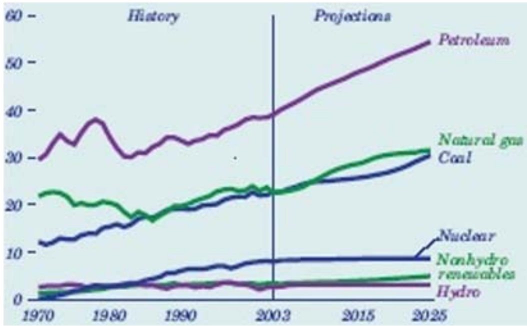


Figure 3: Energy consumption by fuel, 1970 – 2025 (quadrillion Btu)[26]

[22] Executive Committee of the International Energy Agency, “Municipal Solid Waste and its Role in Sustainability,” *IEA Bioenergy*, Abington, UK; February, 2003, p. 2.
[23] Michael Williams (Senior VP of Power Operations, Progress Energy Carolinas, Inc.), 919.546.6640, in a telecon with N. Brown, August 5, 2005.
[24] *Annual Energy Outlook 2005*, Energy Information Administration, US Department of Energy; February, 2005, p. 9
[25] *Ibid.*, p. 4.
[26] *Ibid.*, p. 5.



2. Rising demand for non-energy petroleum derivatives

Petroleum is used for much more than energy. The chemical industry today produces more than 80 billion pounds of plastic products per year; the great majority of these products are based on petroleum-derived materials.[27] These markets are also threatened by the eventual exhaustion of petroleum resources, and biomass is uniquely positioned to fill this looming need. Unlike other renewable energy sources such as solar, wind and geothermal, "biomass is the only renewable that can meet our demand for carbon-based liquid fuels and chemicals."[28] If manufacturing costs of biobased plastics and surfactants could be reduced 30% - 50% from today's levels, biobased products could generate as much as 3 billion pounds of organic products by 2010.[29]

3. Rising worldwide demand for more efficient waste management

The 255 annual tons of Municipal Solid Waste, cited earlier, creates a pressing need for disposal methodologies. The number of landfills available to receive this trash has actually declined by 70% over the past 15 years,[30] increasing the cost and distance for trucking the waste from the place of origin to the landfill site. "Tipping fees," the payment to the landfill to accept the waste, have also climbed to a national average of over $35 per ton. Companies nationwide, but especially in the East Coast with higher population densities, are looking for new means to dispose of all this waste.[31]

4. Decreasing supply of irreplaceable hydrocarbon resources (petroleum, coal, natural gas)

Petroleum and gas are irreplaceable resources and will eventually become exhausted. Although new sources of oil are continually being discovered, and more efficient extraction technologies are always possible, the US Energy Information Agency predicts a sharp fall-off in available petrochemical resources by 2025:

Figure 4: Projected Worldwide Oil Supply[32]

