Contractor's Report to the Board

Technology Evaluation and Economic Analysis of Waste Tire Pyrolysis, Gasification, and Liquefaction

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Executive Summary

Pyrolysis, gasification, and liquefaction (PGL) represent a viable alternative for the disposal of scrap tires (also referred to as "waste tires" in this report). These technologies are currently used for the conversion of carbonaceous materials more extensively in Europe and Japan than in California, but may become more important as the supplies of natural fuels become depleted. The objective of this report was to assess the technological, environmental, and economic features of the application of PGL to process scrap tires.

The disposition of waste tires remains an important issue in California as the population and corresponding number of waste tires continues to rise. Stockpiling or landfilling of scrap tires has negative environmental impacts and may not be the most efficient disposal solution. The State has initiated policies to encourage diversion of waste tires to other applications such as crumb rubber products, civil engineering projects, and tire-derived fuel (TDF).

This policy has resulted in a significant waste tire diversion rate increase from 1990 to 2002. In 1990, California diverted 34 percent of its 27 million waste tires to these uses. In 2002, the diversion percent increased to 75 percent of 34 million waste tires. The annual number of tires disposed of decreased by 50 percent between 1990 and 2002; however, 8.4 million tires were still being disposed of as of 2002. Further, during the late 1990's, two major stockpile fires resulted in over $25 million in cleanup costs.

Pyrolysis, gasification, and liquefaction are thermochemical processes whereby carbonaceous feedstocks are transformed at elevated temperatures. Pyrolysis is thermal degradation or volatilization of the tires without the addition of air or oxygen. Gasification is a process that utilizes a reactive agent such as air, oxygen, hydrogen, or steam. Gasification tends to have a slightly higher temperature range than pyrolysis, with the resulting products being primarily gaseous in nature. Liquefaction operates in a lower temperature range than either pyrolysis or gasification and produces a predominantly liquid product.

This report presents the results of a survey of PGL facilities worldwide. It was found that PGL technologies have expanded considerably in the areas of coal, petroleum coke, natural gas, and mixed waste. Only one, commercial facility in Kaohsiumg, Taiwan, which processes approximately 27,000 tons per year (TPY), was identified that uses PGL for the processing of a primarily scrap tire feedstock.

In California, the Chateau Energy Group is currently refitting a power plant in Imperial County with a plasma arc system for gasification of tire-derived fuel, to be used in conjunction with natural gas to generate up to 45 megawatts of electricity (MW_e). International Environmental Solutions (pyrolysis), Plastic Energy LLC (catalytic cracking/melting), and Pyromex (pyrolysis), through their representative Innovative Logistics Solutions, also have facilities in various stages of permitting, construction, or planning in California that could potentially process tires but are currently targeted for other feedstocks.

Although the application of PGL to tire feedstocks is limited worldwide, no significant technical barriers to the use of these technologies in processing tires seem to exist. This is particularly evident in the significant expansion of PGL use since 2000, including feedstocks that are more heterogeneous than tires, such as mixed waste. The viability of any individual facility appears to depend on a number of other factors, including economic considerations, facility capital costs, feedstock requirements and availability, and the permitting process.

Empirical data on the environmental impacts of PGL facilities using scrap tires are limited and depend on the local air permits and exhaust after-treatment systems utilized at each facility. PGL processes have some emissions advantages compared to conventional combustion processes, since the former are performed in environments with limited or no oxygen and have an output volume that is considerably less than that of standard combustion. Gasification and pyrolysis produce intermediate gases such as natural gas that are cleaner to combust than other organic waste.

Further, data from other practices, such as PGL of feedstocks other than tires, or the use of TDF in cogeneration facilities or cement kilns, can provide an indication of the level of performance that would be obtained for PGL tire facilities. PGL facilities worldwide are currently operating under stringent regulations with other feedstocks, and it is expected that facilities equipped with the most advanced air pollution control systems will be able to meet or exceed the regulatory requirements in California and the rest of the U.S.. Additionally, tests of emissions from facilities using TDF have indicated there are no significant disadvantages to the use of tires as a fuel or fuel supplement. In a number of cases, the use of TDF can provide emissions benefits, with the possible exception of the effects of zinc, which is used in the production of tires.

The ability to produce a range of products can add to the marketability of a PGL system. Products resulting from PGL processes include electricity, chemicals, and diesel fuel, as well as residual carbon black. The products can be used to expand the current uses of scrap tires that include retreading, civil engineering applications, and TDF. Estimates were made of the potential value of scrap tires transformed by PGL in terms of electricity, fuels, and other products. It was found that a hypothetical tire PGL facility with a capacity of 5 million tires per year can produce a gross revenue of over $13.2 million per year, from the combined sales of $9.4 million from synthetic diesel fuel, $1.25 million from the sale of process heat at natural gas equivalent prices, $1.7 million from the sale of off-peak electricity, and $0.8 million from the sale of the recovered steel. On a per-tire basis, the product costs ranged from $2.63 for gasification to $1.29 for liquefaction. Capital costs for PGL facilities were found to range from $621 to $828 per metric ton per year.

In addition, the authors performed an evaluation of the economic life of this hypothetical PGL facility. This included an analysis of operating costs, financing, and revenue streams. At the present energy prices, it was found that the plant would make an estimated $1.37 million in profit by the third year of operation. This plant would recover capital costs in its eighth year, and have a projected annual net profit (discounted cash flow) of $6.96 million, two years after paying off its loan. A cost sensitivity study conducted by the authors indicates that these profit margins and the corresponding economic viability would be enhanced by continuing increases in the costs of electricity and diesel fuel.

Introduction

As the population continues to grow in California, from 34.5 million in 2000 to an estimated 38.5 million in 2004, the management of waste or scrap tires continues to be an important issue. In California, the number of scrap tires generated annually was expected to rise from 31.6 million in 2000 to over 36.9 million in 2004, or slightly less than one scrap tire per person per year in the state. It has been estimated that an additional 1.5 million scrap tires will be imported into California from Utah, Oregon, Nevada, Arizona, and Canada for use in combustion as a fuel supplement, to generate crumb rubber, and in some cases, for landfill disposal.

Although in the past landfilling was the primary method of waste tire disposal, considerable effort has been made over the past 15 years to divert disposal of scrap tires in landfills. In 1990, the California Integrated Waste Management Board (CIWMB) estimated that only 9.2 million of the 27 million scrap tires generated (34 percent) were diverted from landfills. Since that time, landfill diversion levels have increased to 74.9 percent, or 25.1 million of the more than 33 million tires generated. Still, more than 8 million tires were sent to landfills in 2002.[*]

In addition to the large number of scrap tires generated and imported annually, California also has over the years had millions of scrap tires illegally dumped or legally and illegally stockpiled. In the late 1990s, two separate tire stockpile fires occurred, one at the Filbin stockpile in Westley and the other at the Royster stockpile in Tracy. More than 12 million scrap tires were burned in these fires, resulting in considerable environmental damage to the region and significant adverse impacts to local residents. The cleanup of the Westley tire fire lasted three years at a cost in excess of $17 million. The Tracy tire fire burned for over two years before it was extinguished. Cleanup began in the spring of 2003 with an estimated cost of $9 million[†]. Tire stockpiles can also contribute to a number of other environmental and public health threats, such as providing a habitat and breeding ground for mosquitoes as well as other pests and vermin.

The disposal and management of waste tires also remains an issue in other states and countries throughout the world.[‡] The landfilling of tires in Europe has been completely eliminated, and there are also stringent limitations on the burning of tires. Disposal of tires in landfills is also prohibited in 11 states in the U.S. Some states have emphasized the use of waste tires as a fuel supplement, while others, such as Arizona, place very heavy emphasis on recycling tires through use as rubberized asphalt.

In California, legislative measures to deal with the management and diversion of scrap tires have been in place since 1989. The Tire Recycling Act of 1989 (AB 1843, Brown, Chapter 974, Statutes of 1989) set a goal of reducing the stockpiling and disposal of tires by 25 percent within its first four years and established a fee of $0.25 per tire left with

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[*] *California Waste Tire Generation, Markets, and Disposal: 2002 Staff Report*, California Integrated Waste Management Board, Sacramento, Calif., October 2003, Page 5.

[†] *Five-Year Plan for the Waste Tire Recycling Management Program: Fiscal Years 03/04–07/08*, California Integrated Waste Management Board, Sacramento, Calif., July 2003, Page 23.

[‡] *Five-Year Plan for the Waste Tire Recycling Management Program: Fiscal Years 03/04–07/08*, California Integrated Waste Management Board, Sacramento, Calif., July 2003, Page 1.

tire dealers, to be used for funding tire programs. Legislation in 2000 (SB 876, Escutia, Chapter 838, Statutes of 2000) raised the fee to $1.00 per tire, but also included provisions requiring the development of a five-year strategic plan for waste tire management and recycling. As part of the ongoing effort to increase diversion of scrap tires from landfills, the CIWMB is utilizing a range of different strategies and methods, including encouragement to retread tires, promoting the use of rubberized asphalt concrete and of recycled tires in playground mats and other surfacing, using civil engineering applications, using TDF, and developing new technologies that utilize scrap tires.

Although significant progress has been made in efforts to divert waste tires from landfills, a need still exists to expand markets for waste tires to address the continuing rise in the number of waste tires that need to be disposed of each year in the state. Pyrolysis, gasification, and liquefaction are technologies that could be used to divert a portion of the scrap tires currently being landfilled. These technologies are currently used for processing of raw materials such as coal and in other parts of the world such as Europe and Japan with mixed feedstocks.[§,**] The utilization of PGL technologies may be expanded in the future with continuing improvements in the technology. Tighter markets and higher prices for other fuel sources, such as natural gas, gasoline, and diesel fuels, could make the products from PGL technologies more marketable.

It is important to obtain a better understanding of these technologies and their potential impacts on the environment, the economy, and existing markets before utilizing significant resources to more widely promote the use of these technologies in California. The goal of the present study is to provide a technical and economic assessment of the potential for pyrolysis, gasification, and liquefaction to bring about additional diversion of scrap tires from landfills. This assessment includes a survey and evaluation of existing PGL facilities that might be suitable for waste tires, an evaluation of the potential environmental impacts of PGL technologies for waste tires, a characterization of useful products that might be formed via these processes, an economic evaluation of operating costs and revenue potential for a generic PGL process, and a cost sensitivity study for PGL operations.

[§] Hackett, C., Durbin, T.D., Welch, W., Pence, J., Williams, R.B, Salour, D., Jenkins, B.M., and Aldas, R., *Evaluation of Conversion Technology Processes and Products for Municipal Solid Waste.* Draft Final Report to the California Integrated Waste Management Board, 2004.

[**] Heerman, C., Schwager, F.J., Whiting, K.J., Pyrolysis & Gasification of Waste: A Worldwide Technology and Business Review. Juniper Consultancy Services, Ltd., Uley, Gloucestershire, England, 2001.

Section 1: Descriptions of Fundamental PGL Technology With Variations

Pyrolysis, gasification, and liquefaction are thermochemical processes that can be used to convert scrap tires as well as other carbonaceous feedstocks such as coal, wood waste, or municipal solid waste into usable products. This report focuses on PGL applications for scrap tires, although the technologies are similar regardless of the feedstock.

Elevated temperatures designed to convert a predominantly carbonaceous feedstock characterize PGL and other thermochemical processes. Pyrolysis is thermal degradation or volatilization of the tires without the addition of air or oxygen. In contrast, gasification is a more reactive thermal process that utilizes air, oxygen, hydrogen, or steam. Gasification tends to have a slightly higher temperature range than pyrolysis with the products primarily gaseous in nature. Liquefaction operates in a lower temperature range than both pyrolysis and gasification and produces a predominantly liquid product.

Pyrolysis and gasification are typically multi-step processes with many similar steps, including (1) feedstock preparation, (2) introduction of the feedstock into the reactor, (3) the pyrolytic decomposition or gasification reaction, and (4) separation and post-processing of the gases, oils (in the case of pyrolysis), solid char, and ash. This section provides an overview of the pyrolysis, gasification, and liquefaction processes. More detailed descriptions of these processes used by individual technologies are provided in Appendix B.

1.1 Feedstock Preparation and Introduction into the Pyrolysis or Gasification Reactor

The method used to prepare and introduce feedstock into the reactor can vary depending on the specific natures of the tires or processing system. One common method of preparing feedstock is shredding it to promote a more favorable reaction for the material after entry into the pyrolyzer. The feedstock can be introduced into the reaction chamber by a number of methods, including gravity feeding, bottom feeding, or through the use of containers. In many cases, the feedstock material is introduced into the reactor using an airlock system to reduce or eliminate the introduction of oxygen into the system.

1.2 Pyrolysis and Gasification Reactions

1.2.1 Reaction Vessels

The reaction vessel is one of the most variable components of the system design for pyrolysis or gasification processes. The reactor type used depends on a number of variables including the type and preparation of the feedstock and the operating conditions required for the appropriate reactions. Reactors can be characterized as either vertical or horizontal types. A rotary kiln is an example of a horizontal reactor. The three main types of vertical reactors are fixed bed, fluidized bed, and entrained bed.

1.2.2 Pyrolysis Reactions

Pyrolysis is an endothermic process (a process that requires energy input) that induces the thermal decomposition of feed materials without the addition of any reactive gases, such as air or oxygen. The thermal energy used to drive the pyrolysis reaction is applied indirectly by thermal conduction through the walls of a containment reactor. Pyrolysis typically occurs at temperatures between 400° and 800° Centigrade (C). As the temperature changes, the product distribution (or the form of the product) can be altered. Lower pyrolysis temperatures usually produce more liquid products and higher temperatures produce more gases.

The speed of the process and rate of heat transfer also influences the product distribution. Slow pyrolysis (carbonization) can be used to maximize the yield of solid char. This process requires a slow pyrolytic decomposition at low temperatures. Rapid quenching is often used to maximize the production of liquid products, by condensing the gaseous molecules into a liquid. In some pyrolysis processes, a product that is up to 80 percent liquid by weight can be produced.

Hydrogen or steam can also be used in the pyrolysis process to change the makeup of the product distribution. Hydrogen can be used to enhance the chemical reduction and suppress oxidation by the elemental oxygen in the feedstock. Steam can also be used as a pyrolyzing medium, allowing pyrolysis to occur at lower temperatures and higher pressures. The use of water as a pyrolyzing media also allows the feedstock to be introduced into the reactor in an aqueous form. An additional advantage of water or steam is that the resulting char has a relatively high surface area and porosity that is similar in nature to activated charcoal.

1.2.3 Gasification Reactions

The thermochemical process for gasification is more reactive than for pyrolysis. It involves the use of air, oxygen (O_2), hydrogen (H_2), or steam/water as a reaction agent. While gasification processes vary considerably, typical gasifiers operate at temperatures between 700° and 800° C. The initial step, devolatilization, is similar to the initial step in the pyrolysis reaction. Depending on the gasification process, the devolatilization step can take place in a separate reactor upstream of the gasification reaction, in the same reactor, or simultaneously with the gasification reaction.

The gasification reaction can include a number of different chemical reactions, depending on the process conditions and the gasification agent (air, oxygen, steam, carbon dioxide, or H_2). A listing of some of the more important gasification reactions for carbonaceous char is provided in equations 1–8 below. Note that "$\Delta H°$"[††] (delta H degree) is the enthalpy of reaction, which is a positive number for reactions requiring heat (endothermic) and is a negative number for reactions that release heat (exothermic). These reactions will not be discussed in detail, but it is important to note that the range of reactions present provides the opportunity through additional process controls to produce products that can be made for specific uses. For example, synthesis gases for liquid fuels and chemicals are composed of gaseous mixtures of carbon monoxide and hydrogen. This carbon monoxide/hydrogen ratio can be varied under different reaction conditions to yield a broad range of products. Conversely, pyrolysis does not have a reactive step; hence its gaseous yield is produced in a smaller range and typically cannot be used for direct fuel or chemical synthesis without further processing.

Gasification Reactions for Carbonaceous Char

1. $C + CO_2 = 2CO$ $\qquad \Delta H° = +172$ kJ

[††] $\Delta H°$ is the enthalpy of reaction for 1 mole of the pure substance, at a temperature of 298° C, and a pressure = 0.1 MPa (1 atmosphere).

2. $C + H_2O\ (g) = CO + H_2$ $\Delta H° = +130$ kJ
3. $C + 2H_2O\ (g) = CO_2 + 2H_2$ $\Delta H° = + 88$ kJ
4. $C + 2H_2 = CH_4$ $\Delta H° = - 71$ kJ
5. $CO + H_2O\ (g) = CO_2 + H_2$ $\Delta H° = - 42$ kJ
6. $CO + 3H_2 = CH_4 + H_2O\ (g)$ $\Delta H° = -205$ kJ
7. $C + 1/2\ O_2 = CO$ $\Delta H° = -109$ kJ
8. $C + O_2 = CO_2$ $\Delta H° = -390$ kJ

The energy required to drive reactions 1–3 is commonly provided through partial oxidation, as shown in equations 7 and 8. The high rates of heat transfer achievable during the partial oxidation process within the gasifier are such that this process is often considered an autothermal method of gasification. Often, between 20 and 30 percent of the feed mass flow is consumed to provide the energy needed to pyrolyze the feed and complete the gasification of the pyrolytic products.

The oxygen requirement for the partial oxidation process can be supplied by air, oxygen-enriched air, or pure oxygen at a range of different pressures. The method of delivery of the oxygen is an important factor in determining the expense and efficiency of the process, since energy is needed to compress the combustion air or to cause the cryogenic separation of oxygen from the air. This additional energy use lowers the overall energy efficiency of this gasification method. However, due primarily to the absence of nitrogen in the final gaseous product, the calorific value of the product gases can be improved from relatively low values of 4 to 10 megajoules per cubic meter (MJ/m^3) when using low-cost, air-blown partial oxidation driven gasifiers, to values of 10 to 15 MJ/m^3 for oxygen-blown processes, and 25 to 30 MJ/m^3 for hydrogen-blown processes. For comparison, the calorific value of natural gas is about 39 MJ/m^3. Some improvements in thermal energy management for a process may also be possible using indirect heating of the feedstock in the gasifier by circulating hot inert solid particles, such as sand, from a separate externally fired heater.

The reaction of the feedstock and other gaseous products with hydrogen can also provide energy for continuing these reactions, as shown in equations 4 and 6. Recently, progress has been achieved using hydrogen-driven gasification, or hydrogasification, based on the methanation reaction shown as equation 4 above. This is an exothermic reaction, and can be used to sustain gasification temperatures especially if steam pyrolysis has been used to create an activated carbon-rich char having a high surface area. In addition, the exothermic reactions of carbon monoxide, (equations 5 and 6) in the presence of steam and hydrogen can provide enough additional energy to sustain the gasification of the activated carbon char without the need for partial oxidation.

1.3 Post-Processing of Gaseous, Liquid, and Solid Products and Residues

Key aspects of the post-processing of the resultant gases, liquids, and solids are presented in this subsection. The actual products formed from pyrolysis and gasification is discussed in greater detail in Section 4.

The product gases from pyrolysis or gasification can be used for energy production, fuels, or chemical production. A separate combustion chamber outside the pyrolysis and/or gasification chambers is often used for energy production. The thermal energy resulting from the combustion of gaseous products can be used in a variety of ways. These include the production of steam for generating electricity and thermal energy for the production of heat that can then be used in the pyrolysis reactor or in the feedstock drying process.

An important component of any post-pyrolysis or gasification combustion process is the after-treatment equipment used to clean the effluent gases. Although gaseous products can typically be combusted more efficiently than solid materials, advanced emission control systems would still be required to meet regulatory standards. Typical exhaust flue gas control strategies for combustion processes include particulate filters or bag houses, wet scrubber techniques, or electrostatic precipitators. Emissions and ways of controlling them are discussed in greater detail in Section 3.

The post-processing of liquids from pyrolysis and solid products, including oils, char, and ash from pyrolysis or gasification, is another important process step. In pyrolysis, the oils are typically obtained through a condensation step, although the formation of oils is also a function of the process temperature. In many pyrolysis processes, the condensate oil is reintroduced into the process as a fuel for the generation of heat to drive the thermal decomposition process. The oil can also be marketed as a separate product, depending on the amount of additional processing required.

Similarly, the char, or solid carbonaceous portion of the pyrolytic residue, can either be utilized as a fuel for the process or sold as a carbon-rich material for the manufacture of activated carbon or for other similar industrial purposes. The reintroduction or use of pyrolytic char as a fuel source in the pyrolysis process is an important element in the process design for many of the technologies surveyed. The inert ash in the solid pyrolytic or gasification residual is generally not reintroduced into the process, with the exception of some processes utilizing fluidized bed reactors. Some processing of the ash is incorporated in many technologies. This could include water wash/quenching, screening, and the removal of metals. In some technologies, a vitrification step is also included whereby the ash is heated to a temperature above the fusion point of sand, which can then incorporate the soluble components of the ash to produce an impervious residual slag that can inhibit leaching of the ash components into ground water when buried.

1.4 Liquefaction

Liquefaction is the process used to alter a substance from a solid to a liquid state. In the case of scrap tires, this can take the form of a thermal process that melts the rubber of the tire and mixes the resultant liquid with another liquid for transport into a reactor vessel for processing. Practical methods have tried used waste engine oil, heated to 300° C. The Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California Riverside is experimenting with a hydrothermal treatment using high-pressure water heated to 250° C. In both these cases, the liquefaction of the rubber in the tire is used as a process pre-treatment to separate the rubber for pyrolysis and gasification from the steel belting for recovery and recycling.

Section 2: Survey of PGL Facilities Worldwide

The report authors conducted a literature search and interviewed contacts to gather information on PGL facilities and processes. The authors identified 28 companies worldwide that utilize PGL technologies. This number includes companies that currently use tires as a feedstock, as well as those utilizing technologies that could potentially use tires as a feedstock.

Information from companies was obtained by using a survey form (Appendix A) or extracting information from another study conducted by the University of California Riverside for CIWMB on conversion technologies.

Individual profiles were also created for companies that use PGL technologies or that manufacture the systems (Appendix B).

A single facility was identified that uses scrap tires. This plant is located in Kaohsiung, Taiwan, and its processing is based on the TiRec technology developed by Swiss engineering company Alcyon Engineering SA. The plant includes two lines capable of processing approximately 27,000 tons per year (TPY) with a typical operating time of 7,500 hours per year.