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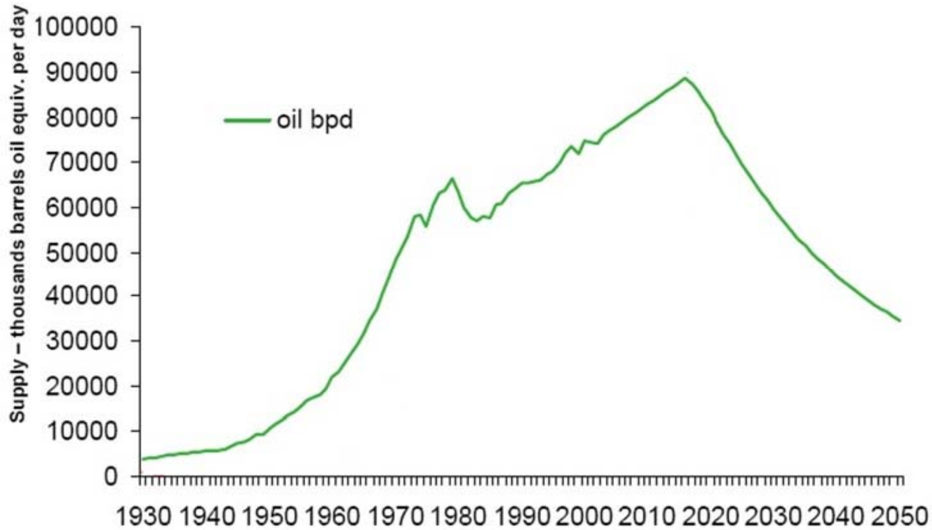
[27] *Fostering the Bioeconomic Revolution in Biobased Products and Energy*, Biomass Research and Development Board, US Departments of Agriculture, Energy and Interior; January, 2001, p. 8.
[28] Bain, Richard, "Biomass Gasification Overview," National Renewable Energy Laboratory; January 28, 2004, p. 3.
[29] *Fostering the Bioeconomic Revolution in Biobased Products and Energy*, Biomass Research and Development Board, US Departments of Agriculture, Energy and Interior; January, 2001, p. 8.
[30] *North American Biomass and Waste-to-Energy Markets*, Frost & Sullivan; 28 May 2003; p. 9.
[31] *Ibid.*
[32] Westwood, John, The World Oil Supply Report 2004-2050, cited in "Global Energy Trends," p. 6, downloaded from Douglas-Westwood Limited website, http://www.dw-1.com/filemaster/t_publicfiles_template.php?filecategory=Published+Papers+%26+Articles, (accessed July 1, 2005)



The eventual depletion of oil reserves, long known as inevitable, is finally looming as a likely event within planning horizons. Clearly, the world economy must developed replacements well before that happens. "Investments made to develop fossil fuels during the first half of the 20th Century led to economic prosperity during the latter half of the 20th Century; Investment made now for renewables, biomass in particular, should lead to environmental, energy, and economic prosperity in the future."[33]

5. Worldwide concern for the environment, including greenhouse gases, global warming and pollution

Despite the non-participation of the United States, most industrialized nations have signed the Kyoto Accord, calling for reduced greenhouse emissions and better control over global warming.[34] The US government, though not signing the Kyoto Accord, nevertheless puts environmental improvement as a high priority, using technology advances and incentives to implement a national policy for reduced emissions (as opposed to punishments).[35]

6. Politico-economic need for greater independence from foreign petroleum resources

The amount of oil imported into the U.S. has been steadily rising over the last ten years, amounting to over 65% today, a proportion 15% higher than in 1973.[36] This increasing dependence of the U.S. on imported oil has become a pressing issue of national security.[37]

Figure 5: Total energy production and consumption,
1970 – 2025 (quadrillion Btu)[38]

[33] Babu, Suresh and Hofbauer, Hermann, "Status of and Prospects for Biomass Gasification," presentation to Science & Technology Conference in British Columbia; August 30, 2004, p. 18.
[34] "Europe Backs Kyoto Accord," BBC News; March 31, 2001, p. 1, http://news.bbc.co.uk/1/hi/world/europe/1252556.stm (accessed July 1, 2005)
[35] *Ibid.*
[36] *Industrial Bioproducts: Today and Tomorrow*, Office of the Biomass Program, US Department of Energy; July, 2003, p. 9.
[37] *Ibid.*
[38] *Ibid.*

Such dependence amounts to a "crisis," because we cannot be assured of constant supply or non-volatile pricing, either of which can negatively affect the American economy and military strength.[39]

IDENTIFYING THE END USER

Technologies are frequently aimed at identified end-users who can materially benefit from the features and benefits of a new technical approach or product. In the case of the electrical energy produced for the national grid, however, the ultimate end users (of the generated electricity) may not care. Electrical power for the home, office or factory is assumed by the end-user to be readily available. While end users DO care about the price of the power they use, and its uniformity, there is little evidence that these end users would influence whether the power came from traditional generation methods or via some new biomass-generation technique. The electricity produced, once uploaded into the national electric grid, is indistinguishable from electricity generated by any other means. Though environmental consciousness is growing in America, "It's still all about saving a penny" when it comes to selecting energy resources.[40] For purposes of this analysis, the ultimate end users of — Redacted —'s technology — energy consumers in the home, business and industrial realms — will be regarded as less relevant than Intermediate Consumers, defined here as business or governmental decision-makers responsible for building new electrical generating capacity; these are the ones who will decide whether to build conventional generators or to use new/experimental technology approaches such as offered by — Redacted —.

Key reasons these end-users find this technology attractive are:

Current Weaknesses and Improvements		
End-User Need	***Weakness of Current Technology***	***Improvements Offered by This Technology***
Low cost energy	Petroleum-derived energy, which accounts for 86% of all industrial energy[41], is currently at record price levels, and projections are that prices will escalate even further.[42]	This technology derives energy from biomass, which is readily renewable.

[39] National Energy Policy, Report of the National Energy Policy Development Group, chaired by Vice President Dick Cheney; May, 2001, p. iv.
[40] Ball, Jeffrey, "Texas Truckers Turn to New Type of Fuel," *Wall Street Journal*, Dow Jones; July 5, 2005; p. 1.
[41] *Annual Energy Outlook 2005*, Energy Information Administration, US Department of Energy; February, 2005, p. 9.
[42] Saefong, Myra, "Oil Settles at Record Above $62 a Barrel," *Wall Street Journal*, Dow Jones; August 5, 2005; p. 1.

Consistently-available energy	Many sources of non-petrochemical, renewable energy, such as wind or solar power, are available only intermittently (i.e., when the sun shines or the wind blows)	Biomass, whether from cultivated or waste origins, is routinely available and can be supplied without interruption.
Clean energy gas	Other biomass gasification technologies normally produce undesirable by-products such as char or ash, which foul the equipment or require additional production steps for cleaning[43]	— Redacted —'s process is believed capable of generating clean syngas, without additional manufacturing steps.

End-Users in a commodity business are frequently focused on price/cost and ease-of-use. This is consistent with what was found in this case — users want to lower their energy costs and do so without large capital investments or additional complication to their manufacturing processes.

Based on our analysis to date, which is constrained by budget and time, we estimate the market to be made up of a number of segments; which of these segments are most relevant to — Redacted — will depend on what — Redacted —'s final marketing and positioning strategy becomes. Gasification of biomass can be thought of as an "enabling tool"; like many tools, it can be applied to a number of uses. Gasification of biomass produces energy, both directly as part of the manufacturing process and indirectly by creating syngas or hydrogen, which are sources of energy which can "packaged" and transported to locations distant from the manufacturing site. If the biomass used by — Redacted —'s process happens to be Municipal Solid Waste, then the production process is also providing a service in waste management. ANY of these markets are "fair game" for the — Redacted — process. Analysis of — Redacted —'s market must therefore cover a number of possible applications, at least until — Redacted — selects one or two for narrow focus and/or specialization. Four principal application markets were considered for the — Redacted — technology: [1] Primary Energy, like the petroleum, natural gas, coal and related industries; [2] Electricity Generation, like hydroelectric, coal-fired, gas-fired and related generators of electricity; [3] Biomass Electricity Generation, like other renewable electrical energy sources like geothermal, wind, solar power; and [4] Biomass Co-Firing, which is a subset of Biomass Electricity Generation, where biomass gasification is combined with coal- or gas-fired generation. The different sizes and growth rates of these segments is provided below.