Beven Recycling, in conjunction with the UK Atomic Energy Authority, operated a pyrolysis facility for four or five years in Witney, UK. The facility had a capacity of approximately 10 tons of tires per week, or 500,000 tires per year. The process utilized batches of approximately 1 ton, or 150–175 tires. The facility produced approximately 300 pounds of steel, 900 pounds of bio-oil, and 450 pounds of fuel gases for every ton of tires processed. During its time of operation, the facility was also reported well tested by a third party test firm for the Department of Trade and Industry.

Environmental Waste International operated a 300-tire-per-day pilot plant between 1994 and 1998, using a microwave heating process to pyrolyze tires.

Several pending PGL projects in California were identified. The Chateau Energy Group is currently refitting a power plant in Imperial County to generate electricity using gasification of TDF in conjunction with natural gas. The original facility was equipped with a Lurgi fluidized bed furnace to which a plasma arc gasifier will be added. The plant is capable of generating up to 45 megawatts of electricity.

International Environmental Solutions (IES) has recently constructed a facility with a capacity of 50 tons-per day. The facility is currently going through the local permitting process. Although the primary feedstocks for this facility are not scrap tires, IES is planning to conduct tests on scrap tires as part of the permitting process.

Table 2-1: Technologies Identified for Pyrolysis, Gasification, and Liquifaction of Waste Tires

Company	Technology	Status of Technology	State/Region	Country
ACM Polyflow	Pyrolysis	Pilot plant	Ohio	USA
Alycon Engineering S.A.	Pyrolysis	Reference plant operating		Switzerland
Ande Scientific	Pyrolysis – bench scale	Not actively promoted	West Midlands	UK
Beven Recycling	Pyrolysis	Demonstration plant – no longer used	Whitney	UK
BPI	Pyrolysis – demo	Not active		UK
Conrad Industries Inc.	Pyrolysis	Pilot plant	Washington	U.S.
Environmental Waste International	Microwave Pyrolysis	Pre-commercial	Ontario	Canada
Hebco International	Pyrolysis	Design - Not actively promoted	Quebec	Canada
Theroux Environmental Consulting Services	Plasma arc gasification	Pre-commercial	California	U.S.
Traidec	Pyrolysis	Pilot scale—status unknown		France
Weidleplan (LIG)	Pyrolysis	Status unknown		Germany

Table 2-2: Other Potential Technologies for Pyrolysis, Gasification, and Liquifaction of Tires

Company That Developed Technology	Technology	Status of Plant or Technology	State	Country
Adherent Technologies, Inc	Pyrolysis			U.S.
Bioengineering Resources, Inc (BRI)	Gasification/Fermentation	Pilot-pre commercial	AR	U.S.
Compact Power	Pyrolysis + Gasification	Semi-commercial		UK
Ebara/Alstrom	Gasification	Commercial		Japan, France
Emery Energy Company, LLC	Gasification	Pre-commercial		U.S.
Enerkem	Gasification	Semi-commercial		Canada
Foster Wheeler	Gasification	Semi-commercial		Finland
Graveson Energy Management (GEM)	Thermal cracking	Pre-commercial	NJ	U.S.
IET Energy Ltd.	Gasification & Combustion		WA	UK / U.S.
Improved Converters (ICI)		Prototype	CA	U.S.
International Environmental Solutions	Pyrolysis	Semi-commercial	CA	U.S.
Interstate Waste Technologies, Inc/Thermoselect	Gasification	Commercial	PA	U.S.
Mitsui-Babcock/Takuma	Pyrolysis	Commercial		Japan, UK
North American Power	Pyrolysis	Semi-commercial	NV	U.S.
Nippon Steel	Gasification	Commercial		Japan
Phoenix Solutions	Plasma		MN	U.S.
PKA	Pyrolysis + Gasification	Semi-commercial		Germany
Pyromex – ILS	Pyrolysis	Commercial		U.S.,Germany
Renewable Oil International, Inc.	Pyrolysis	Commercial	Ontario	Canada
Serpac Environmental	Pyrolysis	Semi-commercial		France

Company That Developed Technology	Technology	Status of Plant or Technology	State	Country
Solena Group Inc.	Plasma torch	Semi-commercial	Wash. DC	U.S.
SVZ	Gasification	Commercial		Germany
Thermoenergy			WA	U.S.
Thermogenics, Inc.	Gasification		NM	U.S.
Thide Environmenal	Pyrolysis	Semi-commercial		France
Von Roll	Pyrolysis	Semi-commercial		Germany
WasteGen/Technip		Commercial		UK

Pyromex AG is another company that is expanding in the California market. It has a subsidiary company, Innovative Logistics Solutions (ILS), in Palm Desert, California. Pyromex has two active pyrolysis facilities in Europe that process sludge.

Other technologies promoted or demonstrated in North America were identified. North American Power is currently operating a pyrolysis facility in Las Vegas, Nevada. The facility processes spent carbon at a capacity of 1,000 pounds per hour for 16 hours a day, five days a week. Conrad Industries of Chehalis, Washington has built and tested two pilot scale plants with capacities of 3.5 and 24 tons per day. ACM Polyflow, Inc. has also built a pilot scale batch pyrolysis reactor capable of processing 1,000 lbs over a period of approximately six hours. The primary goal of the process is the production of useable petroleum-like compounds such as BTEX chemicals (primarily aromatic hydrocarbons and cycloalphatic compounds) and petroleum coke.

Section 3: Environmental Impact of PGL Operations

This section presents an evaluation of the environmental impacts of waste tire PGL operations, plus potential mitigation measures where appropriate. These impacts include air emissions, liquid wastes, and solid residues. Generally, the environmental impacts are similar in all three technologies. When compared to operations that utilize combustion of waste tires, it is generally accepted that PGL technologies will yield equal or lower environmental risks and impacts in most areas. However, the information available is limited, due to the small number of full-scale PGL facilities. Additionally, some older information on PGL facilities may not be relevant due to recent advances in emission controls.

3.1 Air Emissions

Air emissions may be the greatest environmental concern in PGL operations using waste tires. The output gases of pyrolysis and gasification reactors (and subsequent combustion processes, if applicable) can contain a variety of air pollutants that must be controlled prior to discharge into the ambient air. These include particulate matter (PM), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), dioxins and furans, hydrocarbon (HC) gases, metals, carbon dioxide (CO_2), and carbon monoxide (CO).

There are many strategies available for controlling emissions from waste tire PGL processes. Those used depend on the process requirements and scale of each individual facility. The PGL processes differ in a number of key ways from combustion processes, as the former generate intermediate gaseous products that can be converted into fuels or chemicals with almost no direct emissions. In the case of post-combustion processes for electricity production, there are several important factors that differentiate PGL processes from full combustion processes, including:

- The volume of the output gases from a pyrolysis reactor or gasifier is much less per ton of feedstock processed than the volume from an equivalent incineration process. While these output gases may be eventually combusted, the alternative processes provide an intermediate step where gas cleanup can occur. Incineration is limited to the application of air pollution control equipment to the fully combusted exhaust gases.
- Output gases from pyrolysis reactors or gasifiers are typically in a reducing environment, and can be treated or utilized, in contrast with a fully combusted (oxidative) exhaust.
- Subsequent combustion of low-molecular-weight producer gases from pyrolysis and gasification processes is much cleaner than combustion of raw feedstocks (in other words, a PGL process is more similar to combustion of natural gas as opposed to combustion of coal).
- Pyrolysis and gasification processes use very little or no air or oxygen.

These factors make control of air emissions less costly and less complex than that required for incineration.

While exhaust gas cleanup of PGL processes may be less involved than that associated with incineration, proper design and operation of the process and emissions control systems are necessary to ensure that all health and safety requirements are met.

3.1.1 Emissions Control for a PGL Facility

There are a number of different emission control strategies that can be applied to PGL processes. An example of a mid-process air pollution control system is the Thermoselect® process, a high-temperature gasification conversion technology.[1] The company currently has four facilities in commercial operation worldwide, with three others under construction. The Thermoselect® process is capable of processing a variety of different waste streams, including tires.

The Thermoselect® process uses gasification for primary processing. After completion of the gasification stage, the synthesis gas exits the gasifier at approximately 1200^{o}C and flows into a water jet quench where it is instantaneously cooled to below 95^{o}C. The rapid cooling prevents the formation of dioxins and furans by dramatically reducing the residence time of the synthesis gas at high temperature. Entrained particles (such as elemental carbon and mineral dusts), heavy metals, chlorine (in the form of hydrochloric acid [HCl]), and fluorine (in the form of HF) are also separated out in the quench. The quench water is maintained at a pH of 2 to ensure that heavy metals are dissolved as chlorinated and fluorinated species, so that they are washed out of the crude synthesis gas.

Following the quench process, the synthesis gas flows into a demister and then into alkaline scrubbers, where the remaining particulates and HCl/HF droplets are removed. Then the gas passes through a desulfurization scrubber for the removal of hydrogen sulfide [H_2S] by direct conversion into elemental sulfur. The scrubber is a packed bed that is sprayed with scrubbing liquor consisting of water and a dissolved Fe-III chelate that oxidizes the H_2S to elemental sulfur and water. Finally, the gas is dried in a countercurrent packed bed scrubber using tri-ethylene glycol liquor. The fully cleaned synthesis gas can then be conveyed to engines, boilers, or turbines for electricity production. Alternatively, the gas can be converted to higher molecular weight fuels such as diesel fuel.

3.1.2 Air Emissions Data for PGL Plants Using Waste Tires

Emissions data are limited for PGL plants using waste tires, as there are limited active facilities utilizing tires and only a few historical facilities where emissions data are available. The defunct facilities were typically operated at a pilot or demonstration scale and not at a full commercial scale. A listing of emissions from several tire pyrolysis facilities is provided in Table 3-1. Some additional data for particulate phase metals, semi-volatile organics, and volatile organics are also provided in Table 3-2. While these data provide some insight into PGL tire processes, the control of emissions is always specific to a facility and dependent upon the pollution control equipment.

Table 3-1: Emissions for Various Pyrolysis/Gasification Facilities/Technologies
(Values are in mg/Nm^3 unless noted.)

	PM	NO_x	CO	VOC	SO_2	Dioxins/ Furan (ng – TEQ/Nm^3)	HCl	Cd	Pb	Hg
Regulatory Limits										
U.S. EPA Limits	18.4	219.8	89.2		61.2		29.1	0.01533	0.1533	0.0613
German Limits (17thBImSchV)	10	200	50		50	0.10	10	0.03	0.50	0.03
Facility Emissions Levels										
Alcyon Tirec[2]	25	150	50		300					
Beven Recycling[3]	1.6	60	25	6.9	127		<0.001	<0.05	0.07	<0.05
Conrad[4]	2.5	210			310.5					

Notes:

PM = particulate matter

NOx = oxides of nitrogen

CO = carbon monoxide

VOC=volatile organic compounds

SO_2 = sulfur dioxide

Cd = Cadmium,

Pb=Lead,

Hg=Mercury

Table 3-2: Emissions Estimates From Conrad Industries[a]

	Concentration ($\mu g/m^3$)	Emission Rate[b] (lbs per MMBtu)
Particulate Matter Associated with Metals		
Aluminum	1.51	6.7×10^{-8}
Chromium	0.82	3.7×10^{-8}
Iron	9.89	43.9×10^{-8}
Magnesium	0.45	2.0×10^{-8}
Manganese	0.09	0.4×10^{-8}
Mercury	0.05	0.2×10^{-8}
Nickel	2.95	13.1×10^{-8}
Potassium	1.84	8.2×10^{-8}
Sodium	18.62	82.7×10^{-8}
Zinc	0.65	2.9×10^{-8}
Semi-Volatile Organic Compounds		
Bis-(2-ethy-hexyl)phthalate	10.2	45.3×10^{-8}
Butyl Benzyl-phthalate	1.7	7.5×10^{-8}
Di-n-butyl-phthalate	0.9	4.0×10^{-8}
Naphthalene	2.87	12.7×10^{-8}
Phenol	1.4	6.2×10^{-8}
Volatile Organic Compounds		
Benzene	20.2	c
Ethylbenzene	24.1	c
Toluene	30.8	c
Xylenes	16.2	c

a These estimates reflect the composition of pyrolytic gas, which is either burned in the process as fuel or (for the excess pyrolytic gas) vented to the facility's flare. These estimates do not reflect atmospheric emissions.

b These emission rates were calculated by taking the average concentrations reported for the compound and multiplying it by the average flow rate for the test runs. An energy input value of 31 MMBtu was used to calculate lbs/MMBtu.

c Flow rates were not reported. Thus, pounds of emissions per hour could not be calculated.

3.1.3 Air Emissions for Other Thermochemical Processes

Waste tires are widely used as a fuel in cement kilns, co-generation plants, and standard boilers throughout California, the U.S., and the world. In a 2002 study, the California Air Resources Board examined the emissions from four different facilities using tires as fuel for either cement kilns or cogeneration facilities.[5] A listing of the four facilities examined and their annual tire use rate is provided in Table 3-3. All continued to use tires as a fuel supplement in 2004.

Additionally, the Mount Poso Cogeneration Company in Bakersfield is using tires as a fuel supplement, with an eventual consumption goal of up to 2 million tires per year. The California Portland Cement Company in Colton is also planning to increase use of tires. The National Cement Company of California in Bakersfield is planning to conduct trials with a goal of full-time use of scrap tires as a fuel supplement in its cement kiln. Several other facilities have used scrap tires and been permitted for tire use but do not actively use them due to operational or other issues. These facilities include the Cemex cement plant in Apple Valley, the Riverside Cement Company plant in Oro Grande, the Jackson Valley Energy Partners cogeneration facility, and the Rio Bravo Poso facility in Bakersfield.

Table 3-3: Four California Facilities Permitted to Burn Scrap Tires With Coal[6]

Facility	Tires Burned in 2001 (Millions)
Cement Facilities	
California Portland Cement Co. (Colton)	0.9
Lehigh Southwest (Redding)	1.5
Mitsubishi Cement Co. (Lucerne Valley)	1.8
Cogeneration Facilities	
Stockton Cogeneration Co. (Stockton)	1.2
Total	5.4

The total annual emissions for criteria pollutants and toxic emissions of the four facilities in Table 3-3 are provided in Tables 3-4 and 3-5. It should be noted that these tables quantify total emissions for the facilities. They do not provide an indication of the benefits or liabilities of using the tires as a fuel supplement with coal versus coal only.

Table 3-4: 2001 Criteria Pollutant Emissions From Tire-Burning Facilities (Tons Per Year)[7]

Facility	TOG	ROG	NO_x	SO_x	CO	PM	PM_{10}
Cement Facilities							
California Portland Cement Co. (Colton)	2	1	1200	77	110	31	29
Lehigh Southwest (Redding)	13	10	600	7	1900	69	64
Mitsubishi Cement (Lucerne Valley)	7	4	1700	300	570	75	42
Total	22	15	3500	384	2580	175	135
Cogeneration Facilities							
Stockton Cogeneration Co. (Stockton)	10	0	110	220	80	22	2
Total	10	0	110	220	80	22	2
Grand Total	32	15	3610	604	2660	197	137

TOG =Total Organic Gases

ROG =Reactive Organic Gases

NO_x = oxides of nitrogen

SO_x = sulfur oxides

CO = carbon monoxide

PM = particulate matter

PM_{10} = particulate matter less than 10 microns

Table 3-5: 2001 Toxics Emissions From Tire-Burning Facilities (Pounds Per Year)[8]

Facility	Acetaldehyde	Benzene	Formaldehyde	HCl	Total Metals	Total PAHs
Cement Facilities						
California Portland Cement Co.(Colton)	7	10	26	870	9	1
Lehigh Southwest (Redding)	7	9	26	860	9	1
Mitsubishi Cement (Lucerne Valley)	19	24	66	2200	23	3
Total:	33	43	118	3930	41	6
Cogeneration Facilities						
Stockton Cogeneration Co. (Stockton)	36	17	150	50000	310	1
Cogeneration Facilities Total:	36	17	150	50000	310	1
Grand Total:	69	60	268	53930	351	7

PAH = polycyclic aromatic hydrocarbon

The emissions from thermochemical processes other than PGL at facilities that utilize scrap tires including cement kilns, boilers, and paper and pulp mills have been studied by the CIWMB,[9] the U.S. EPA,[10] and other organizations.[11] The data from these studies are reviewed here since they can provide a comparison to emissions from scrap tire use in PGL operations.

There are several cogeneration facilities in California that use tires as a fuel supplement, including the Stockton Cogeneration Company and the Mt. Poso Cogeneration Company in Bakersfield. The Modesto Energy Limited Partnership previously operated a dedicated tire-to-energy facility in Westley, California. Emissions of NO_x, SO_x, and PM were controlled using a lime slurry spray scrubber, a selective non-catalytic NH_3 injection system, and a bag-house at this facility. The emissions of the Westley facility were compared to those of other facilities using scrap tires to supplement their fuel needs. This facility had emissions of PM, SO_x, NO_x, and CO several orders of magnitude lower than those of the other electricity-producing facilities utilizing scrap tires.[12] This comparison demonstrated the importance of emission control equipment utilized in comparison with fuel type in evaluating air emissions. Comprehensive emission tests were also performed at the Stockton facility.[13]

The high temperatures (typically around 2600° F) and long residence times inherent in the operation of cement kilns provide a unique disposal technique for scrap tires, resulting in a lowering of emissions. The solid ash constituents and steel belts remaining from the combustion process are integrated into the product. The CIWMB conducted tests using tires as a fuel supplement at the RMC Lonestar kiln in Davenport and the Southwestern Portland Cement (now CEMEX) kiln in Victorville.[14] Although there was significant variability within the day-to-day measurements, both tests showed reductions in NO_x emissions of about 22 percent when using the tires. Comparisons of data from these kilns for other pollutants revealed that the changes encountered when using tires were not significant or consistent, although higher CO emissions and lower SO_2 emissions were observed for one kiln.

The U.S. EPA reviewed emissions for tire use in kilns and found that emissions were not adversely affected by tire use and often provided a lowering of emissions.[15] Other reports for tire use in cement kilns also indicate that emissions can be reduced by the use of tires in the combustion system. Guigliano et al. reported significant reductions in NO_x and SO_x using tire chips as a supplementary fuel in cement kilns, with other gaseous emissions mostly unaffected.[16] The incorporation of TDF at the California Portland Cement Co. plant in Colton was also expected to provide reductions in NO_x emissions of approximately 20 to 41 percent.[17]

A summary of some general trends observed when using TDF is presented in Table 3-6. Of the pollutants listed in the table, the only increase was in zinc, which is used in the production of tires.

Table 3-6 General Trends Observed When Using TDF[18]

Pollutant	Effect of TDF
CO	None
SO_2	None
NO_x	Decrease
PM	None
Total Hydrocarbons	None
Zinc	Increase
Other Metals	None or Decrease
Dioxins/Furans	None
Benzene	Decrease
Formaldehyde	Decrease
Semi-Volatiles	Decrease

3.1.4 Dioxin Emissions

Dioxins and furans are compounds consisting of benzene rings, oxygen, and chlorine and are toxic in nature. Dioxins and furans can be formed when waste streams containing chlorine (including inorganic chlorine) are processed under conditions where the flue gas has a significant residence time in a temperature range of 480-1290^{o} F. They are typically formed downstream of the combustion process. In this temperature range, hydrogen chloride (HCl) in the flue gas reacts with oxygen to form chlorine (catalyzed by heavy metal vapor, such as copper). The chlorine subsequently reacts with hydrocarbon radicals to form dioxins and furans. The absence or the low levels of oxygen present in pyrolysis and gasification helps inhibit the formation of dioxins and furans. Since tires do not have a significant amount of chlorine, it is not expected that tire use in alternative conversion processes will lead to any significant increases in dioxin emissions.

Emission systems for the control of dioxins and furans have also advanced considerably in the past 15 years. Cold-quenching and/or high-temperature incineration of intermediate products can be used to prevent or destroy dioxin emissions. In cold quenching, intermediate gases are quickly cooled in a caustic scrubber solution in order to prevent the de novo synthesis of dioxins and furans. Alternatively, or in addition to cold quenching, high-temperature incineration of intermediate gases can prevent formation as well as destroy dioxins and furans already present, as is the case with high-temperature incineration of landfill gases.

3.1.5 EPA AP-42 Emission Factors

In surveying the literature, the authors found that EPA AP-42 emission factors for "starved-air" combustors[19] are often cited as being representative of pyrolysis/gasification processes, since many of these technologies use a limited amount of air or oxygen in their design. The basic design of a modular starved-air combustor consists of two separate combustion chambers referred to as "primary" and "secondary" chambers.

The material is batch-fed to the primary chamber that is typically operated with between 40 percent and 60 percent combustion air. The waste is burned on grates or hearths, with typical residence times of up to 12 hours. Gases from the primary chamber are subsequently combusted in the secondary chamber, with excess air levels of between 80 percent and 150 percent. While this process may represent certain types of pyrolysis and gasification processes, there are many other designs that use very little if any oxygen or air in the thermal process.

Furthermore, the AP-42 emission factors show control efficiencies for processes equipped with only an electrostatic precipitator (ESP). ESPs are designed to remove PM, but have little effect in removing gaseous air pollutants. PGL facilities seeking a permit in California, however, would likely require a range of other air pollution control technologies to reduce gaseous emissions, including cold quenching, scrubbers, catalytic reduction units, and activated carbon filters. Overall, care must be taken in evaluating the emissions from a particular facility, including consideration of all emissions systems.

3.2 Liquid Residues

The primary liquid products from tire PGL processes are pyrolysis oils and any residual scrubber solutions from the air pollution control equipment. Pyrolysis oils from tires and other products are complex mixtures of hydrocarbons. The liquid fraction can contain a range of species including acids, alcohols, aldehydes, aromatics, ketones, esters, heterocyclic derivatives, and phenols, along with varying amounts of water.[20] A more detailed description of the specific species comprising oils is provided in Section 4. These oils typically contain a number of substances that can be considered toxic, but can be handled safely using typical industrial practices. These oils represent an intermediate product that is not disposed of, but can be used either via combustion for energy production or for the production of other chemicals if upgraded.

Residual products from the gas cleaning and water recovery processes can be handled using well-established procedures. These residual products include industrial-grade salts and a separate precipitate containing the heavy metals from the feedstock stream. In some cases, this precipitate may be rich enough in zinc and lead to warrant recovery in a smelter operation.