SEGMENT	***Market Size***	***Growth Rate***	***Base Year***	***Short version of Basis for Estimate***
Energy Market	98.22 quads	1.4%	2003	Primary energy consumption in the US, as projected by USDOE from 2003 through 2025[44]
Electricity Generation Market	3,892 billion kilowatts hours	3.8%	2005	Electricity capacity and generation in the US, as projected by USDOE from 2005 through 2025[45]

[43] Bain, Richard, "Biomass Gasification Overview," National Renewable Energy Laboratory; January 28, 2004, p. 11.
[44] *Annual Energy Outlook 2005*, Energy Information Administration, US Department of Energy; February, 2005, p. 9
[45] *Ibid.*, p.61

Biomass-to-Electricity Market	44.9 billion kilowatts hours	4.5%	2003	Electric power sector generation from “wood and other biomass”, combined, as projected by USDOE from 2003 through 2025[46]
Biomass Co-Firing Market	10.6 billion kilowatts hours	4.6% ’03 – ‘15 -5% ’15 – ‘25	2003	Electric power sector generation from “wood and other biomass co-firing”, combined, as projected by USDOE from 2003 through 2025[47]

A preliminary estimate of the price for this technology can be viewed either as a price for electricity generated by the process, or the price (capital cost) of a facility to produce the electricity. Taking first the price of the generated electricity, this is a “commodity” and its pricing has been forecast by the US Department of Energy as follows[48]:

Price						
	2003	**2010**	**2015**	**2020**	**2025**	**CAGR**
Average Electricity Price (per kilowatt hour)	7.4 ¢	6.6 ¢	6.9 ¢	7.2 ¢	7.3 ¢	-0.1%

Price per kilowatt hour is seen as very stable throughout this 20-year projection period, with rising energy costs being offset by greater efficiency and increased use on non-petroleum sources. Biomass energy generation must operate within this overall pricing structure. Since the current average price per kilowatt hour for biomass-produced electricity is 8 – 12 cents/kilowatt hour,[49] it is clear that either (A) costs must be brought down, and/or (B) governmental incentives or subsidies must be made available before commercial viability of biomass energy generation can be assumed.

Looking next at capital costs, the cost of a turn-key biomass gasification plant having a 300 ton/day capacity is estimated by — Redacted — Energy to be in the neighborhood of $9 million; larger, higher-capacity plants would be proportionately more expensive.[50] An expert at the Electric Power Research Institute also provided a “generic” cost model for electricity generation from biomass, as follows:[51]

10,000	Btu/kWh	$12,000,000	$ capital cost
$1,200	/kW capital cost	12	$M capital cost
$0.12	$/Btu/hr	0.20	/yr capital charge
120000	$/(MMBtu/hr) [Btu of input]	$2,400,000	/yr capital charge
5.5	MMBtu/bbl	$0.50	/gal capital
10,000	kW eq size	611	gal/hr capacity
100	MMBtu/hr input	16	MMBtu/ton biomass (dry ton)
80%	eff.	6.25	ton/hr biomass input
80	MMBtu/hr fuel out	97.7	gal/ton dry biomass

[46] *Ibid.*
[47] *Ibid.*
[48] *Ibid.*, p.9.
[49] Bain, R., Amos, W., Downing, M and Perlack, R., *Highlights of Biopower Technical Assessment: State of the Industry and the Technology*, National Renewable Energy Laboratory, US Department of Energy; April, 2003, p. 2.
[50] Telecon with — Redacted — Company, July 21, 2005,
[51] Hughes, Evan, “Custom cost estimate,” created for and delivered to Norman Brown on July 28, 2005.

42	gal/bbl	$2.50	/MMBtu biomass fuel cost
130952	Btu/gal	$40.00	/ton dry biomass cost
90%	annual capac factor	$0.41	/gal cost of biomass feed
7884	hours/yr production		
4,816,407	gal/yr	24	operating staff
		$80,000	/cost per year per oper.
Cost Breakdown:		$1,920,000	/yr cost of oper labor
$0.41	biomass feed	5%	non labor O&M/yr as % of cap cost
$0.12	O&M	$600,000	/yr non lab O&M
$0.40	oper labor		
$0.50	capital	150	dry ton/day biomass input
-----------			size of the plant
$1.43	/gal total cost of gallon of product	100	MMBtu/hr size
		$12,000,000	capital cost of plant

Input Data:

Elec.Heatrate	10,000	Btu/kWh	
Cap. Cost	$1,200	/kW	
Cap. Cost	$120,000	/(MMBtu/hr)	
Efficiency	80%	Btu out / Btu in	
An. Capac. Fctr.	90%		
Hours/year	7884	hours	
Bio. Cost	$2.50	/MMBtu	
Plant size (if electric power)	10,000	kWe	
Fixed charge rate (1/year)	0.20		

Bottom Line:

Cost of the liquid fuel product = $1.43 per gallon

Plant size: 4,816,407 gal/yr of product (liquid fuel)

We also identified other potential applications for the technology.

Other Applications Identified	
Application	***Potential Competitive Advantages of Technology***
Production of Petrochemical-Replacement Products	By utilizing biomass as feedstock, — Redacted —'s process could serve as an integral part of a "biorefinery," where more than just energy is produced.; the Biomass Technical Advisory Committee has set a goal of 12% of total production of chemicals and materials to come from biomass by 2010, with 18% in 2020 and 25% in 2030, compared to 5% today.[52] — Redacted —'s process in theory would use "multiple forms of biomass to produce a flexible mix of products, including fuels, power, heat, chemicals and materials.[53]
Rural Economic Development	An electricity generating plant built from — Redacted —'s technology is likely to be smaller and more modular than a typical generating plant based on petrochemical fuels. This is because the biomass feedstock is relatively poorer in Btu capacity, requiring transportation of much bulkier source material.[54] Biomass generators have limited ranges of 50 – 100 miles from their source of biomass.[55] Biomass generation plants are thus optimally located very near to large sources of biomass; since farms and ranches are primary sources of waste biomass (both food and animal wastes), location of

[52] *Industrial Bioproducts: Today and Tomorrow*, US Department of Energy, Office of the Biomass Program, July, 2003; p.12.
[53] *Ibid*., p. 7.
[54] *North American Biomass and Waste-to-Energy Markets*, Frost & Sullivan; 28 May 2003; p. 27.
[55] Bain, R., Amos, W., Downing, M and Perlack, R., *Highlights of Biopower Technical Assessment: State of the Industry and the Technology*, National Renewable Energy Laboratory, US Department of Energy; April, 2003, p. 4.

	biomass generators in such rural areas is optimal. This can give a boost to local economic development in these farm- and ranch-rich rural areas. In addition to the indirect benefits to farmers and ranchers, of a ready use for their generated waste, a more significant development would occur if the farmers were to produce biofuel-specific crops.[56]
Hydrogen Production	Syngas can also be used to produce hydrogen.[57] This makes it well suited to participate in the "hydrogen economy" being forecast to develop and grow in the early part of this century.[58] California sees an early network of 150 to 200 hydrogen refueling stations throughout the State by 2010, according to a Blueprint Plan required by Governor Arnold Schwarzenegger in Executive Order S-7-04[59]

The following material is available on this technology.

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[56] *Roadmap for Biomass Technologies in the United States*, Biomass Research and Development Technical Advisory Committee, US Departments of Agriculture and Energy; December, 2002, p.3.

[57] "The Biomass Economy," NREL Journal/JA-810-31967, National Renewable Energy Laboratory, US Department of Energy,; July, 2002, p. 3.

[58] "California Hydrogen Highway", May 24, 2004, http://www.hydrogenhighway.ca.gov/ (accessed May 31, 2005.

[59] Baxter, Shannon, "Implementation Plan for Developing a California Hydrogen Highway Network Blueprint," *Draft Summary*, H2 Highway Implementation Advisory Panel; October 18, 2004, p. 1.