3.3 Solid Waste Residues

The solid residue remaining from PGL processes is typically an inorganic ash or a char. The inorganic ash is the residue from the 3 percent to 5 percent of inorganic material in the tire that cannot be converted to energy or products through PGL. The ash contains non-volatile trace metals that are more concentrated in the ash than in the feedstock, but with proper management can be treated and disposed of in a manner that does not pose an environmental threat. In some cases, metals can be recycled from the ash.

The leachability of the ash is used to indicate whether the ash is classified as a hazardous or non-hazardous waste. U.S. EPA leachability characteristics are provided in Table 3-7. Zinc is one of the more important metals in tire PGL, since it is used during the production of tires. In high-temperature gasification processes, the ash can also be vitrified to form a slag. The slag is a hard, glassy substance that is formed when the gasification systems operate above the fusion or melting temperature of the ash. Since the non-volatile metals are fused into the slag, there is little if any leachability potential. The other solid residue is char, which is the remaining carbonaceous solid residue. The char can be used directly or with some processing in a variety of applications, described further in Section 4, and as such is not considered a waste product.

Table 3-7: U.S. EPA Leachability Limits for Non-Hazardous Waste

Item	Metal (including compounds)	U.S. EPA TCLP Test Limit (mg/L)
1	Mercury (Hg)	0.2
2	Cadmium (Cd)	1.0
3	Thallium (Tl)	Not Applicable
4	Arsenic (As)	5.0
5	Lead (Pb)	5.0
6	Chromium (Cr)	5.0
7	Copper (Cu)	Not Applicable
8	Nickel (Ni)	Not Applicable
9	Zinc (Zn)	Not Applicable
10	Boron (B)	Not Applicable
11	Barium	100.0
12	Selenium	1.0

Source: U.S. EPA Toxicity Characteristic Leaching Procedure (TCLP)

One additional source of solid waste residues is the material generated by bag-house filters and electrostatic precipitators. This material deposits on the bag filters as cakes or powders of fine particulate matter, which must be periodically cleaned, a process usually under automatic control. Procedures for handling and disposal of these wastes are already well-developed for other processes, and should be adaptable to use with tire PGL.

Section 4: Assessment of PGL Tire Products and Their Markets

This section presents an evaluation and assessment of potential products from scrap tire PGL operations. Included also is a brief examination of current product markets for waste tires and for the materials and products that could be formed from application of PGL to waste tires. The authors have included a brief description of the tire production process in Appendix D so readers may see the potential end use and environmental impacts of waste tires.

By weight, tires from passenger cars and light trucks account for about 84 percent of the waste tires generated. Heavy-truck and bus tires compose 15 percent of the scrap tires produced, while heavy equipment, off-road, and airplane tires make up the remaining 1 percent. On the average, passenger tires weigh 25 pounds new and 20 pounds when scrapped; truck and bus tires weigh 120 pounds new and 100 pounds when scrapped.[21]

4.1 Tire Composition

The composition and properties of tires ultimately affect the range of their potential uses after they are scrapped. The construction and composition of tires vary considerably, depending on their intended application. Table 4-1 presents the basic composition of passenger versus truck/bus tires. Although these different types of tires have different amounts of natural and synthetic rubber, each has about 60 percent to 70 percent recoverable rubber. The table also shows that about 70 percent to 80 percent of a waste tire is composed of carbonaceous material that can potentially be converted using an alternative thermochemical conversion process. Most of this carbonaceous material is currently recovered through conversion to rubber products.

The primary inorganic component of the tire is steel, which can either be processed prior to using the tire in a thermochemical process or recycled as an ash product residual. Another important component of waste tires is sulfur, which can be a contaminant in some alternative processes.

Table 4-1: Percent Composition of Passenger, Bus, and Truck Tires[22]

	Composition						Recoverable Rubber*
	Natural Rubber	Synthetic Rubber	Carbon Black	Steel	Sulfur (average)	Fabric, Fillers, Accelerators	
Passenger Tires	14	27	28	14–15	1.28	16–17	60–70
Truck/Bus Tires	27	14	28	14–15	2.5	16–17	60–70

*Passenger tires = 35% natural, 65% synthetic

*Truck tires = 65% natural, 35% synthetic

Table 4-2 presents an ultimate analysis for passenger versus truck/bus tires, including comparisons to TDF and coal. This analysis includes the heating values (an essential component of any thermochemical process is the heating value of the fuel), elemental components by percent, and the ash residual by percent. As shown in the table, tires represent roughly 10 percent to 15 percent more energy per pound than coal.

Table 4-2: Ultimate Analysis for Scrap Tires vs. Coal[23]

Ultimate Analysis (percent by weight)								
Fuel Type	**Heating Value in BTUs/Lb**	**Carbon**	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulfur**	**Chlorine**	**Ash**
Passenger Tires	15,843	89.48	7.61	<0.01	0.27	1.88	0.07	3.9
Truck Tires	14,968	89.65	7.50	<0.01	0.25	2.09	0.06	5.5
TDF	15,688	89.51	7.59	<0.01	0.27	1.92	0.07	4.2
Bituminous Coal	13,560	75.8	5.1	8.2	1.5	1.6	Not listed	7.8

4.2 Current Markets for Waste Tires

The current paths for tire recycling, reuse, and disposal provide a basis to evaluate the availability of tires for use in other processes, such as alternative conversion technologies. A summary of the current markets for scrap tire disposition in California is provided in Table 4-3, and a listing of potential scrap tire applications is provided in Table 4-4. Some recycling alternatives use whole tires, thus requiring no extensive processing, while other alternatives require that tires be split, punched, shredded, or ground to make new products.

Table 4-3: California Waste Tire Generation, Diversion, and Disposal, 1990–2002

(Numbers in millions of passenger tire equivalents [PTE])[24]

A	B	C	D	E			F		G	H		I	J	K	L
Year	California Population (millions)	Estimated Waste Tires Generated[2]	Reused	Recycling and Other Uses[3]			Retreaded[4]		Exported	Tire-Derived Fuel (TDF) Combusted		Imported[7]	Total Number of Calif. Tires Diverted[8]	Remaining Calif. Tires Disposed C minus J	Percent of Calif. Tires Diverted[9] J/C
							Light	Heavy		Energy Product[5]	Fuel Suppl.[6]				
1990	29.5	27.0	1.0	0.6			0.9	1.4	1.3	2.4	1.6	0.0	9.2	17.8	34.1%
1991	30.1	27.5	1.0	0.8			0.8	1.4	1.3	4.1	1.7	0.4	10.7	16.8	38.9%
1992	30.7	28.2	1.1	1.1			0.7	1.4	1.3	4.7	2.1	0.6	11.8	16.4	41.8%
1993	31.1	28.5	1.3	1.5			0.7	1.4	1.3	4.7	3.0	0.3	13.6	14.9	47.7%
1994	31.7	29.0	1.3	1.7			0.7	1.7	1.3	5.7	6.0	0.2	18.2	10.8	62.8%
1995	32.3	29.5	1.5	1.8			0.7	1.7	1.7	4.7	6.1	0.6	17.6	11.9	59.7%
1996	32.6	30.0	1.5	2.3			0.7	1.7	1.7	4.3	4.6	1.5	15.3	14.7	51.0%
1997	33.2	30.4	1.5	5.4			1.0	1.8	1.7	3.5	5.5	3.2	17.2	13.2	56.6%
1998	33.8	30.9	1.5	9.1			1.0	1.8	3.1	4.5	3.0	2.2	21.8	9.1	70.6%
				Crumb Rubber	Civil Eng.	Other									
1999	34.0	31.1	2.4	5.8	0.7	3.6	0.8	1.7	1.5	3.8	4.1	2.0	22.5	8.6	72.3%
2000	34.5	31.6	3.6	7.3	1.6	4.1	0.7	1.7	1.9	1.0	4.2	3.2	22.9	8.7	72.5%
2001	34.8	33.3	1.5	7.7	3.0	4.2	0.7	1.7	2.6	1.0	4.2	1.7	24.9	8.4	74.8%
2002	35.0	33.5	1.5	5.8	3.0	5.9	0.6	1.7	2.0	1.1	5.0	1.5	25.1	8.4	74.9%

1 Based on 20-pound average weight of a passenger car scrap tire.

2 To estimate waste tires generated for 1990–2000, staff used the formula of 0.915 of a tire per person, per year. For 2001–2002, staff used the formula of 0.958 of a tire per person, per year.

3 This category includes tires used in ground rubber products and other products made from scrap tires. It does not include tire buffings from retreading, because buffings are accounted for in the "Retreaded" category. However, since tire buffings are recycled, the number of scrap tires recycled is greater than shown here. The three-way split in 1999 shows the number of tires diverted through crumb rubber products, civil engineering applications, and other uses (recycling, alternative daily cover, agriculture use, etc.).

4 "Light" refers to passenger and light-truck tires. "Heavy" refers to heavy-duty truck tires. Tire buffings are included during the retreading process.

5. This figure represents the number of tires combusted in power plants primarily from the annual waste tire stream, but may also include some stockpiled tires from site clean-ups.

6 This figure represents the number of tires combusted primarily from the annual waste tire stream, but may also include some stockpiled tires from site cleanups.

7 This figure includes tires imported for combustion as a fuel supplement or used to generate crumb rubber. It does not include imported tires disposed of in landfills.

8 This figure is determined by summing the number of tires reused, recycled, retreaded, exported, combusted for energy production, and combusted as fuel supplement, and then subtracting the number imported. The figure represents the total number of tires diverted, primarily from the annual waste stream.

9 This figure represents the percentage of California scrap tires diverted primarily from the annual waste stream.

Table 4-4: Potential Uses for Scrap Tires

From Crumb Rubber	
Road/Rail Uses	Rubberized Asphalt Concrete
	Acoustic Barriers
	Road Base
	Portable Traffic Control Devices
	Ripple Strips and Speed Bumps
	Rail Crossings, Sleepers, and Buffers
	Roadside Safety Railing
Construction and Industrial Uses	Foundation Material
	Industrial Flooring and Footpaths
	Anti-Static Computer Mats
	Acoustic Barriers
	Sprayed-Up Roofing, Insulation, and Waterproofing
	Adhesive Sealants
	Mounting Pads and Shock Absorbers
	Membrane Protection
	Airfield Runways
	Shoe Soles
	Carpet Underlay
	Children's Playground Surfacing
	Compounding With a Wide Range of Plastic (such as polypropylene, copolymers, polystyrene, ABS, thermoplastic rubbers of ethylene and propylene, flexible foam)
	Pond Liners
	Compression Molding Compound
	Extrusion Compounding for Rubber Products
	Injection Molding Compound
	Solid Tires for Industrial Equipment
	Conveyor Belts
	Lightweight Fill (shredded tires)
	Sludge Composting (shredded tires)
Automotive Uses	Filler in New Tire Manufacture
	Tire Retreads
	Solid and Pneumatic Tires
	Oil Spill Absorber
	Floor Mats, Mud Flaps, Molded Protection Strips
	Special Friction Brakes
	Automotive Door and Window Seals
	All-Track Segmented Earthmoving Tires

	Gaskets
	Adhesive Sealants
Automotive Uses, continued	Sprayable Sealants for Automobile Wheel Housings
	Vehicle Bumper Bars
	Flooring for Truck Trays and Tipper Bodies
Rural/Landscaping Uses	Flooring
	Turf and Horse Training Tracks
	Watering Systems, Rubber Hosing, and Low-Pressure Irrigation Drip Hoses
	Flowerpots, Wall Hangers, Plant Pots
	Animal Bedding
	Protective Fencing
	Sprayable Linings for Grain Silos, Storage Tanks, etc.
Sporting Uses	Flooring
	Sporting Fields, Athletic Tracks, Tennis Courts, etc.
	Gymnasium Flooring and Matting
	Equestrian Surfaces and Workout Areas
Bulk Products and Mining Uses	Filter for Landfill Leachate Ponds
	Erosion Control Landfills
	Road Base/Stone Replacement
	Leachate Pond Liners
	Oil Spill Absorber
	Aggregate Surfacing
	Mulches
Whole Tires	
Erosion Control, Dams, Artificial Reefs, Breakwaters, Highway Crash barriers, playground equipment, and home construction	
Retreading	
Vehicle Tires (including buses, trucks, airplanes, off-road vehicles, and racing cars)	
Fuel	
TDF for utilities, pulp and paper mills, industrial boilers, cement kilns, co-generation plants	
Other Uses	
Marine (dock buffers, floating docks), Non-Slip Flooring, Packaging, Filler, Recycling Bins	

4.2.1 Reuse

Used tires that still have a legal tread depth can be resold by a dealer, rather than prematurely disposed of or recycled. In 2002, 1.5 million tires were reused, or 4.5 percent of all scrap tires generated.

4.2.2 Retreading

Approximately 2.3 million tires were retreaded in 2002, with nearly all of these for heavy-duty and commercial trucks. Retreading tires can be one of the most cost-effective diversion methods; however, only certain tires can be retreaded due to their initial construction or excessive wear. Truck or heavy-equipment tires are usually the best-suited for retreading. The cost savings over new tires makes this application profitable for both the retreader and the consumer. Cost savings to the consumer can exceed $100 per tire. This is a particularly attractive option for fleet operators.[25, 26]

4.2.3 Energy Recovery

In 2002, one of the largest end uses of tires in California was energy recovery. Approximately 6.1 million tires were consumed in cement kilns, energy recovery facilities, or co-generation facilities (5 million were consumed by the cement manufacturing industry and 1.1 million by a cogeneration plant in Stockton).

The high heating value of tires (in excess of 15,000 BTUs per pound) makes scrap tires an effective fuel supplement. Several cement kilns around the state are currently permitted to burn tires as a supplement to their use of coal. Since tires are constructed within a narrow range of materials and have a low moisture level, tire derived fuels have well-defined and consistent fuel. Tire use in cement kilns in California can make up approximately 25 percent of the fuel requirements.[27]

4.2.4 Crumb Rubber Applications

Approximately 6 million tires were used in crumb rubber applications in 2002, primarily for both paving and molded products.

Paving: A variety of state and local government agencies, including Los Angeles County and the California Department of Transportation (Caltrans), have shown that rubberized asphalt concrete is a significant and viable end use for tires. The use of rubberized asphalt concrete provides a variety of benefits, including a longer-lasting surface (lasts 50 to 100 percent longer than conventional asphalt surfacing), resistance to rutting and cracking, reduced road noise (50 to 80 percent quieter than conventional asphalt surfacing), reduced pavement thickness, and reduction of ongoing maintenance expenses (as much as $22,000 per lane mile versus conventional asphalt resurfacing), skid resistance, and easy processing, using the same equipment as would be used for conventional asphalt.

Molded Rubber Products: This market represents a significant potential for value-added recycling. CIWMB staff estimated that 1.8 million tires were used for crumb rubber products, including playground cover mats, speed bumps, carpet tiles, rubber mats, and other molded products.

Soil Amendments and Other Uses: Tests and demonstration projects have shown crumb rubber used as an additive to soil can increase soil permeability as well as airflow. Other uses include, but are not limited to, industrial flooring, sealants, carpet pads, pond liners, and oil spill absorbers.

4.2.5 Exports

Tire export (consisting of both reusable and scrap tires) reduces the number of tires requiring eventual disposal in California. Approximately 2 million reusable and scrap tires were exported in 2002.

4.2.6 Alternative Daily Cover

Alternative daily cover (ADC) has been a popular program for many communities. Tires used for ADC are diverted at very low costs and also count toward the mandated waste diversion goals of AB 939. Approximately 3.9 million scrap tires were used for ADC in 2002.[28]

4.2.7 Landfill

The landfill should be the "market of last resort" for scrap tires. Statutes prohibit placing whole tires in landfills. Landfilling whole tires can consume a large volume of landfill space since the tires are relatively incompressible and about 75 percent of the space a tire occupies is void, providing a potential site for gas collection. Scrap tires can also "float" upward, sometimes piercing the landfill cover. Tires must therefore be cut apart in some manner before being deposited in a landfill.

By national standards, California has very low landfill disposal costs, and it has been pointed out that these low costs act as a barrier to the development of alternative markets. On the other hand, a lower landfill fee reduces illegal dumping.

4.3 Alternative Conversion Technology Products

PGL operations can provide several significant and useful products. A summary of the potential products of different alternative conversion technology processes is provided in Table 4-6. Synthetic natural gas generated in the PGL process contains high amounts of carbon monoxide and carbon dioxide, but the natural gas can be used to generate electricity or as an intermediate synthesis gas to make liquid fuel. Oil derived from tire PGL processes is similar to No. 6 fuel oil, a low-grade petroleum product with some contamination. Carbon black is an important industrial carbon produced by partial combustion of hydrocarbons. Steel, a potential waste product of the process, can be sold as a recycled material.

Table 4-6: Products Available Per Process Used

Conversion Technology	Primary Product	Secondary Products	Solid Residues (recycle or landfill)	Value of Secondary Products	Organic Waste Component Processed
Complete Gasification	Synthesis Gas	Fuels Chemicals Electricity	Ash Metals	Very high and variable.	All organics low moisture
Incomplete Gasification	Producer and Synthesis Gases	Electricity. Some marketable fuels.	Char Ash Metals	Moderate. May need refining at additional expense.	All organics low moisture
Hydro-Gasification With Steam Pyrolysis	Synthesis Gas	Fuels Chemicals Water. Electricity.	Ash Metals	Very high and variable	All organics wet or dry
Indirectly Fired Pyrolysis With Drier and Gasifier	Producer and Synthesis Gas	Electricity Some marketable fuels	Char Ash Metals	Moderate. May need refining at additional expense.	All organics low moisture
Indirectly Fired Pyrolysis With Drier	Producer Gas	Electricity Some marketable fuels	Char Ash Metals	Moderate. May need refining at additional expense.	All organics low moisture

4.3.1 Gaseous Products From Alternative Conversion Technologies

One of the most important products from alternative conversion processes are the gaseous products, including synthesis gas. This gas can be used for production of fuels or as a producer gas for the generation of energy. The commercial applications of synthesis gas are split between chemical production, fuel production, and energy production through the gasification process for other materials, such as coal and petroleum. Prior to 1990, nearly all of the products from synthesis gas were used for chemical production, fuel production (mostly Fischer-Tropsh diesel) and natural gas.[29]

The percentage of gasification facilities producing electrical power and utilizing post-combustion products increased during the 1990s and has risen significantly since 2000 due to demand and deregulation of electricity markets. However, on a worldwide basis, the capacity of gasification for chemicals, fuels, and gases is still larger than the capacity for power production. For the specific processing of organic wastes, the production of electricity is the most common use of the resulting synthesis gas.

Electricity or direct energy is one potential product of PGL processes for scrap tires. As discussed in Section 3.1.3, the use of scrap tires is more typical in cogeneration processes that operate on combustion. For this application, the synthesis gas must be compared directly with other potential fuel sources. As shown in Table 4-3, the heating value in BTUs per pound is approximately 10 to 15 percent higher than for coal. TDF also competes against other types of fuel and may sell at a discount to coal of about $1 per ton. The average price estimate for TDF ranges from about $2 to $40 per ton. It has been found that it is economically feasible and environmentally sound to use tires as a supplemental fuel in cement kilns, power plants, and pulp/paper boilers.

Other potential products of PGL processes include chemicals, fuels, and synthetic gases, which can be stored and sold when the market price is prime. Such products are already commonly produced by gasification systems for coal and petroleum. A listing of the products that can be formed for the various conversion technologies is provided in Table 4-7. This includes a range of liquid fuels and chemicals including methanol, Fischer-Tropsch diesel fuel, hydrogen, synthetic ethanol, and substitute natural gas.

Table 4-7 Fuels and Chemicals that can be Produced from Synthesis Gas Feeds[30]

Direct Synthesis	Indirect Synthesis (Via Methanol)	Other Syntheses
Hydrogen	Formaldehyde	Olefins $\underline{H_2/CO}$ Aldehydes
Methanol	Acetic Acid	Co/Rh Alcohols
Ammonia	Methyl Acetate	
Carbon Monoxide	Acetic Anhydride	Isobutylene $\underline{CH_2OH}$ MTBE
Medium BTU Gas	Vinyl Acetate	H^+
Methane	Methyl Formate	Acetylene $\underline{CO}$ Acrylic Acid
Higher (C_1-C_4) Alcohols	Formic Acid	Ni
Gasoline	Ethanol	
Diesel Fuel	Dimethyl Carbonate	Olefins $\underline{H^+}$ Highly-branched Acids
Isobutanol	Dimethyl Oxalate	CO
Isobutane	Gasoline	
	Diesel Fuel	RCOOH $\underline{H_2/CO}$ RCH2COOH
	Ethylene	RuO_2/HI
	Propylene	
	BTX	Nitroaromatics $\underline{CO}$ Isocyanates
	Chloromethanes	Pd
	Methylamines	
	Methyl Glycolate	Terephthalic Acid $\underline{CH_2OH}$ Dimethyl Terephthalate
	Ethylene Glycol	

4.3.2 Oil and Carbon Black

PGL systems can generate an oil-based liquid equaling 30-80 % of the product derived from organic content of the tire feedstock. However, isolation of a single oil is difficult.

This fuel is similar to No. 6 fuel oil, which DOE estimated in February 2004 to have a market value of $0.594 per gallon (24.95 per barrel).[31] Lubricants can also be generated and used to upgrade used/re-refined oils. Carbon black, which can be recovered from the char, can be sold from $0.40 to $0.45 per pound.[32] Synthetic gas and synthetic diesel can be generated and can be sold at rates near the price for the virgin products.

4.3.3 Steel

Sources of steel from the tires are: bead wire, which is many wraps of thin wire to add structure to tire wall and form a tight leak-proof hold on rim, and belt wire comprised of cords of thin, high tensile wire. Marketing feasibility depends on the cleanliness, quantity, and packaging of the steel pieces. The cleanliness of recovered steel refers to the amount of rubber contamination. Steel with less than 10% rubber is considered acceptable in the marketplace. Thermal processing of scrap tires is one method of recovering steel with little or no rubber contamination. The type of pyrolytic process is a factor in the quality of the end products. When a batch process is used, removing the steel and carbon black is simple. Continuous tire PGL systems usually grind the tires into chips, which may result in steel and fiber contamination of the end products rendering them less valuable in the marketplace.

The major use of steel is to manufacture new iron or steel products. However, this use is limited by sulfur emissions from the residual rubber. The scrap steel market shifts with its business cycle, and tire-derived steel is used during peak demand. During off peak cycles, the processor may have to give it away or pay markets to take the steel. The average estimated price for tire-derived steel ranges from about $32 to $39 per ton while clean high quality steel prices range from $40 to $60 per ton.[33] If the steel is reclaimed after the tires are shredded, the steel will be cut into small pieces and bailing would be difficult and less efficient. Scrap steel from PGL is clean enough to be sold to scrap processors. The added cost of transportation and storage may decrease the income from this waste product but it may be cheaper then paying a tipping fee for disposal. The demand for tire-derived steel is limited in California because there is only one steel mill and the quality of the steel used is low because of residual rubber. However, the demand is much higher in several regions of North America and Asia.

4.3.4 Fiber

Fiber is another potential waste product from tires. Potential uses for tire fiber waste include: fiber applications, concrete, carpet, soil amendment, sound deadening, insulation, mulch, and recycling into plastics. There is very little demand for this fiber because of contamination by rubber. Limited applications for tire-derived fiber include fillers or stuffing for toys or furniture, additives for plastics, rubber, and concrete. The supply is so much greater than demand that much of the product is brought to landfills. Disposal costs range from about $25 to $39 per ton, with a shipping distance ranging from 17 to 49 miles. The average price estimate for tire-derived fiber ranges from about $12 to $30 per ton, with a shipping distance ranging from 4 to 396 miles. The market price for commercial suppliers of fiber is about $19 to $29 per ton. Approximately 21% of the fiber recovered is used as tire-derived fuel.[34]

4.4 Implications and Comparisons with Current Markets

The value of tire-derived rubber varies with the market conditions of each area or region. A company that uses 45,000 pounds/week (2,340,000 pounds/year) of shredded rubber may pay $340 - $360/ton for the product. Several companies have been found that market scrap tires or products of scrap tries. One company that uses whole tires in their cement kiln process charges $13.00/ton up to 18,000 tons to receive tires, after which there is no charge. By the end of 2004 this company expects to handle 25,000 tons of tires, increasing to 30,000 tons of tires by 2005. They receive the tires from a distributor of used and refurbished tires. Several companies have developed many forms of tire-derived products including shredded tires, which are sold for $5.00/ton and 2" x 2" tire pieces which may sell for $4.00/ton. Another company that sells crumb in 2,000-pound minimum lots has 10-mesh crumb that sells for $0.15/pound ($300/ton) and 30-mesh crumb for $0.17/pound ($340/ton). Typically crumb rubber prepared for recycling can sell for 10 times the price paid for TDF chips.

Section 5: PGL Operating Costs

This section presents methods used to determine tire PGL operating costs from empirically based data from a small number of process facilities.

5.1 Processes Surveyed and Analyzed

Data are presented on the operating costs of scrap tire and other comparably functioning PGL facilities that have been published in: (1) the refereed technical literature, (2) commercial literature and/or referenced web sites, (3) responses to the requests for information sent out in the technical survey, and (4) information obtained from conference reports and proceedings.

The operating costs of these facilities will depend on: (1) costs and quantities of labor used, (2) cost and quantities of utilities and expendable supplies needed to operate the facility, and (3) the capital costs for construction of the facility. These data were analyzed and extrapolated to obtain equivalent present day capital and operating costs.

5.2 Summary Results

5.2.1 Estimated Scrap Tire Quantities, Energy, and Steel Content

An estimate of the number of scrap tires available for energy and steel recovery in California may be made by extrapolation of the data from Table 4-4 of this report.

The quantity of scrap tires stored in stockpiles is estimated at 3 million. An additional estimated quantity of 49 million scrap tires have been shredded and placed in the state's only mono-fill in Azusa, California. The estimated energy content in millions of equivalent barrels of crude oil and the steel content originally in these tires are tabulated in Table 5-1. The quantity of scrap tires landfilled in 2002, as estimated by the CIWMB, is also presented in Table 5-1. This estimate is based on the disposition of scrap tires shown in Table 4-4, and the assumed linear correlation of 0.9571 annual tires scrapped per capita of California population, as developed by the CIWMB.

An estimate of the number of scrap tires going to landfills in 2003 and 2004 can be made from estimates of the California population and its rate of increase.[35] Assuming that in 2002 the population was 35.0 million, with a rate of increase of about 2%, the estimated number of scrapped tires in 2004 is about 36.4 million, with an estimated 25% or 8.7 million scrap tires going to landfills. For the economic analyses made later in this report, it is assumed that at least 5 million tires will be available each year for alternative conversion using PGL technologies.

5.2.2 Estimated Values Used for PGL Process Analysis

The chemical energy and steel content of scrap tires can be estimated from the data presented in Table 4.1 and 4.2. Table 5-2 shows the procedure used to derive the energy and steel content of an average scrapped tire, using the characteristics and distribution previously defined for passenger and truck tires. The values of energy and steel content in an average scrapped tire in California are shown in this table and will be used in all subsequent PGL process and economic analyses in this report. The value of 443 MJ/average tire or 14 tires per barrel of crude oil equivalent are useful conversion factors that can be applied to estimating the potential chemical energy content of a stream of scrap tires.

Table 5-1 Estimated Number of Scrap Tires Available for Energy and Steel Recovery

Type	Million Tires	Equiv. M bbl Crude Oil	M Tons Steel
Stockpiled	3	0.21	14.40
Mono-fill	48	3.4	228.5
Estimated Number of Tires Landfilled Since 2002			
Year	**California Population, million**	**Tires Discarded, million**	**Tires landfilled, million**
2002	35.0	33.5	8.4
2003 (estimated)	35.7	34.2	8.5
2004 (estimated)	36.4	34.8	8.7

Table 5-2 Estimated Energy and Steel Content of Scrap Tires and TDF Used for PGL Process Analyses

	Whole Tire	Whole Tire	Whole Tire	Whole Tire		Steel/ Tire	Steel/ Tire	Less Steel	Less Steel	
Fuel	**BTU/lb**	**MJ/kg**	**lb/tire**	**kg/tire**	**Dist.**	**lb/tire**	**kg/tire**	**lb/tire**	**kg/tire**	**MJ/tire**
Passenger Tires*	15,843	36.85	20.0	9.1	85%	3.0	1.4	17.0	7.7	284.16
Truck Tires*	14,968	34.82	100.0	45.4	15%	15.0	6.8	85.0	38.6	1342.33
Average Scrap Tires	**15,712**	**36.55**	**32.00**	**14.51**		**4.80**	**2.18**	**27.20**	**12.34**	**442.88**
Bituminous coal**	13,660	31.77								

* Waste recovery, Inc analytical data 1/21/97 (Malcolm Pirnie engineers)
** Perry's Chemical Engineers' Handbook, 6th Ed. 1984 (Malcolm Pirnie engineers)

The changes in world crude oil over the last six years are shown in Figure 5-1. Most analysts are forecasting prices well above $40 per barrel for the next five years. Many studies put the threshold price for the economic development of synthetic fuels derived from PGL processes at about $30 per barrel. Therefore, the conversion of the chemical energy in scrap tires, at the equivalence of 14 tires per barrel of oil, is economically feasible at current market rates.

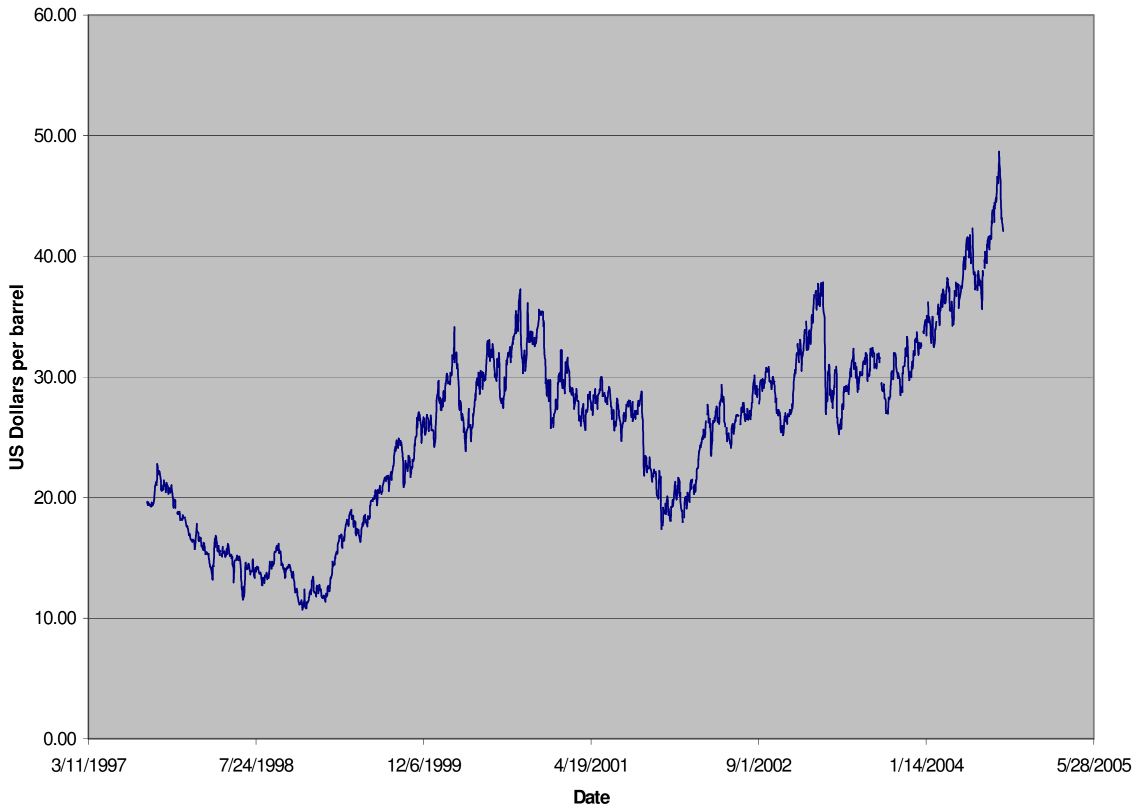


Figure 5-1 World Crude Oil Price History (Source: UN-EIA, Vienna, August 31, 2004)

A relationship between crude oil, and other primary energy prices, and the average value of energy content of scrapped tires can be obtained using energy contents and market prices. Table 5-3 shows how this relationship may be constructed knowing the spot price of primary energy supplies. For example, on 8/10/04, the spot price of sweet crude oil was quoted at $44.85 per barrel. This price is equivalent to an energy cost of $7.23 per GJ for the crude oil, and an estimated energy value of an average scrapped tire at $3.20 per tire. Similarly, regular gasoline was quoted at $1.2265 per gallon wholesale from the refinery, which is equivalent to $9.36 per GJ of energy, and $4.14 per average scrapped tire. Low sulfur diesel fuel was quoted at $1.1984 per gallon wholesale, or about $8.50 per GJ, making the average scrapped tire worth $3.92 when converted into synthetic diesel fuel. Natural gas was quoted at $5.42 per million BTU, or about $4.70 per GJ, which is equivalent to $2.08 for the average scrapped tire. On 8/10/04, coal was quoted at $65/ton for west coast delivery, which is equivalent to $2.05 per GJ, and only $0.91 for the average scrapped tire. With electricity quoted at $52.42 and $60.01 per MWh for off-peak and -peak delivery, this would give scrapped tires values of $2.31 and $2.62 per tire when converted into electricity. Finally, each tire has about $0.16 of steel when quoted at $65 per ton wholesale. It should be noted that prices represent the value of tires on an energy equivalent basis, and do not account any conversion costs that may be associated with tire conversion depending on the specific use, as discussed below.

Table 5-3 Relationship of Crude Oil, Other Energy Products and Average Scrap Tire Values

	Prices on:	LA Sweet Crude	Reg. NY oxy Gasoline	NY low S Diesel	Henry Hub Nat. Gas	Coal	Firm off Peak Electricity	Electricity	Steel
	Date	$/bbl	$/gal	$/gal	$/1000 scf	$/ton	$/MWh	$/MWh	$/ton
	8/10/04	44.85	1.2265	1.1984	5.42	65	52.42	60.01	65.00
Equivalent Cost	$/GJ	$7.23	$9.36	$8.50	$4.70	$2.05	$4.85	$5.56	
GCV (HHV)	MJ/kg	6.200	0.131	0.141	1.153	31.773			
Value Energy/av. tire	$/tire	$3.20	$4.15	$3.76	$2.08	$0.91	$2.15	$2.46	$0.156
Total Value/av. tire	$/tire	$3.36	$4.30	$3.92	$2.24	$1.06	$2.31	$2.62	

This economic analysis may be extended further to estimate the gross revenue from the gasification of scrapped tires for the co-production of synthetic fuels, electricity, and process heat. Table 5-4 shows the estimated gross revenue per scrap tire from gasification at $2.63 per tire, comprising revenues of $1.88 from the sale of synthetic diesel fuel, $0.34 from the sale of electricity, $0.25 from the sale of processed heat at the equivalent energy cost of natural gas, and $0.16 from the sale of the steel in each tire.

These estimates may be used to extrapolate the gross revenue from a hypothetical gasification plant that is processing five million scrapped tires per year. Table 5-4 also shows that this plant could be expected to have a gross revenue of over $13.16 million per year, from the combined sales of $9.4 million from synthetic diesel fuel, $1.25 million from the sale of process heat at natural gas equivalent prices, $1.72 million from the sale of off-peak electricity, and $0.8 million from the sale of the recovered steel. The gross revenue of $13.2 million per year from a co-production thermochemical conversion plant for five million tires per year may be compared to the gross revenue of $6.1 million from the sale of tire derived fuel sold at coal equivalent energy prices.

Estimates of the gross revenue per tire from separate gasification, pyrolysis, and liquefaction processes may be made by extrapolating the results obtained in the previous section. Table 5-5 shows the results of this extrapolation. The gasification conversion efficiencies and product revenues are copied from the values in Table 5-4. The pyrolysis conversion process is assumed to transform 36% of the feed stock energy into pyrolytic oils, estimated to be worth about $0.58 per tire, 27% into pyrolytic gases worth about $0.56 per tire, and 37% into pyrolytic char worth about $0.34 per tire. Similarly, the liquefaction process is assumed to convert 55% on the feed stock energy into pyrolytic oils worth $0.88 per tire, 5% into pyrolytic gases worth $0.05 per tire, and 40% in pyrolytic char worth about $0.36 per tire.

Table 5-4: Estimated Gross Revenue from Gasification with Synthetic Fuel Production, Electricity and Process Heat

	Gross Revenue					Coal
		Diesel Fuel	Natural Gas	Electricity		
Conversion Efficiency*		50%	12%	16%	Steel/tire	
Product Revenue/Tire	$2.63	$1.88	$0.25	$0.34	$0.16	
Estimated Gasification Plant Revenue Distribution						
	Dollars Per Year (millions)					
5 million tires/year	$13.16	$9.41	$1.25	$1.72	$0.78	
Tire Derived Fuel Valued at Coal Equivalent Price						
5 million tires/year	$6.09				$0.78	$5.31

*The conversion efficiencies are based on Aspen version 12.1 using hydrogasification as the base process and an electrical conversion efficiency of 40%.

Table 5-5 Estimated Gross Revenue per Tire from Gasification, Pyrolysis and Liquefaction Processes

	Gross Revenue	Pyrolytic Oils	Natural Gas		Coal	Steel
Gasification						
Conversion Efficiency		50%	12%			
Product Revenue/tire	$2.63	$1.88	$0.25			$0.16
Pyrolysis						
Conversion Efficiency		36%	27%		37%	
Product Revenue/tire	$1.64	$0.58	$0.56		$0.34	$0.16
Liquefaction						
Conversion Efficiency		55%	5%		40%	
Product Revenue/tire	$1.45	$0.88	$0.05		$0.36	$0.16

5.2.3 Capital Costs per Unit Feedstock Throughput

The thesis by Klein[36] presents information on the capital and operating costs of various integrated gasification systems for combined cycled power generation from different forms of solid waste. Faaij et al.[37] present a comprehensive breakdown of capital and operating costs for gasification systems for the conversion of biomass wastes and residues into electricity. The Environmental Manual [38](EM) for power development provides an extensive database of performance, environmental impact, and costs associated with many forms for power conversion worldwide. It includes data on plants using gasification of biomass and coal for the production of fuel gases or electric power. A cost and performance analysis of biomass-based integrated gasification combined-cycle (BIGCC) power systems was undertaken by Craig and Mann[39] at NREL.

To Correct the Capital Cost from earlier reports to 2004-dollar equivalents, the U.S. Consumer Price Index shown in Figure 5-2 was used.

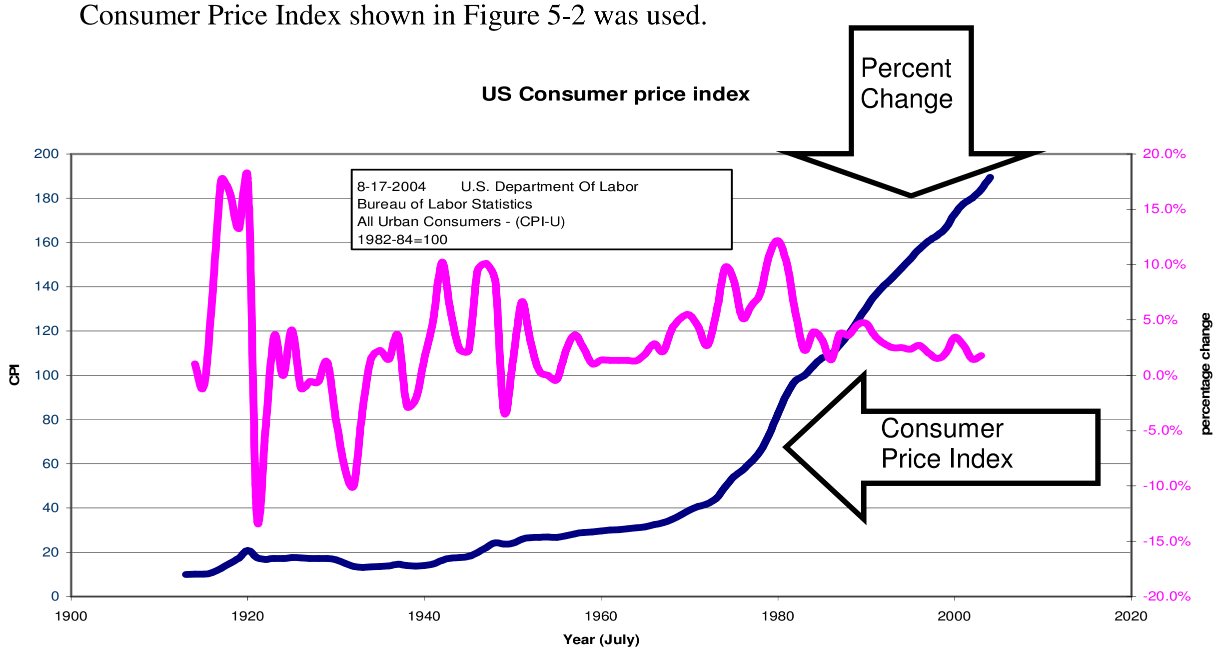


Figure 5-2 US Consumer Price Indexes and Percent Annual Rate of Inflation Used to Correct Earlier Quoted Prices to 2004 Dollar Equivalents

Since much of the published technical literature on PGL technologies originates in Europe, the economic analyses often used the Euro currency. The equivalent US Dollar value for these data was converted from the Euro using the official conversion rates published by the European Central Bank.[40]

The reported capital and operating cost data from the above cited references are listed in Table 5-6. These data have also been normalized to obtain the costs per unit feed rate ($/tons per year) and electric power output ($/kWe).

Table 5-6: Capital and Operating and Maintenance Cost Estimates From Various Sources, Normalized and Corrected for 2004 Values

Feed Material	Gasifier Type	Feed Rate Plant (thousands of tonnes/yr.)	Size Plant (kW thermal)	Capital Costs, $/tpa	Size Plant, kWe	Capital Costs $/kWe	Conversion Efficiency, Percent (HHV)	O&M Annual Cost, Percent Capital	Total Ops. Cost, $/ton	End Note Source	
Coal	IGCC	0.611	530,504	752.7	200,000	2,300.0	37.7	2.5	18.8	#41	
Coal	IGCC	1.206	1,047,120	636.7	400,000	1,920.0	38.2	2.5	15.9	#41	Themista
Tires	IGCC	0.233	289,996	732.0	74,500	2,290.9	25.7	2.5	18.3	#39	Batelle
Tires	IGCC	0.239	154,048	650.2	47,000	1,713.5	30.5	2.5	48.0	#39	TPS
Tires	Min	0.072	89,552	620.8	30,000	1,853.0	33.5	2.5	19.3	#40	TPS
Tires	Max	0.072	89,552	828.1	30,000	2,472.1	33.5	2.5	25.8	#40	Alcyon
Tires	Small scale	0.030	24,069	750.0	8,063	2,238.8	33.5	2.5	15.0	#3	PI
Tires	Small scale	0.030	24,069	720.0	8,063	2,149.3	33.5	2.5	14.4	#3	Beven
Tires	Medium	0.100	80,230	690.0	26,877	2,059.7	33.5	2.5	13.8	#3	
Biomass	HPDGADT	0.125	155,512	712.7	56,000	1,588.0	36.0	15.1	61.7	#42	
Biomass	HPDGGP	0.125	155,512	720.8	56,000	1,606.0	36.0	15.2	63.6	#42	
Biomass	HPDGAUGT	0.267	332,494	678.4	132,000	1,371.0	39.7	15.9	61.6	#42	
Biomass	LPIHGAUST	0.276	344,633	488.9	122,000	1,108.0	35.4	20.7	55.2	#42	
Biomass	LPDGAUST	0.222	277,045	637.7	105,000	1,350.0	37.9	16.5	59.5	#42	
	Average:	**0.258**	**256,738**	**687**	**92,536**	**1,859.0**	**34.6**	**7.6**	**35.1**		

Nomenclature for type of gasifier codes used above:

IGCC — Integrated gasifier with combined (Brayton and Rankine) cycle power conversion configuration.

HPDGADT — High-pressure directly-heated gasifier with aero-derivative gas turbine for power conversion.

HPDGGP — High-pressure directly-heated gasifier with "greenfield" plant with advanced utility gas turbine for power conversion.

HPDGAUGT — High-pressure directly-heated gasifier with advanced utility gas turbine for power conversion.

LPIHGAUGT — Low-pressure indirectly-heated gasifier with advanced utility gas turbine for power conversion.

LPDG — Low-pressure directly-heated gasifier with advanced utility gas turbine for power conversion.

5.2.4 Operating Costs Derived From Capital Costs

In Table 5-6, the gasification plant operating costs have been normalized both by capital costs, as a percentage of these costs, and by input feed rate, as dollars per annual ton fed into the plant, assuming that a homogeneous feed stock is used. This latter figure is often used by design engineers of thermal conversion plants that are not necessarily intending to use the gasification product gases for electricity production. For example, gasification plants that are intended for synthetic fuel production have lower capital construction costs as well as operating and maintenance costs, since these plants do not have to acquire and maintain complex power conversion equipment.

5.2.5 Operating Costs Reported Directly

Some gasification plant operators and designs report operating costs directly and do not normalize these results. In the life cycle analyses that were developed for this report, a hybrid method was used, assuming operating cost estimates of 3 percent of capital costs and costs for labor, supervision, and materials for maintenance operations as 4 percent of capital costs. However, the estimated actual expenses are used for any feedstock-related chemical, catalyst, fuel, and preparation costs. This feature is especially important in Section 6, where sensitivity to cost and price changes for feedstock preparation, and supplementary fuel use are studied.

5.2.6 Normalized Operating Costs Per Unit of Feedstock Throughput

As mentioned in a previous section, operating cost can be normalized using the feedstock feed rate. This method of analysis is particularly useful for inhomogeneous feedstocks, or when considering alternative methods of feedstock preparation as replacement candidates for existing methods. For example, the operators of the Montebello Texaco Gasification Research Center[‡‡] developed an alternative method for whole tire pre-treatment, using liquefaction in a bath of hot oil. The de-polymerized tire became pumpable oil-rubber slurry, which could be sent to a gasifier using a high-pressure metering pump. The steel and other fibers in the tire were not liquefied and fell to the bottom of the oil bath. These materials were easily recovered and sold to material recycling companies. The economic feasibility of this process required a steady supply of liquefaction oil, but this supply could not be assured using the original waste engine oil. However, studies using the pyrolytic oils from plastic wastes appear to be successful. An economic analysis of this alternative pre-treatment technology for whole tires has begun using estimates of the different operating costs per unit feedstock input into the pyrolytic and gasification processes.

5.3 Life-Cycle Cost Analysis

A method of life-cycle cost analysis was developed to estimate the system cost structures over an extended period of time. The basic data entry sheet for this analysis is shown in Appendix E. Conversion efficiencies are based on modeling of hydrogasification using Aspen Version 12.1 and an assumption of 40 percent electrical conversion efficiency. Revenue and expense data are reported in millions of dollars using discount pricing to relate these values to current dollars.

5.3.1 Tabulated Results

The results of performing the life cycle analysis on a hypothetical tire gasification plant processing 5 million tires per year are shown in Table 5-7. The tire collection and pre-treatment

[‡‡] Closed by Chevron-Texaco on 6/30/04 and sold to General Electric Co., Power Systems Division

cost and the conversion plant product selling price parameters that were varied, are tabulated in the first five columns of the table comprising:

(1) Collection and pre-treatment costs from $0 to $40 per dry ton as received at the gate of the plant.
(2) Synthetic fuel selling prices from $0.60 to $2.40 per gallon.
(3) Electricity sales off peak from $26.20 to $104.89 per MW-hour.
(4) Natural gas selling price from $2.71 to $10.84 $/GJ used the value the process heat sales.
(5) Steel selling price from $32.50 to $130.00 per ton.

The profitability results from the life-cycle cost analysis are displayed in the next six columns in Table 5-7, comprising:

(a) The first year of positive cash flow.
(b) The amount of the profit in that year.
(c) The first year of positive cumulative cash flow.
(d) The amount of capital cost recovered in that year.
(e) The discounted cash flow values at the end of the analytic period in 2016, which is two years after the loan has been paid off.

(f) Cumulative cash flow values at the end of the analytic period in 2016, which is two years after the loan has been paid off.

The individual life cycle cost analyses for 12 different cases were studied. These cases are presented in Appendix E. One can see the effects of changing the pre-treatment expense (shown as an effective collection cost per ton of feed stock material), changes in the total revenue from selling synthetic diesel fuel, electricity, process heat sold at the avoided cost of purchasing natural gas, and the recovered steel sales.

Table 5-7: Results Matrix of Life-Cycle Cost Study for Tire Gasification Plant

Variable Cost/Price Parameters					Profitability		Capital Cost Recovery	Discounted Cash Flow in 2016, m$	Cumulative Cash Flow in 2016 (thousands of dollars)	Workbook Sheet Name
Collection Cost ($/dry ton)	Synthetic Fuel Sales Price($/gal)	Off-Peak Electricity ($/MWh)	Natural Gas Sales, ($/GJ)	Steel Sales	First Year	Profit, (thousand of dollars)	First Year			
$0.00	$1.20	$52.40	$5.42	$65.00	2008	$2.19	2012	$7.43	$28.31	c0d120
$20.00	$1.20	$52.40	$5.42	$65.00	2008	$1.37	2013	$6.96	$21.44	c20d120
$40.00	$1.20	$52.40	$5.42	$65.00	2008	$0.55	2014	$6.49	$14.57	c40d120
$0.00	$2.40	$52.40	$5.42	$65.00	2008	$9.94	2009	$13.50	$101.87	c0d240
$20.00	$2.40	$52.40	$5.42	$65.00	2008	$9.12	2009	$13.03	$95.00	c20d240
$40.00	$2.40	$52.40	$5.42	$65.00	2008	$8.30	2009	$12.56	$88.13	c40d240
$0.00	$1.20	$104.80	$5.42	$65.00	2008	$6.95	2009	$11.03	$72.92	c0d120e2x
$40.00	$2.40	$104.80	$5.42	$65.00	2008	$11.90	2009	$16.36	$122.92	c40d240e2x
$40.00	$2.40	$104.80	$10.84	$130.00	2008	$11.46	2009	$15.62	$121.16	c40d240(egs)2x
$20.00	$1.20	$52.40	$10.84	$130.00	2008	$3.35	2011	$8.46	$39.96	c20d120(gs)2x
$20.00	$0.60	$52.40	$2.71	$65.00	2009	$1.53	After 2016	$4.75	$-2.04	c20d060(g).5x
$20.00	$0.60	$26.20	$2.71	$32.50	2015	$3.10	After 2016	$3.00	$-23.01	c20d060(egs).5x

5.3.2 Summaries of Estimated Capital and Operating Costs for PGL Plants

Table 5-8 lists the capital costs in dollars per tons per annum (tpa) and in dollars per kilowatt------ (kWe), the effective power conversion efficiency, and the annual operating costs (as a percent of the capital costs for each of the conversion systems), and subsystem configurations.

Table 5-8 Estimated Capital and Operating Costs for PGL Conversion Plants

Conversion Process	Capital Costs $/tpa	Capital Costs $/KWt	Conversion Efficiency (percent)	Annual Operating Costs (% capital)
Gasification with electrical power and process heat co-generation.	687	637	34.6% IGCC EPGS	7.5%
Gasification Alone. No air separation.	237	220	86% HP SPR+HGR	2.5%
Synthetic fuel process with heat recovery.	225	209	24.5% SMR+FTR with TMS	5.5%
Electric power with process heat co-generation.	450	417	26.2% steam turbine EPGS	6.5%
Gasification with synthetic fuel, electricity and process heat.	687	637	48% FT-SD 16% EPGS 2% heat and TMS	7.5%
Pyrolysis alone. No EPGS or heat recovery.	150	139		3.5%
Pyrolysis with EPGS and heat recovery.	600	556	26% EPGS 32% heat and TMS	6.5%
Liquefaction with no heat recovery.	137	127		2.5%
Liquefaction with heat recovery.	257	238	32% heat and TMS	4.5%

Nomenclature:

IGCC	integrated gasifier and combined (Brayton and Rankine) cycle power conversion 556
EPGS	electric power generating system.
HP SPR+HGR	high pressure steam pyrolysis and hydrogasification.
SMR+FTS	steam methane reformer and Fischer-Tropsch fuel synthesis reactor.

Section 6 Analysis of Price Sensitivity for PGL Operations

The sensitivity of the estimated cost and expected revenues from the sale of synthetic diesel fuel, off-peak electrical power, and process heat co-produced by the conversion of tire PGL operations varies, depending on the world markets and prices for energy and industrial materials. At present, little data is available for currently operating facilities on tires and how these facilities would be affected by market changes. The value of tire PGL operations is based on a combination of the avoided cost of conventional disposal (via landfill) and the expected revenue stream from co-production. If expected revenue is to be used, then production of commodities with high value and large market potential should prevail. Since crude oil, carbon, and steel prices vary much more than the tire tipping fees, the analysis will be based on these data.

6.1 Factors That Affect the Cost of PGL Operations

There are several factors that affect the cost and ultimately the profitability of PGL tire energy conversion operations. They include the following:

(a) Collection of Feedstock

Feedstock collection costs are mainly the transportation costs to haul the scrap tire to the secondary processor. Transportation fuel expenses probably are the most volatile component of this expense.

(b) Extent of Pre-Treatment Required

Some processes can utilize the whole tire, while others require the separation of the organic components from the steel.

(c) Selected Conversion Process

Each PGL process has different products that result from the conversion process. Selecting those products with the largest market potential and highest selling price would provide the most profitability for operating the plant.

(d) Operating Expenses of Selected Process

Operating expenses vary for each PGL conversion process. Those conversion methods that produce the greatest number of energy products that sell for the highest market price will be able to lower the effect of high operating costs.

(e) Product Collection From Process

Low cost methods to extract and post-treat products of conversion will lead to higher profit margins. For example, pyrolysis oils, though low in cost to produce, require expensive refining to upgrade to saleable products.

(f) Product Post-Treatment Needed for Marketing

Those PGL conversion technologies that require additional post-treatment of the products will have less overall profitability.

(g) Storage of Products

Products of PGL conversion that can be easily stored at low expense (such as liquid transportation fuels) will be more profitable than products with high-expense storage (such as required for gaseous fuels that cannot be easily liquefied).

(h) Distribution and Marketing Costs to Sell Products

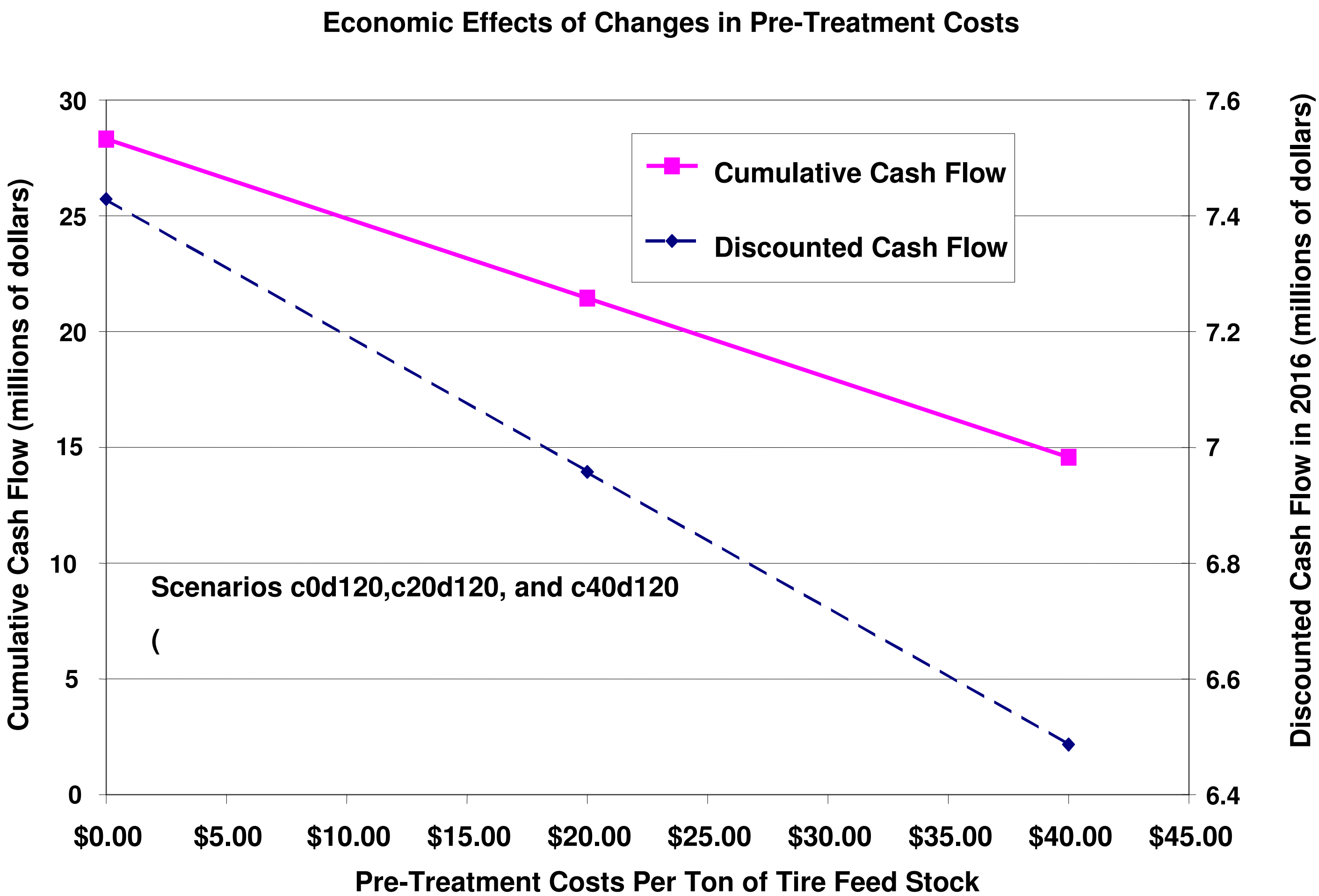
Those conversion products that can market into an existing infrastructure (such as synthetic diesel fuel) will be more profitable than those requiring a new infrastructure (such as hydrogen gas).

The collection of scrap tires as feedstock for PGL operations may be considered an extension of the existing scrap tire hauling industry. This industry comprises small-business transportation companies that collect scrap tires at their normal source, which is the tire service shop selling and installing new replacement tires. These scrap tire transporters operate on the profit they generate from disposal fees or by selling the tires to secondary processors.

Obviously, the higher the intrinsic value of the scrap tire to the secondary processor, the greater is the economic incentive that the tire hauler has to provide the scrap tires. As the economic analysis presented later in this section will show, as the values of primary energy and metal products continue to rise, the economic potential for tire PGL will become more viable.

The effect of changes in tire collection and pre-treatment costs on the discounted and the cumulative cash flows in the post-loan year of 2016 are shown in Figure 6-1, where 2016 is 11 years after construction started, and 2 years after the loan is paid.

Figure 6-1 Economic Effects of Changes in Tire Pre-treatment Costs on First Year Profit in 2008 and Cumulative Cash Flow in 2016



6.2 Sensitivity to World Price of Energy

To assess the sensitivity of tire conversion plant economics to changes in the world price of oil, the life-cycle analysis for a co-production plant processing 5 million tires per year was undertaken, using synthetic diesel selling prices that varied from a high of $2.40 per gallon to a low of $0.60 per gallon.

Figure 6-2 presents the effects that changes in the selling price of diesel fuel and in pre-treatment costs will have on cumulative cash flow in 2016. Figure 6-3 presents the effects on the discounted cash flow in 2016, two years after the loan is paid off.

Figure 6-2 Effects of Changes in Selling Price of Diesel Fuel and Pre-Treatment Costs on Facility's Cumulative Cash Flow in 2016

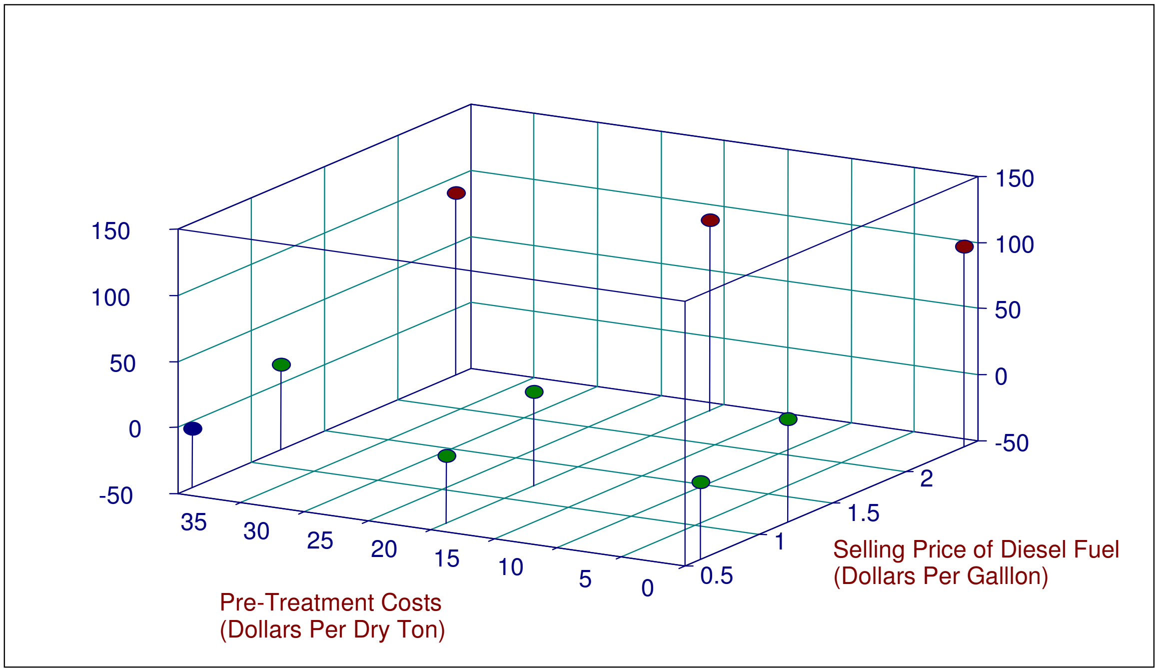
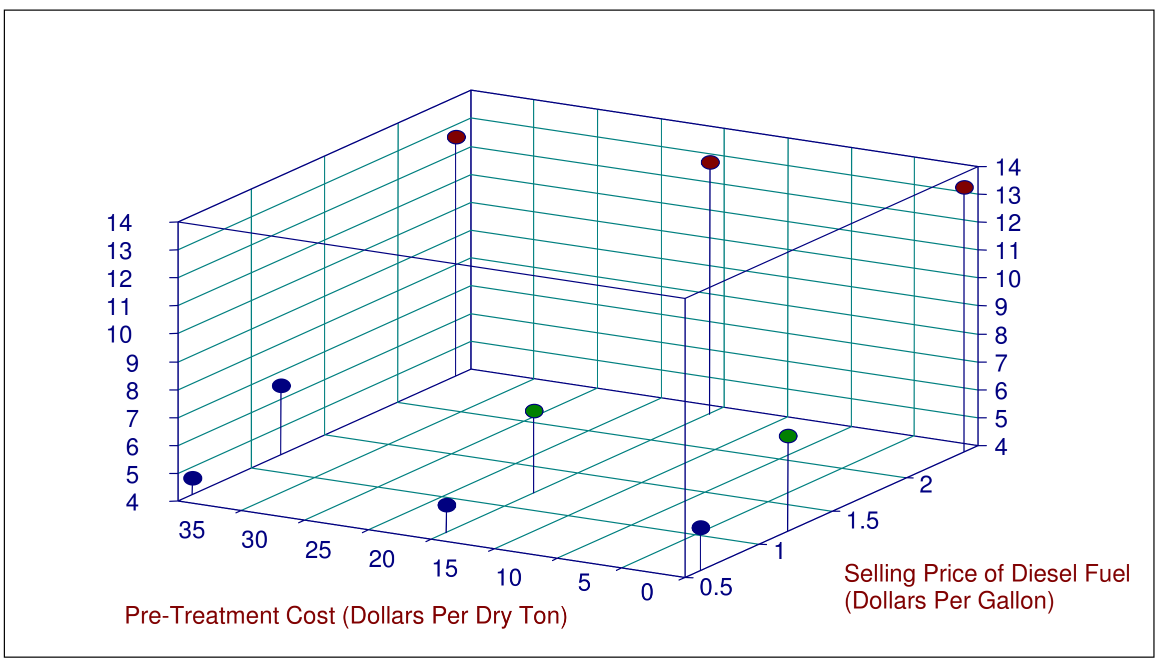


Figure 6-3 Effects of Changes in Selling Price of Diesel Fuel and Pre-Treatment Costs on Facility's Discounted Cash Flow in 2016



The sensitivity of cumulative cash flow and discounted profit in 2016 is directly related to the price of petroleum-derived diesel fuel, which is used as the surrogate selling price for any synthetic diesel fuel produced by PGL conversion of tires in California. As can be seen in the life-cycle analyses in Appendix E, and Figures 6-1 through 6-3, all measures of profitability decrease as the price of diesel fuel falls.

Similarly, if the selling price for electricity, natural gas, and steel were to fall below the present values, PGL conversion profitability would decrease, though not as severe a response would occur as with changes in world oil prices.

With world oil prices, and most energy commodity prices at close to historical highs, the conversion of the energy content of scrap tires into high-value alternative fuels, electricity, and process heat offer the prospect of profitability. The report authors examined the results of the economic life-cycle analysis of a hypothetical thermochemical conversion plant processing 5 million tires per year, and co-producing electricity and process heat. The authors concluded that at present energy prices, the plant (with a capital and loan cost of $46.53 million) would be able to make an estimated first-year profit of $1.37 million in the third year of operation (2009), after paying all loan and operating and maintenance expenses, estimated taxes, and tire collection and pre-treatment costs (equal to $20 per ton of feed stock). This plant would recover capital costs by 2013 and have a projected annual net profit (discounted cash flow) in 2016 of $6.96 million per year.

Should energy prices increase above their present values, scrap tire conversion to fuels and energy would become more economically viable. When combined with other waste organic materials and the potential for revenue generated by their conversion to fuels and energy, the processing of scrap tires by one or more PGL conversion technologies would very likely be economically profitable, even with privately financed capitalization.

Conversely, the sensitivity studies indicate that should world energy prices fall by 50 percent, a tire conversion plant would not provide a net cumulative cash flow. This is considered an unlikely condition.

Section 7 Recommendations

1. Although evidence suggests advanced tire PGL processes should be able to meet permit limits for comparable industrial processes, it is suggested that an emphasis should be placed on collection of emissions and other process data as PGL facilities begin operation. This should not only include criteria pollutants but also trace species such as metals, dioxins, and furans.
2. Further efforts should be conducted to determine the potential value of tires as a resource that can be used to displace petroleum products or natural resources used in energy production. The true market value of tires should be determined based on potential products that can be derived from tire PGL, including electricity, diesel fuel, process heat, pyrolysis oils, and char.
3. As tire composition and the distribution of tires between passenger cars and trucks changes over time, tires (passenger and truck) should be analyzed for rubber, fillers, fiber, steel content, and BTU value to evaluate how this market value may evolve over time.
4. As a first step in developing tire PGL, the possibility of using tires in conjunction with other feedstocks at PGL facilities should be investigated.
5. PGL continue to be investigated as a potential strategy in disposing of scrap trips. This strategy could be used in conjunction with other programs already in place to further reduce the number of tires sent to landfill. To promote PGL technologies, the State could provide incentives for the development of PGL facilities at or near existing tire processing/disposal facilities, including municipal landfill sites, waste management sites, and tire recycling/recapping facilities. Developing PGL processes that produce a range of products could add to the marketability and viability of a PGL system.
6. Preliminary economic models indicate that gasification of tires could be economically viable based on current market rates for commodities such as diesel fuel, off-peak electricity, and process heat. This includes generation of a positive cash flow after only a few years of operation and an overall cumulative cash flow over an 11-year period. This situation would likely improve in the future if commodity prices continue to rise. Such a model could be further developed to incorporate more details on operational, process, and supply/demand elements.

Abbreviations and Acronyms

ADC	alternative daily cover
ASR	automobile shredder residue
Atm	atmospheres
Bbl	barrel
BIGCC	biomass integrated gasifier combined cycle
BTU	British thermal unit
CIWMB	California Integrated Waste Management Board
d	day
EPGS	electric power generating system
FT	Fischer-Tropsch
GWh	gigawatt-hour (10^9 watt-hours)
h	hour
H_2	hydrogen gas
HP SPR+HGR	high pressure steam pyrolysis and hydrogasification
HHV	higher heating value
IGCC	integrated gasifier combined cycle
kg	kilogram
kJ	kilojoule
kW	kilowatt
kWe	kilowatt electricity
kWh	kilowatt-hour
LFG	landfill gas
MJ	megajoule (10^6 joules)
MMBtu	million Btus
MSW	municipal solid waste
Mt	million short tons
MW	megawatt
MW_e	megawatt of electricity
MWh	megawatt-hour
MW_{th}	megawatt of thermal energy

NETL	National Energy Technology Laboratory
Nm^3	normal cubic meter
PCDD/F	polychlorinated dibenzo-p-dioxins and dibenzofurans
Quad (Q)	10^{15} Btus
Short ton	U.S. customary ton (2,000 pounds)
SMR+FTS	steam methane reformer and Fischer-Tropsch fuel synthesis reactor.
TEQ	Toxic equivalent
ton	Short ton (2,000 pounds)
tonne	metric ton (1000 kilograms
TWh	terawatt-hour (10^{12} watt-hours)
y	year

Glossary of Terms

This glossary contains general definitions of some terms that appear in the report.

- **Combustion:** A rapid conversion of chemical energy into thermal energy. The reaction is exothermic. Organic matter is oxidized with sufficient air (or oxygen) for reactions to go to completion. The carbon and hydrogen are oxidized to carbon dioxide and water, respectively.

- **Fischer-Tropsch Synthesis:** A process for producing mainly straight-chain paraffinic hydrocarbons from a synthesis gas having the correct mixture of CO and H_2. Catalysts are usually employed. Typical operating conditions for FT synthesis are temperatures of 390–660°F and pressures of 15–40 atmospheres, depending on the desired products. The product range includes the light hydrocarbons methane (CH_4) and ethane (C_2), LPG (C_3-C_4), gasoline (C_5-C_{12}), diesel (C_{13}-C_{22}), and waxes (>C_{23}). The distribution of the products depends on the catalyst and the process conditions (temperature, pressure, and residence time). The synthesis gas should have low tar and particulate matter content to avoid progressive contamination of the catalysts. Biomass-derived synthesis gas for FT liquid production is pre-commercial. However, it may be more easily commercialized than coal since it has smaller quantities of contaminants to remove in the synthesis gas cleaning process.

- **Gasification:** Production of energetic gases from solid or liquid organic feedstocks usually by partial oxidation. Primary energetic gases produced are hydrogen, carbon monoxide, and methane, along with an inorganic ash residue.

- **Hydrogasification:** Gasification using hydrogen gas to react with the carbon in organic materials to produce a methane-rich gas effluent and provide heat for the process. Any pyrolytic products present are usually converted into methane. Steam pyrolysis is often used as a precursor process that can enhance the hydrogen reaction kinetics, despite the presence of water in the feed. Since oxygen is not intentionally introduced, carbon oxides are reduced and methane increased as the hydrogen pressure is increased. Toxic hydrocarbons, like furans and dioxins, are chemically reduced by hydrogasification to less hazardous chemical compounds.

- **Integrated Gasifier Combined Cycles (IGCC):** Combined cycle systems that incorporate a gasifier for the purposes of converting the solid fuel to a fuel gas for combustion in a gas turbine using the Brayton cycle. Combined cycle (CC) power systems can extract more useful energy from a given amount of input energy or fuel by utilizing two power cycles in sequence: (1) a gas turbine Brayton cycle and (2) a steam Rankine cycle utilizing heat rejected in the gas turbine exhaust. In such systems, the steam boiler is conventionally referred to as a heat recovery steam generator (HRSG). Gas turbines require a clean, particle-free exhaust gas for expansion through the turbine. Using the effluent gases from gasified biomass or coal as a turbine fuel requires cleanup before introduction to the combustion chamber of the turbine, similar to those present in commercially cleaned natural gas. Gasification of coal for IGCC is being done in over 20 facilities worldwide.

- **Incineration**: Generic term in the industry that connotes any process that combusts waste.

- **Liquefaction:** Process used to alter the state of aggregation from a solid to a liquid state. In the case of scrap tires, this can take the form of a thermal process that melts the rubber of the tire and mixes the resultant liquid with another liquid for transport into a reactor vessel for processing.

- **Pyrolysis:** Thermal degradation of carbonaceous material in an oxygen-free reactor. Pyrolytic oils, fuel gas, chars, and ash are produced in quantities that are highly dependent on temperature, residence time, and the amount of heat applied.

- **Starved Air Incineration:** Usually a two-fold process. In the first stage, the reactor is fed with sub-stoichiometric levels of oxygen, creating a reducing environment, driving the organic components into the gas phase and leaving the inorganic material as ash residue. The next stage that follows thermally oxidizes the organic gases by mixing them with excess oxygen.

- **Steam Pyrolysis:** A thermally driven decomposition of organic material in a high-pressure superheat steam reactor. The steam produces more gas products and less pyrolytic oil than dry pyrolysis. The pyrolytic char formed is highly porous and is often used to make activated carbon from waste biomass. The activation of the char enhances the reactivity of the gasification process, especially when using hydrogen.

- **Stoichiometry:** Generally the molar or mass relationships among reactants and products of a chemical reaction. In any combustion reaction, for example, there is a specific molar or mass ratio of oxygen or air (which contains 21 percent oxygen by volume) to fuel that is required for complete combustion to occur (fuel fully oxidized to carbon dioxide and water). This ratio is called the "stoichiometric ratio" or the "stoichiometric air-fuel ratio." The inverse ratio is referred to as the "stoichiometric fuel-air ratio." If excess oxygen or air is supplied, the combustion occurs under fuel-lean conditions. If insufficient oxygen or air is supplied, the combustion is fuel-rich. The ratio of the stoichiometric air-fuel ratio to the actual air-fuel ratio is called the equivalence ratio (ϕ), so that fuel-lean conditions occur at equivalence ratios less than 1, and fuel-rich conditions occur at equivalence ratios greater than 1. An equivalence ratio equal to 1 specifies the stoichiometric air-fuel ratio. The inverse of the equivalence ratio is the air- or lambda-factor (λ). Combustion conditions are commonly described by the equivalence ratio, while gasification conditions (extremely fuel rich) are commonly described by the air-factor.

- **Synthesis gas** - A mixture of carbon dioxide, carbon monoxide, and hydrogen gas formed via gasification for the express purpose of synthesizing products.

Appendix A: Survey Questionnaire

To whom it may concern:

Each year California generates over 33 million reusable and scrap tires. About 3 million scrap tires are currently stockpiled throughout the state. The California Integrated Waste Management Board (CIWMB) estimates that nearly 25 million (75%) are diverted annually for various uses. The remaining 25% are either shredded and disposed of in permitted solid waste land fills, stored at permitted sites, or illegally disposed of.

In order to reduce the amount of material flowing to landfills or illegal dumping grounds, the state of California is interested in converting these residual materials into higher-value products such as manufactured goods, energy, alternative fuels, chemicals and other industrial products. Emerging conversion technologies have potential to help solve some of these tire management problems. CIWMB is exploring a new vision for the future that could involve technologies that convert organic materials into useful energy, ethanol, solvents, and other products.

Pursuant to this goal, the CIWMB has contracted the University of California, Riverside to evaluate the technology and economic analysis of scrap tire pyrolysis, gasification, and liquefaction. Our objective is to identify and evaluate technologies and processes that may be able to reduce the amount of material being stockpiled or illegally dumped by converting into useful products. A final report documenting the evaluation will be submitted to the CIWMB at the conclusion of the project, and will be available from the CIWMB web site as a contractor report and database. The report and database will be used by state and local government agencies and other stakeholders in pursuing alternative waste conversion technology projects.

Your company was identified as a potential candidate for the evaluation of these technologies. In order to initiate the evaluation, we are requesting some basic information about your technology. We would appreciate if you can take a few minutes to complete the following survey:

GENERAL

1. Do you have a pyrolysis, gasification, or liquefaction technology that can accept whole or pre-processed tires as a feedstock?
2. What is the commercial status of your technology (commercial, pre-commercial, pilot, proposed)? _____________________
3. If applicable, what fee do you (would you) charge for your feedstock ($/ton)?
4. If applicable, what is the current market rate for your product(s) ($/unit)? _____________ What type of product(s)? _______________________(Please list each type of product)
5. Do you hold patents to the technology or do you license from a patent holder? If so, please provide the patent numbers.____
6. If applicable, how many separate units of this technology do you or others (e.g., licensees) operate and where are they located?__________________________
7. Can you please provide a description of how the process operates? In particular, we are interested in the mass flows and compositions of input/output streams (energy and material flows). If possible, please include a process flow diagram labeled with specific mass and energy flows and compositions for each stream.

   ____

   ____
8. Does your technology currently process scrap tires? _____________
9. If yes, are scrap tires a primary or secondary feedstock? ______________________.
10. Do you presently interface with a used tire transport company to obtain your feedstock materials?
    a. If not co-located and you do not haul, how does the material get to your facility and how much does it cost to be delivered?
    b. Do you currently have a contractual arrangement for your feedstock with the company? _____. If not, are you interested in pursuing such an agreement? ______
11. What pre-processing of your scrap tire feedstock is required? For example, does the feed stock need to be shredded, cut, or ground to a certain size (please indicate a range of acceptable particle size)?
    ____

    ____

    ____

SPECIFIC

12. What is the design capacity and actual amount of scrap tire or scrap tire component material processed in tons per day?

    ____

13. Please describe the quantity and type of any solid and liquid residual (process wastes and by-products) output streams and how you manage or intend to manage them:

    ____

    ____

14. What other feedstock(s) can your technology use? Does the process require (or is it optimized for) co-feeding with these other feedstocks? If co-feeding, what are the relative amounts?

    ____

15. What are the ultimate products of your conversion technology and how much of each product do you generate (e.g. electricity, syngas, liquid fuels). If electricity, how big is the facility in kW or MW? (See question # 7 regarding process flow diagram.)

    ____
    _

16. What other material and energy inputs does your process require (e.g. water, steam, electricity, natural gas)? Please quantify in terms of amount per unit mass of feedstock processed or converted (See question #7 regarding process flow diagram.)

    ____
    _

17. What is the mass reduction efficiency (see definition below) of your technology (% by wt.)? __________Alternatively, can you tell us the mass flows for your systems including feedstock, products, and all waste or byproduct streams (See question #7 regarding a process flow diagram.)?

18. What is the carbon conversion efficiency (see definition below) of your technology? _________Alternatively, can you tell us the elemental composition of your input materials and the species (or elemental) concentrations in your products and residues (See question #7 regarding a process flow diagram.)?

19. Can you estimate the energy conversion efficiency (see definition below) of your conversion technology (%)? _____________(See question #7 regarding a process flow diagram.)

20. Do you have any source emissions testing, compliance test reports, or other environmental impact data you can share with us? _____

21. Have you attempted to obtain permits for a conversion facility, and if so, is it now fully permitted? If not, what permits are lacking or pending?

    ____

22. Can you tell us how the facility is financed and what incentives, if any, you have been able to obtain or use?

    ____

23. Do you have any promotional literature or technical documents you can share with us? __________

Please e-mail your response to xxxx (xxxx@cert.ucr.edu) or fax to (909) 781-5790 as soon as possible. Thank you in advance for you participation.

DEFINITIONS

MASS REDUCTION EFFICIENCY

$$= 100\% \times \frac{(mass\ of\ MSW\ input - mass\ of\ solid\ process\ waste\ output)}{mass\ of\ MSW\ input}$$

CARBON CONVERSION EFFICIENCY

$$= 100\% \times \frac{(moles\ carbon\ in\ output\ gases\ and\ oils)}{(moles\ carbon\ in\ all\ inputs)}$$

or

$$= 100\% \times (1 - \frac{moles\ C\ in\ process\ residue}{moles\ C\ in\ all\ inputs})$$

NOTE: Gross carbon conversion efficiency includes carbon dioxide gas in output gases. Net carbon conversion efficiency includes only those energetic carbon compounds that have a finite calorific value – please identify whether gross or net

ENERGY CONVERSION EFFICIENCY

$$= 100\% \times \left(\frac{energy\ content\ of\ all\ products}{energy\ content\ of\ all\ inputs} \right)$$

Please specify whether higher heating value (HHV) or lower heating value (LHV) is used and provide information on temperatures of output products and residues.

Appendix B: Descriptions of PGL Technologies Identified From Survey and Literature Review

The technologies described below are capable of incorporating scrap tires. It is important to note that sulfur and pretreatment are key issues with respect to thermochemical processing of tires. In some cases, further research in these areas will be required in order to make the technology viable for use with tires.

Semi-Commercial

The companies in this category have at least one commercial plant or are in the process of commissioning a fully commercial plant for tires.

Alcyon Engineering SA[41,42] (Switzerland)

Alcyon is a Swiss engineering company that has developed a pyrolysis process known as the TiRec process. The company has a separate "TiRec FUEL" process that incorporates only the pyrolysis unit and a "TiRec COGEN" process that incorporates the pyrolysis reactor and a separate generator/gasification process for the pyrolysis products. The TiRec COGEN process utilizes a separate gasification system for the semi-coke byproduct and a generator for the gases and oils produced in the pyrolysis process. The pyrolysis reactor operates at a shell temperature of 1022°F, resulting in a product temperature of approximately 790°F, and a pressure of approximately 0.8 atmosphere. The reactor operates in a batch mode and is capable of handling up to three batches of 1,100 pounds each per hour.

Alcyon is currently operating a TiRec plant in Kaohsiung, Taiwan. The plant includes two lines capable of processing 24,802 metric tonnes per year each with a typical operating time of 7,500 hours per year. Each line incorporates two separate pyrolysis reactors. The plant is operated by a customer and not directly by Alcyon, so only limited feedback on the plant operation was available.

Pre-Commercial

Environmental Waste International (EWI)[43,44] (Ajax, Ontario, Canada)

EWI manufactures and markets systems that use microwave heating to pyrolyze the feedstock in an inert or low-oxygen atmosphere. The basic process is like pyrolysis with standard volatile gases, tars, and char as the products (relative amounts and compositions are feedstock-dependant). The company is focusing on used tires and biomedical waste as the primary feedstocks for their commercialization efforts. These feedstocks were selected after a series of technological, economic, and market studies. Other potential feedstocks include chemical sludge, automobile shredder residue (ASR), and animal wastes.

EWI has installed one unit for the disposal of medical waste in Liverpool, UK. This unit is currently undergoing licensing and environmental approval. A company press release indicates the company has an agreement with a private firm in the UK to design and build its first facility to pyrolyze scrap tires with the microwave heating process. The facility would be capable of converting 3,000 tires per day. EWI also indicates that it has received deposits for two additional orders for medical waste units. EWI also operated a 300 tire-per-day pilot plant between 1994 and 1998.

Material and energy flow diagrams on the company website claim that a tire conversion facility that consumes 6,000 tires per day can provide sufficient energy to drive a 5-MWe steam turbine (if all pyrolysis oils and gases are burned in a boiler). The magnetrons and balance of plant will consume 3 megawatts of electrical power, leaving 2 megawatts available for export.

Renewable Oil International (ROI)[45] (Florence, Alabama)

Renewable Oil International is a pre-commercial company that uses scrap tires as a feedstock cut into 2-inch shreds. ROI charges minimal fees to receive the tires, only enough to cover the shredding cost. ROI's process is economic with a zero feedstock cost. The company has patents pending in the U.S. and Canada. At the present time, ROI has one plant in Russellville, Alabama, and one under construction in Massachusetts. The process wastes and by products include: oil, which is sent to a refinery, steel, which is recycled, charcoal, which is sold to a coal-fired power station, and gas, which is combusted in the process. ROI claims that sulfur emissions from the scrap tires are a problem. The addition of lime or calcium carbonate has been shown to reduce sulfur emissions as well as improve the quality of the oil. Further, the carbon black contains inorganic ash and cannot be used as a replacement for high-quality carbon black produced from natural gas.

Pilot or Demonstration Scale

The companies in this category have demonstrated their technology at a pilot scale level and are in the process of moving to a more commercial scale or are actively seeking opportunities to move to a more commercial scale.

ACM Polyflow Inc.[46] (Akron, Ohio)

The primary goal of the process is for the development of useable petroleum-like compounds such as BTEX chemicals (primarily aromatic hydrocarbons and cycloalphatic compounds) and petroleum coke. According to the material provided, ACM Polyflow flow has conducted some tests on a batch reactor capable of processing 1,000 pounds of material over a period of approximately six hours. Company plans call for up to 200 facilities nationwide that each can process 50 tons per day.

The process is reportedly aimed at a broad range of polymer wastes, including tires, polymeric MSW, automobile shredder residue, polymeric electronic waste, carpet, postconsumer and post-commercial polymeric waste, and limited amounts of PVC. The process is currently being patented, so only limited information is available on system design. The waste undergoes primary shredding into 6-inch to 8-inch chunks and drying prior to processing. The waste enters the reactor via an airlock system. After the pyrolysis processing, the coke remains are recovered through an airlock at the bottom of the reactor, and the non-condensable gases are combusted to provide thermal energy for continuous process operation.

Beven Recycling[47,48,49] (Gloucestershire, UK)

Beven Recycling, in conjunction with the UK Atomic Energy Authority, developed a low-volume pyrolysis process for the recovery of products from used tires. A small-scale facility based on this technology was constructed in Witney, UK, with a capacity of approximately 10 tons of tires per week, or up to 500,000 tires per year. This facility reportedly operated for approximately four years but is no longer in operation. The technology is described briefly. The tires are placed in an indirectly heated retort pyrolysis chamber in 1-ton increments (approximately 150–175 tires). The resulting pyrolysis gases pass through a water-cooled condenser where they are condensed into a bio-oil. Any remaining gases pass through a small scrubber and then to a gas burner that produces energy to self sustain the process. When the process is completed, the residual carbonaceous char and steel are removed from the retort after being cooled and separated. On a mass basis per ton of tires, the process produces approximately 285–350 pounds of steel, 880–905 pounds of carbon char, 505–605 pounds of bio-oil, and 420–465 pounds of synthesis gas. The process has reportedly been well-tested and was considered to be proven at the current scale by a third party, Tebodin (UK) Ltd., for the Department of Trade & Industry.

<u>Conrad Industries, Inc.</u>[50,51,52] (Chehalis, Washington)

Conrad Industries, Inc., has developed a pyrolysis process that can be utilized for the thermal conversion of various organic wastes into gas, oil, and carbon products. The system is called the Advanced Recycling Technology (ART) process. The system is designed for use with feedstocks shredded to 2-inches with a moisture content of 15 percent or less. The reactor is a horizontal unit and feedstock enters via a rotary air lock and a screw feeder. The solid products from the reaction vessel are transferred to the classifier for separation. The exiting gas stream is drawn into a condensing system for oil recovery. The remaining non-condensable gas fuels can be used in burners to maintain process temperatures or for use in other energy recovery systems.

The company provided operational data for tires and some additional data for plastics. For tires, the material balance for the system output included 36 percent pyrolysis oil, 32 percent fixed carbon, 21 percent non-condensable pyrolysis gases, 8 percent steel and fiberglass, and 3 percent water. Based on 1 TPH of tires, it was indicated that the system energy input would be approximately 33 million BTUs per hour, with an energy output of 8 million BTUs per hour in pyrolysis gases, 13 million BTUs per hour in pyrolysis oil, and 8 million BTUs per hour in carbon char.

Two pilot scale demonstration plants with capacities of 3.5 and 24 tons per day have been constructed and tested in Chehalis, Washington,. The ART system can be designed in modules with capacities of 24, 48, and 72 tons per day (TPD). Conrad Industries has also conducted a three-year study with the American Plastics Council to demonstrate the conversion of post-use plastics into liquid petrochemical feedstocks.

<u>Thermogenics, Inc.</u>

Thermogenics, Inc. is based in Albuquerque, New Mexico. This company has developed a directly heated downdraft gasifier that is continuously fed and air-blown. It was designed to handle loads from 0.5 to 3 TPH. Thermogenics has reported a total of three commercial units built. Thermogenics' market strategy is to create alcohol fuel from the syngas, collaborating with Power Energy Fuels, Inc. Thermogenics and its partners have purchasers ready for the product as soon as production starts. Thermogenics is currently planning a demonstration tour of California with its trailer-mounted system.

Small Pilot Plant/Bench Scale/Research Companies

The companies in this category have either developed small sub-commercial, pilot, or bench scale units, or have developed the theoretical basis for a pyrolysis process that has not been demonstrated on a larger scale.

Ande Scientific[53,54] (Smethwick, West Mildands, UK)

Ande Scientific developed a pyrolysis process in collaboration with Wellman Furnaces Ltd. that they call the "continuous tire pyrolysis system." Ande Scientific is not currently actively promoting this process, but would be amenable to further develop the process given the appropriate financial resources. This system is designed for a capacity of 100 tires per hour, but no active facilities with the technology have been built. The system utilizes an indirectly heated pyrolysis reactor with a magnetic separator to remove the residual steel from the tire. The pyrolysis gases produced are condensed to form a bio-oil. The remaining pyrolysis gases are combusted to provide thermal energy for the pyrolysis unit or elsewhere. Ande Scientific remains involved in processes for the disposal of tires, including a technology whereby the scrap tires are rolled into discs and a thermoplastic elastomer is made from crumbed tires.

BPI Projects [55] (Manchester, UK)

BPI Projects developed a pyrolysis process for scrap tires based on a chain grate furnace. The synthesis gas produced is subsequently combusted in a waste heat boiler to generate steam that can be used as a heat source or to generate electricity. The technology was apparently acquired by Energy Power Resources, a UK project developer. EPR built a 12,000-tpy demonstration plant in Denmark, which operated in 2001, and had plans for additional plants. However, recent phone conversations with Energy Power Resources indicated this company is now only marketing full combustion systems..

Hebco International[56,57] (Montreal, Quebec, Canada)

Hebco International Inc. is a Canadian firm that is marketing a pyrolysis process for use with automobile shredder residue and tires. Its pyrolysis process is based on a design the company obtained in 1995 and is currently updating. The pyrolysis process is said to utilize shredded feedstock and produces the standard bio-oil, char, and pyrolysis gases. The pyrolysis gases are combusted and with the thermal energy used in part to drive the pyrolysis process. Hebco has no active facilities.

Traidec DTV Process [58] (Sainte Foy L'Argentiere, France)

Traidec developed a pyrolysis process initially designed for the disposal of medical waste generated by a local pharmaceutical company. The reactor has a rectangular box design and uses a two-level conveyor to transport the waste. The company also developed a plant designed to target industrial waste streams and tires. A 1,320-pound per-hour plant was constructed to process shredded scrap tires and has been extensively tested at the Traidec facility. The system was operated for extended periods of time on various waste streams. A 2-TPH plant was also engineered. The company's current status is not known.

Weidleplan & LIG [59]

This technology is a pyrolysis technology developed for processing scrap tires. The process was originally developed by a small German engineering company, was subsequently acquired by Weidleplan Industry GmbH, and then acquired by a company called LIG. It is the authors' understanding that LIG was having financial problems, but the current status of the technology is not known. The process was designed for tires and includes stages for size reduction and separation, pyrolysis, combustion and carbon activation. The pyrolysis process takes place at a temperature of 1110–1290°F, with the remaining syngas and pyrolysis oil converted in a two-stage combustion reactor. This process was initially tested in a small pilot scale project. A 25,000-tons-per-year tire shredding plant was reportedly installed in Miltzow with operation expected for the third quarter of 2002. It is not known what the status of this plant is.

Other Technologies

The following pyrolysis and gasification technologies were identified that have operational facilities for mixed wastes such as MSW or auto shredder residue that potentially would also be technically viable for tires.

Full Scale Commercialization

Nippon Steel (Tokyo, Japan)

The Nippon Steel "Waste Melting Process" evolved from metallurgical processing technology. The process accepts unsorted MSW that has been processed to the required particle size. From Juniper,[60] the Nippon Steel process uses a fixed bed gasifier, with enriched oxygen air injection in the melting section. Nippon Steel has the largest capacity of any PGL process for mixed waste with a capacity of over 1 million tons per year, 21 commercially active facilities, and 5 more facilities in planning.

Ebara/Alstom (France, Switzerland and Japan)

Alstom Power (Meudon-la-Foret, France) acquired ABB Enertech in 1999. ABB had exclusive license of Ebara's (Japan) fluidized bed technology, which has several commercial facilities in Japan.[61] Ebara builds and operates full MSW combustion facilities in Japan and some other Asian countries. Ebara also has developed the TwinRec and EUP gasification processes through the Japanese initiative to develop more sustainable waste disposal technologies. Ebara has approximately a dozen facilities active in processing mixed wastes and plans for a 1,500 tons-per-day facility to open in Malaysia in 2006.

Mitsui/Takuma/Siemens [62,63,64]

The "Schwel-Brenn Verfahren" process (or "Thermal Waste Recycling Process") was marketed by Siemens in Europe in the mid to late 1990s and is now marketed by Takuma and Mitsui in Japan.

The basic process combines pyrolysis with high-temperature combustion and can be utilized with tires, MSW, sewage sludge, or ASR. The system utilizes a horizontal reactor where the waste is pyrolyzed at 840°F for about one hour. The original Siemens process was actively promoted in Europe. Siemens experienced considerable problems with the continuous operation of its Fürth Plant in Germany that culminated in a serious accident at the site. According to European sources, one of the main causes of the accident was poor feedstock preparation in that the unit did not utilize shredding and was accepting items as large as a full mattress with springs. As a result of the problems with the Fürth plant, Siemens eventually withdrew from the market beginning in 1999.

The original Siemens process appears to be more successfully applied in Japan by license holder Mitsui Babcock and Takuma. Mitsui Babcock currently has six active installations processing between 150 and 450 tons per day. This includes one facility that has operated since 2000; the other facilities have been in place for at least a year. Mitsui Babcock incorporated several design upgrades on the Siemens design, including the shredding of to-be-processed waste and a different sealing mechanism for the pyrolysis drum, which should avoid the previous issues found at the Fürth facility. Licensee Takuma also has several facilities in operation. A 99-ton-per-day ASR processing plant has been operating in Fukuoka for the Kanemura Co. Ltd since 1998. A 179-ton-per-dayt facility for processing MSW has been operating for approximately 1 year in KoKubu City in Japan. One other facility is processing MSW at 133 TPD in Oshima, Hokkaido Island, Japan.

SVZ Concept

One of the oldest and most historically important gasification facilities for mixed waste is the Schwarze Pumpe site in former East Germany. This site is currently the largest operating facility in the world for mixed waste. This site is operated by Sekundarrohstoff-Verwertungszentrum (SVZ), which is now a subsidiary of Global Energy, Inc., of the U.S. The plant began operation in the 1950s for the production of town gas from coal in the area, but was commissioned to operate on waste in 1997. The facility treats more than 450,000 tons per year of solid wastes and another 55,000 tons per year of liquid wastes,[65,66,67,68,69] although a recent gasifier survey has reported even higher values.[70] The feedstock types accepted are diverse and include postconsumer plastics, ASR light fractions, sewage sludge, TDF, wood waste, oil, paint and refinery residues. The facility produces 75 megawatts of electricity and 300 TPD of methanol. There are 10 separate gasifiers in the facility. Seven are Lurgi Dry Ash gasifiers; and the other three are a Lurgi multi-purpose gasifier, a British Gas-Lurgi, and a Noell KRC.

Thermoselect [71,72,73,74,75] (Locarno, Switzerland)

The Thermoselect High Temperature Recycling process was developed beginning in 1989 stemming from work in the earlier 1980s. The process uses a slow pyrolysis process followed by fixed-bed oxygen-blown (atmospheric pressure) gasification and ash melting. Waste is loaded into a chamber where it is compacted by hydraulic press to one-fifth its original volume and moved (in plug flow fashion) through a cylindrical heating channel where drying and pyrolysis occurs and the lower end at about 570°F before entering a high-temperature reactor at about 1500°F.

In examining the Thermoselect technology, the authors found it is one of the more widely applied technologies on a commercial basis. The initial development of this system was focused in Europe. A semi-commercial, 110 TPD facility was built in Fondotoce, Italy, and has been in continuous commercial operation from 1994 to 1999. A facility was then built in Karlsruhe, Germany, in 1999. This facility had problems that led to considerable delays in commissioning. A 792 TPD facility was finally commissioned in 2001 and appears to have operated since then. Recent information indicates that the facility is still having financial problems,[76] although representatives from the North American subsidiary of Thermoselect indicate that these issues are being addressed.

The delays in the commissioning of the Karlsruhe facility, in combination with other issues, resulted in problems with other early Thermoselect orders, including those at Hanau, Tessin, and Ansbach. Reportedly, the Ansbach facility has been built, but has not completed final commissioning. Thermoselect also has a number of other facilities in various stages of development in Europe, including one in Poland, two in Spain, two in Italy, and three in Ireland.

Facilities in Japan seem to have proceeded through commissioning more easily, indicating that the technology itself appears to be viable. A facility in Chiba, Japan, has been operating since 1999 and been operating commercially at a capacity of 330 TPD since 2002. This plant was built by the Kawasaki Steel Corporation, Thermoselect's original Japanese partner. A second plant with a capacity of 140 TPD has been operating in Mutsu, Japan, since 2003. Additionally, plants in Mizushima KCS and Kawagoe City, Japan, are currently under construction. Other plants in Isahaya, Sainokuni City, and Yoshino, Japan, are in various stages of planning and construction. JFE is the company currently providing the Thermoselect technology for Japan.

A U.S. company, Interstate Waste Technologies, is marketing the Thermoselect process in North America and the Caribbean. Interstate Waste Technologies indicated that projects are currently being negotiated in Costa Rica, U.S. Virgin Islands, and Puerto Rico.

WasteGen UK, Technip [77,78,79,80]

WasteGen UK is marketing "Materials and Energy Recovery Plants" (MERPS). This company seems to be the inheritor of rotary kiln pyrolyzer technology developed by PLEQ, a now-defunct East German company, and then the Technip division of the Mannesmann Company. Franz-Eicke von Christen is the technical director for the company. He was a founder and director of the original PLEQ Company. Technip is operating separately and appears to be promoting this same technology.

A full-scale unit has been operating in Burgau, Germany, since 1987. The plant is operated by the municipality. The plant processes a mixture of MSW, industrial waste, and sewage sludge. The facility uses two rotary kilns, 66 ft long by 7.2 ft diameter. Each processing line is capable of 3 ton per hour. Some 40,000 tons per year of waste material is pyrolyzed at the facility. The outer surface of the kiln is heated to 1020°F, resulting in a temperature of 840–880°F in the reaction zone, which is operated at a slight vacuum. The residence time in the reactor ranges from 30 minutes to 2 hours; 1 hour is typical. Technip also has a second facility northeast of Dortmund at Hamm in Germany that has been operating since 2002 with a capacity of 110,000 tons per year with two streams of 7.3 tons per hour. Technip is informally working with Duratek to incorporate a large-scale steam reforming plant at this facility.

Semi-Commercial

BRI Energy, LLC[81] (Fayetteville, Arkansas)

BRI is marketing technology based on a bacteria developed by Dr. James I. Gaddy that can metabolize synthesis gas and emit ethanol as a product. The BRI technology combines an upfront thermochemical process to produce synthesis gas with a biochemical process using these bacteria. BRI claims that the process takes less than seven minutes from feeding into the gasifier to the production of ethanol. By contrast, standard methods for sugar fermentation require 36–48 hours. There is one pilot facility in Fayetteville, Arkansas. Currently, this plant is processing salt water-immersed wood from Alaska. BRI is also negotiating facilities in the San Joaquin Valley, Los Angeles County, Minnesota, and Illinois.

Compact Power Process[82,83,84,85,86,87]

This process developed by Compact Power Ltd. of the U.K. uses pyrolysis, gasification, and high-temperature combustion for processing different kinds of waste. Compact

Power began operation in 1992 and built a pilot scale plant in 1994. Between 1995 and 1999, a series of trials were conducted at the Compact Power Plant to obtain emissions and performance data. The company began preparations for a commercial facility in 1998 at a waste transfer station at Avonmouth in Bristol, U.K., in 1998. Construction began in early 2000 and was completed by April 2001, and the facility received a permit to operate in September 2001. The plant began continuous operation in January 2002. The facility operates two lines with a capacity of 1,100 pounds per hour each or an annual capacity of 9,000 tons per year. Recent news releases indicate the company is looking to sell, but still operate, the facility to provide capital for additional ventures and expenses.

Enerkem Technologies Inc., Université de Sherbrooke, and KEMESTRIE INC. (Sherbrooke, Quebec, Canada)

Enerkem Technologies Inc. is a subsidiary of the Kemestrie Inc. Group, a spin-off company of the Université de Sherbrooke, founded in 1992. Their process utilizes a bubbling fluidized bed (BFB) gasifier, with air or oxygen operating at pressures of up to approximately 16 atmospheres. The process includes proprietary catalysts for cracking tar and other components in the producer gas. The process is capable of operating on biomass, sorted MSW, and plastics.

The Poligás plant in Ribesalbes (Castillón), Spain, owned by Poligás Ambiente, S.L., and built by Environmental International Engineering, S.L. (EIE), has recently gone into operation. Spain's Institute of Energy Diversification and Efficiency (IDAE) and the waste management company Revima participated in the project. Financing was provided by regional government (Valencia) and EU funds. The plant is fueled with discarded plastics wrappings from the ceramics industry. This plant reportedly (Enerkem website[88]) is generating 7 MWe (80 MMBTU per hour of synthesis gas) from approximately 27,560 tons per year of waste plastic. It has run for approximately 5,000 hours since August 2003.

In 2002, Enerkem began working with the City of Sherbrooke to convert waste into synthetic gas (BioSyngaz-Estrie project). Federal, provincial, and corporate monies financed the project. The pilot unit was designed and constructed with the capacity to convert 2.8 tons of sorted municipal waste residue per day. Enerkem, the City of Sherbrooke, provincial and federal agencies have partnered to build and operate a pilot plant based on the BIOSYN process for sorted MSW. Reportedly, the system ran at a capacity of 5 TPD for more than 1,000 hours since 2002 with technical reports and feasibility studies that should be complete at this time.

Foster Wheeler Energia Oy (Finland)

Foster Wheeler, in cooperation with Kymijärvi Power Station at Lahti, Finland, has installed an atmospheric (air-blown) circulating fluidized bed (ACFB) gasifier next to the coal/fossil fuel fired utility boiler. The thermal capacity of the gasifier is 40–70 MWth, depending on the moisture content of the fuel (which can be up to 60 percent). The process operates on different feedstocks including refuse-derived fuel. The project demonstrates commercial scale feasibility of close coupled gasification of low quality ”opportunity” fuels which otherwise could not be utilized in the combustion boiler.

A municipally owned waste management company (Päijät-Hämeen Jätehuolto Oy) started the processing of refuse-derived fuel in 1997. In the first year of operation, 1998, just less than 9000 tons of residential refuse fuel was gasified, accounting for 22 percent of the energy through the gasifier (the bulk of the gasifier energy came from wood residues–-71 percent). For the year2000, over 22,000 tons of refuse fuel was consumed, accounting for 36.6 percent of the energy acquired through the gasifier.[89]

Foster Wheeler installed a bubbling fluidized bed gasifier (BFB) as part of an integrated recycling process at the Corenso United Oy, a large paper and cardboard/packaging material manufacturer. Used multilayer packaging material (which includes plastic film and aluminum foil layers, for example, Tetrapak aseptic drink containers) is recycled by separating as much of the cellulose material from the plastic and aluminum as possible and then gasifying the remaining plastic and aluminum-containing portion in the Foster Wheeler BFB. The gasifier is 40 MWth in capacity and recovers about 3,000 tons per year of aluminum and gasifies 27,000 tons per year of polyethylene.

Graveson Energy Management [90,91] (Summit, New Jersey)

Graveson Energy Management (GEM) has developed a process similar to fast pyrolysis that it calls thermal cracking. The technology can be used for the disposal of various organic wastes including MSW, industrial wastes, wood waste, waste oils, sewage sludge, and tires. GEM operated a commercial-size 36 TPD unit in South Wales from 2000 to 2002 for the processing of MSW. The unit is South Wales was planned for expansion from 1.5 tons per hour (TPH) to 6 TPH, but financial issues for the operator have currently put this project in limbo. It should be noted that as part of the approval process for the South Wales facility, analysis of waste, raw gas, char, and combustion gas were performed by an independent outside laboratory. This facility used an autoclave as part of the up-front processing that caused some problems in the handling of the waste. Orders for six units have been secured and are in various stages of planning. These orders include two the U.K., one in the U.S., one in Spain, one in Canada, and a second in a discussion stage in Canada. A different feedstock handling system is planned for future orders that will incorporate magnetic separation of metals and a shaker table to separate other inorganics prior to shredding followed by an additional magnetic separator. GEM has also operated a 0.5 TPH prototype unit for testing since 1998.

International Environmental Solutions [92] (Romoland, California)

International Environmental Solutions (IES) is currently in the process of commissioning a 50- TPD facility in Romoland, California, based on pyrolysis technology. The IES process applies high temperatures (1200°F–1800°F) indirectly to a retort chamber, which houses an environment free of flame and oxygen. Inside, the hydrocarbons and other waste components are converted into gases and basic elemental solids via destructive distillation and molecular decomposition. All off-gasses are diverted to a thermal oxidizer operating at 2200°F or higher for conversion to carbon dioxide, oxygen, and water vapor. The solid residues of the waste stream are passed out of the retort as carbon, sterile sands, and/or fixed, non-leachable metals.

The IES facility is working with the South Coast Air Quality Management District (SCAQMD) to meet all of the agency permit requirements. Testing includes a variety of waste streams including, but not limited to: biosolids, MSW, fireworks, infested forest trees, and tires. Initially targeted wastes include medical waste, electronic waste, and fireworks with infested forest tree bark.

Waste heat at the Romoland facility will be used to generate electricity for use on-site as well as to power a wastewater treatment facility also constructed at the site. Power will be adequate to meet all site needs. Future IES systems will be larger and will provide electricity for offsite sale or use.

The IES facility is constructed pursuant to proprietary patents and patent applications currently on file both in the U.S. and abroad.

<u>North American Power Company</u> [93] (Las Vegas, Nevada)

North American Power Company has developed a pyrolysis unit dubbed the Thermal Recovery Unit (TRU). The TRU is a pyrolysis unit followed by a thermal oxidizer. Organic material (hazardous and non-hazardous) is sorted and shredded to a 1" or 2" particle size feedstocks include: tires, plastics, woods, soils, municipal, industrial, and medical wastes, pesticides, oil field sludge, and PCB contaminated materials. North American Power currently has a facility with two TRU systems running in Las Vegas, NV. This facility has processes 1000 lbs. or material per hour over a 16 hour a day, 5 day a week operation. The Las Vegas facility is currently using regenerate activated carbon, which is the primary ingredient in most modern air and water filtration systems. Although the facility is not currently using MSW, it is believed the facility does have this capability. The close proximity to the California border also merits attention.

<u>PKA Umwelttecnik</u>[94,95,96,97] (Aalen, Germany)

This is a pyrolysis process followed by gas converter (cracker). Feedstocks that can be utilized with the system include tires, automobile shredder residue (ASR), MSW, industrial and plastic waste and contaminated soil. The preprocessed material is conveyed into a rotary pyrolysis drum that is externally heated to 930-1020°F by hot combustion gas (from burning natural gas during start-up, or from burning a portion of the pyrolytic gas that can be recycled if available in sufficient quantity and quality). A PKA facility in Aalen, Germany, has been operating on a blend of MSW, commercial waste, and sewage sludge since 2001. This unit has a capacity of 28,000 tons per year. PKA indicate there is a char/ash melter with the facility. PKA has a 31,000 TPY unit installed in Freiberg/Saxony, Germany, where high aluminium content industrial waste is pyrolyzed for recovery of the aluminium, which is sent to an adjacent aluminium melting plant. Pyrolysis gas is sent to the aluminium plant as well. This facility has been operating continuously since the summer of 2001. A 9,000 TPY sewage drying plant has been operating since 1993 in Bopfingen, Germany. A smaller 0.4 TPH facility has also been used for testing since 1994.

<u>PYROMEX – ILS Inc.</u>

Starting in 1989, Pyromex successfully implemented its technology into the European market, developing its waste neutralization systems, its pyrolysis technology, and its patented "ultra-high temperature gasification" system. This system, operating between 1832°F and 3100°F, converts the "pyro" gas coming from the retort into an energetic mix of selected gases, with synthesis gas (H_2 and CO) making up the largest fraction at around 70 percent by volume. The main product of the Pyromex technology is energy, with some mention of the inert basalt material from the gasification chamber, as well as the recyclable material, having some market value. Pyromex has a 25 TPD facility that was commissioned in Emmerich, Germany, in February 2002 for sludge treatment and has been operating continuously since then. Another 25 TPD sludge treatment facility was planned for commissioning in Neustadt a.d.W., Germany, in May 2004. Pyromex is represented in North America by Innovative Logistics Solutions, Inc. A 400 TPD ASR processing system is being developed at Adams Steel in Anaheim, California. A 250 TPD green waste processing facility is also being developed at SoCal Greenwaste in Thousand Palms, California. <u>SERPAC Pyroflam Process</u> [98,99,100] (L'Arbresle Cédex, France)

The P.I.T. Pyroflam process was developed by BS Engineering S.A. affiliate SERPAC Environment of France. The Pyroflam process is designed for use with mixtures of solid wastes with sewage or other sludges. The process utilizes a horizontal reactor that incorporates both a pyrolysis chamber and a subsequent combustion chamber. The pyrolysis reactor operates at 1110–1290°F. Serpac operated a 26 TPD demonstrator unit located at the Budapest, Hungary airport from 1996 to 2003. Serpac has installed a new 45 TPD facility in Keflavic, Iceland, that is scheduled to begin operation shortly.

Solena Group[101] (Washington, DC)

The Solena Group has developed an integrated plasma gasification and combined cycle (IPGCC) plant that can process municipal solid waste, industrial, toxic, hospital, and other wastes, including tires and plastics. The IPGCC process uses a high-temperature plasma torch to dissociate wastes into a synthesis gas, which is used to power a gas turbine and combined cycle steam turbine. No IPGCC systems have been built. The company or current members have been involved in a wide variety of projects and ventures that utilize plasma arc technology. Most of the applications were related to hazardous or low-level nuclear waste volume reduction or in metals production. The company is involved in attempts to locate pilot-scale facilities in the Caribbean to help serve the cruise line industry with potential shipboard waste disposal systems. The company is involved in development projects in Spain, France, the UK, the U.S., and Malaysia.

ThermoEnergy: STORS & TIPS (Richmond, Washington)

ThermoEnergy's Integrated Power System (TIPS) is being marketed in coal gasification. It recovers energy from the water in the process gases and recovers liquid carbon dioxide. However, its process is not clear.

Two other systems have been developed by ThermoEnergy. The Sludge-To-Oil Reactor System (STORS) converts wastewater to bio-oil or char with a CV resembling medium-grade coal (5,000–10,000 BTUs per pound). One demonstration facility in Colton, California, is processing 5 million gallons of wastewater per day. The facility also utilizes the company's Ammonia Recovery Process (ARP), thus producing high-energy fuel from STORS and fertilizer from ARP. The facility runs on raw, digested, and waste-activated sludge.

Thide Environmental[102,103,104] (Voisins Le Bretonneux, France)

The EDDITh process was developed by Thide Environment S.A. of France and the Institute Francais du Pétrol (IFP). The process is based on a rotating drum pyrolysis scheme. Following materials sorting and drying, the material is conveyed into the rotating pyrolysis drum. The material is pyrolyzed at a temperature of 840–1020°F with a residence time of approximately 30 minutes. Thide-Environmental has a 50,000-TPY facility in the town of Arras, France, that is beginning full operation May of 2004.[105,106,107] Thide has an 0.8 TPH pilot plant in Vernouillet, France, that accumulated approximately one year's worth of operating experience since its construction in 1992. Thide Environmental also has licensed its process to Hitachi for Japan.[108,109,110] It has a plant in L'usine d'Itoigawa, Japan, with a capacity of 25,000 tons per year that has been operating since May 2002 and a plant in Izumo, Japan, with a capacity of 70,000 tons per year that has been operating since May 2003. It also has a 1 TPH pilot plant that has accumulate 5000 hours of operation since 1999.

Von Roll RCP[111,112] (Zürich, Switzerland)

Von Roll has a long history of utilizing conventional moving grate technology for waste processing dating back to the 1930s. The Recycled Clean Product process is a moving grate and melting process that has been used for applications with organic material, residual waste from recycling, and ASR. A demonstration plant using the Recycled Clean Product technology was installed and began operations in Bremerhaven, Germany. Although the moving grate furnace and smelting technologies are well known technologies, several years were required to bring the Bremerhaven facility up to full operation and the combining of the different technologies does add to the complexity of the system. Since 1997, the plant was able to increase production processing to approximately 4,400 tons of material in 1999 and 7800 tons of material in 2000. A 50 kiloton-per-year plant fuelled by ASR is also planned for Switzerland.

Pre-Commercial

Adherent Technologies, Inc. (Albuquerque, NM)

Adherent has developed a proprietary thermochemical process that can use combinations of different carbonaceous feedstocks to produce a hydrocarbon product that can be used for chemical or fuel applications. Feedstocks are generally mixed and neat plastics, electronics, carbon/thermoset composites, and tires. Once the hydrocarbons are removed, materials such as fibers and metals can be separated and purified for reuse. Adherent Technologies, Inc. has a pilot plant only in Albuquerque, New Mexico. The baseline design of the facility is based on a throughput of 100 tons per day of material.

Emery Energy Company (Salt Lake City, Utah)

The Emery Energy Company has developed a fixed-bed gasification process that can potentially be used for a range of feedstocks, including MSW as RDF, scrap tires, and other biomass feedstocks. The system incorporates a downstream syngas cleaning process that removes gaseous pollutants prior to its combustion for power generation. Process flow diagrams for a 20-MW_e and a 70 MW_e facility are shown in Figures B-1 and B-2. The Emery technology is currently in the precommercial/pilot plant stage of development. Emery has a 25 TPD/ 7 MW_{th} pilot plant in central Utah and a new 3 MW_{th} pilot plant in Salt Lake City. Emery has also designed a 70 MWe gasification system with INEEL/Bechtel and GE Power Systems and gasifier vessels of up to 600 tons per day. The project is receiving U.S. Department of Energy funding.

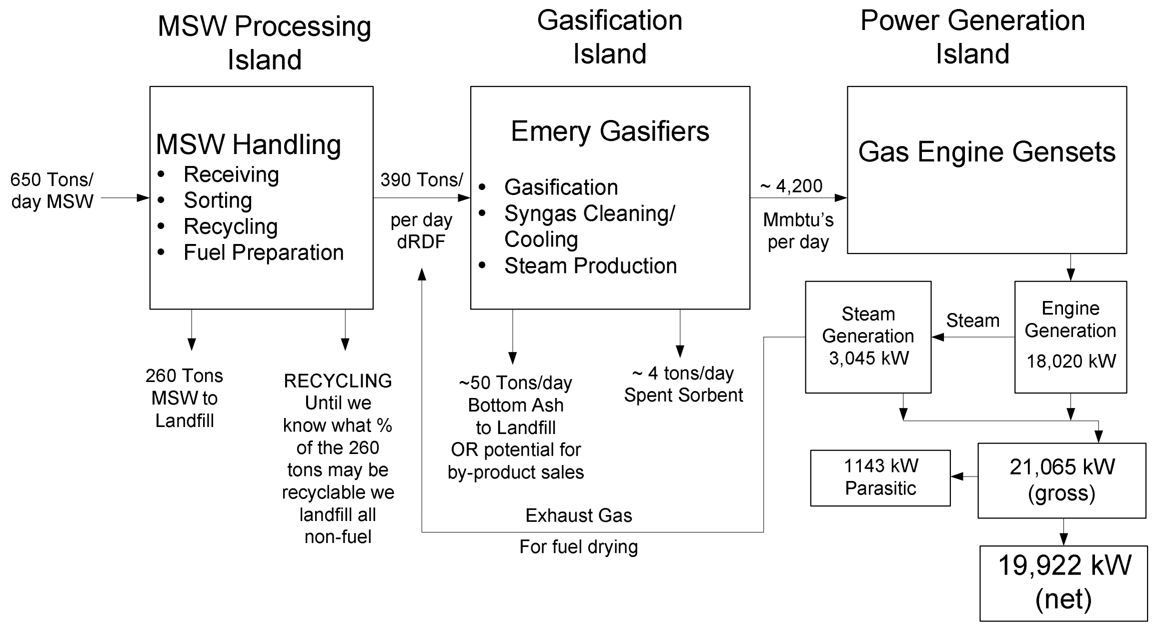


Figure B-1 Process Flow Diagram for 20 MWe MSW Gasification Power Plant Recently Proposed to a Municipality in California

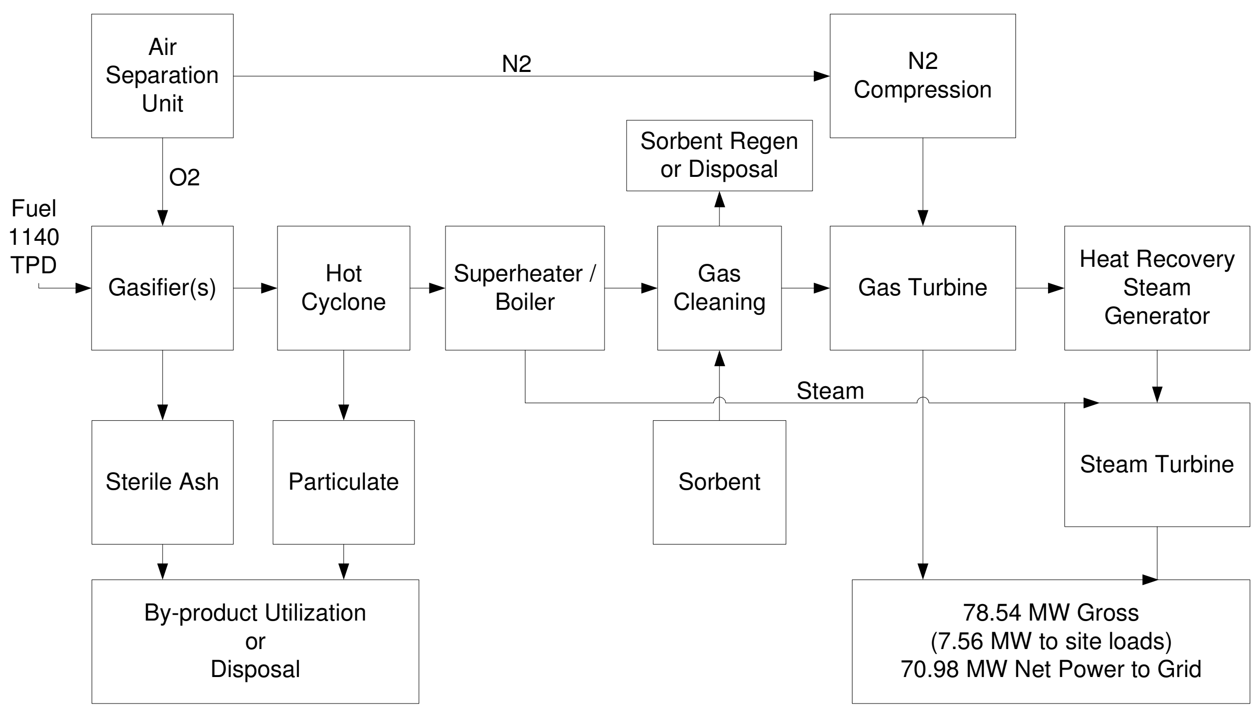


Figure B-2 Simplified Process Flow Diagram for 70 MWe Biomass Gasification Power Plant (Designed under U.S. DOE Contract DE-FC26-01NT41531)

Improved Converter, Inc. (Sacramento, California)

Improved Converter Inc. currently has an Advanced Multi-Purpose Converter that is in the prototype phase awaiting funding of approximately $800,000. There are no commercially operating facilities at this time. The technology is reported designed for a variety of feedstocks including biomass materials, toxic and industrial wastes, oil shale, and oil sands into a crude oil substitute and iron ore into molten iron. The technology is also designed for mixtures of different components such as MSW, tires, and petroleum coke.

International Environmental Technologies, Inc. (IET)/Entech Renewable Energy Systems (Heathfield, UK)

IET markets the Entech technology in the UK and claims that it can handle a variety of wastes, from RDF and MSW to animal waste and hazardous materials. The material is fed into a gasification chamber running at 1020°F. The process gas is then fired and the heat is gleaned for either heating or electricity. The gases are then cleaned according to EU requirements. IET reportedly has one prototype and several other facilities that have either failed to receive permits or have been shut down since beginning operations.

Appendix C: Summary of Dioxin and Furan Reductions Since 1990

Section removed after submittal of final report because it was not pertinent to the scope of the report.

Appendix D: The Tire Production Process and Materials Used in the Production of Tires

It is important to understand the processing and manufacturing of tires in order to get a full appreciation of the application of PGL for tire processing. In particular, by having some understanding the formulations and chemical compounds used to make tires, some insight can be gained into potential end-use and environmental effects of scrap tires. The tire manufacturing process has several steps, including the manufacture of rubber, the integration of belts into the rubber, and the curing or vulcanization process. Figure D-1 provides a summary flow chart of the process. The tire manufacturing process is briefly described in the following section, along with a short description of materials used in the manufacture of tires. Some of the materials and tire manufacturing processes are described in greater detail in the CIWMB publication entitled *Effects of Waste Tires, Waste Tire Facilities, and Waste Tire Projects on the Environment* (CIWMB pub. #432-96-029).

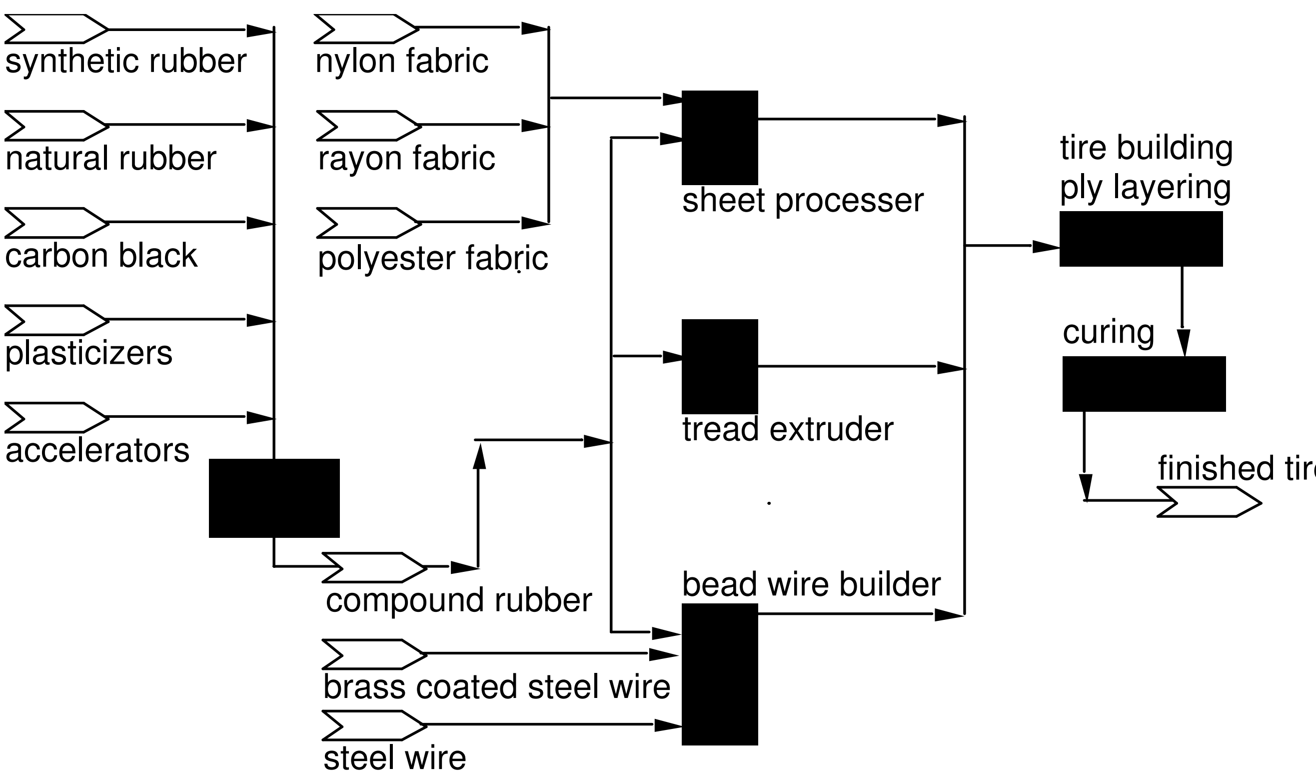


Figure D-1 Flow Chart Summarizing Tire Manufacturing Process

Material Added During Rubber Production

The rubbers used in tire manufacturing are all thermal set polymers. These polymers have various additives that serve a variety of functions. The basic units of the polymer(s) used in tires are natural rubber, synthetic polyisoprene, polybutadiene, and, presently the most commonly used, styrene butadiene.

There are several additives that go into the monomers and/or polymerized rubbers. Primary activators for tire rubber are zinc oxide, stearic acid, litharge, magnesium oxide, amines, and amine soaps. These compounds reduce the time to vulcanize rubber from several hours to a few minutes. They also allow the vulcanization process to use less sulfur and still maintain a uniform vulcanite. These compounds are said to activate sulfur to form the sulfur bridge necessary for good vulcanization of the rubber.

Age resistors, or antioxidants, are also added to the rubber to provide for longer life without degradation. These materials protect the tire from oxygen and ozone. They are derivatives of p-phenylenediamine. These compounds stop chain destruction of the rubber by combining with the free radicals formed as intermediates during degradation of the tire rubber.

Softeners and extenders are also added. These are used to increase the workability of the rubber during preliminary processing before vulcanization. They consist of mostly petroleum oils and coal tar fractions. Peptizers or catalytic plasticizers, generally thiophenols, other thiol compounds, and disulfides can be used as well to reduce the viscosity of the rubber during preliminary processing. These compounds are usually recovered in solvent extraction processes but can be found in proprietary rubber compositions.

The major pigment in tires is carbon black. To manufacture tires with white walls, titanium dioxide is used. Carbon black is also called a filler. In many cases, carbon black is known to reduce tensile strength. But for tire rubber, the appeal of the black color, the resistance to staining by other additives such as antioxidants, and the ability to improve abrasion resistance, make it the ideal filler. By mass, there is more carbon black in tire rubber than any other additive.

Cord and Fabrics, Structural Importance, and Chemical Make-Up

Rubber alone does not provide tire durability.. The cord and fabric of a tire provide for the tire's continued structural integrity, increased wear resistance, and grip on the road.

Layers of fabric (plies) made from rayon, nylon, and polyester are used in addition to the wire beadstock (cord) to make up the structural component of the tires. One of the most important factors in maintaining the tire's structural integrity and wear resistance is the adhesion of the fabrics to the rubber. This is done by placing a steel wire bead around the circumference of both sidewall openings. This bead is then used to attach the fabric layers.

Steel and brass-coated steel may be used in addition to rayon, nylon, and polyester to form the plies. Steel is drawn and twisted in the same fashion as the fabric (yarn). The configurations of fabric and steel vary with manufacturer and make of tire.

The layers of reinforcing material are firmly adhered to the rubber and remain effective after the tire has been subjected to repeated and varying strains in use. Thus, the tire's durability and its ability to perform under increasingly severe operating conditions are directly linked to the adhesion of the ply material to its adjacent rubber surface.

The Vulcanization or Curing Process

The fabric with rubber, the bead stock with rubber, and the rubber tread are combined on a drum by layering (the tread is put on last). There can be as many as 40 layers of fabric and steal bead wire on a truck tire. Once the layers are put on, the tire stock is put into a mold over an inflatable steam-heated tube. The tube is inflated and the mold is closed. The tire is heated and cured and the excess rubber extrudes out of weep holes in the mold. Curing times and temperatures vary widely between manufacturers and tire compositions. The curing is where the cross-linking of the polymer chains or vulcanization takes place. Typical curing times are around 20 minutes with temperatures around 160°F.

The main applications of elastomers require that the polymer chains be cross-linked after being formed into a desired shape (like a tire). After cross-linking of the polymer chains in the curing process, the article is elastic. It deforms under stress but returns to the shape it had when vulcanization occurred if the stress is removed. The most common method of cross-linking elastomeric polymers is through the use of sulfur. The sulfur forms a bridge between large chains of polymer, linking them together in a fixed pattern.

Tire rubber manufacture requires a variety of operations that produce and require heat, such as mixing, extruding, calendering, and molding, during which time cross-linking of the polymer to an appreciable extent cannot be tolerated. Delayed-action accelerators are able to prevent premature cross-linking. These delayed-action accelerators are not accelerators initially but undergo chemical reactions during processing to become such.. The main accelerators in use exhibit some degree of delayed action. If more delay is required, a vulcanization retarder can be incorporated.

Appendix E: Life-Cycle Cost Analyses of PGL Facilities

The following page shows the basic data entry sheet for life-cycle cost analysis that was used to estimate the system cost structures over an extended period of time. The conversion efficiencies are based on modeling of hydrogasification using Aspen Version 12.1 and an assumption of 409 percent electrical conversion efficiency. Revenue and expense data are reported in millions of dollars using discount pricing to relate these values to current dollars. The individual life cycle cost analyses for the 12 parametric cases studied are displayed as Tables E-1–E-12.

Life Cycle Cost Analysis **Project Title: CE-CERT Generic Tire Gasification Co-production Plant** Date/Time 2/22/2005 12:22 :

Summary Table	61,700	tonnes feed/year	Peak power output:	12.53	MWe		Power sales: MWeh/yr	100256
Annual CE feed:>	2,255,752	GJ/year	Peak SDF PE ouput:	37.80	MWc		Fuel sales: gal/year	8062973
Feedstock:	**Used tires**		**Power Conversion Efficiency:**	16.00 %	to electricity		Heat sales: MWth/yr	77072
Daily feed rate:	**185.1**	dtonne/day	**Synthesis Conversion Efficiency:**	48.25 %	to synthetic fuel		Fuel production: MWch/yr	302361
Feed GCV:	**36.56**	GJ/tonne	Recovered heat:	9.63	MWt	12%	**Plant Capacity:>** 8000 hours/yr	
			Heat lost energy:	18.36	to environment		Capacity factor 91.32%	
Discount Rate %:	**10%**	<	Peak PE feed rate:	78.32	MWc PE rate		**Synthetic Fuel GCV:>** 44.4 MJ/kg or GJ/tonne	
Inflation Rate %:	**3%**	<	Annual feed rate:	56085	dston/yr		Synthetic fuel production: 24515.80 tonne/yr	
Effective Rate %:	7%		Annual SDF production rate:	1088501	GJ/yr		Synthetic fuel production: 176992.10 bbl/yr	
Tire feed Tires/year	**5**	<mil./year	Annual SDF production:	8062973	gal/year		7.22 bbl/tonne	
tire rubber/year	0.0617	<m tonne/yr	Annual electricity production:	360920	GJ/yr	23.4%	heat lost/year>	528872.79
steel/year	11.4	<k tonne/year	Annual electricity production:	100256	MWeh/yr		heat energy/yr:	277457.50

Project Start Year:	**2005**	<	**Construction loan period:**	**10**		**Length of time for construction:**	1	<
Loan Amount	$46.63 million (U.S. $)		**Project End year:**	**2015**	<	Period of time for analysis:	11	years
Loan Interest rate %	**6%**	<						

Date> 8/10/2004									
Diesel fuel price>	$8.50	$/GJ	50.316	$/bbl	diesel #2>	1.198	$/gallon	steel price 65 $/ton	
Natural gas price:>	$4.70	$/GJ	16.923	$/MWc-hr	nat. gas>	5.42	$/1000scuft		
Electricity price>	52.4	$/MWe-hr	4.8519		electricity>	5.24	cent/kWh		
Plant capacity:>	8000	hours/yr	91.32%				Startup Ramp yr:	2006 2007 2008	
Capital:	687	$ per dry ton/yr input feed stock processing capacity					Startup Capacity (%):	10 25 75	
Feed rate	67877	tons/year							
Cap. cost	46,631,353	US dollars							

	crude		diesel	nat. gas	coal	hydrogen	electricity	US short ton => lbs	2000
	6.2	<GJ/unit>	0.141	1.153	28.6	0.343	10.8	kgs>	9.072
	$/bbl	*$/GJ(HHV)*	*$/gallon*	*$/1000scf*	*$/ston*	*$/1000scf*	*$/MWh*		
scap tire data:		kg/tire		GJ/tonne		kg/tire			
tire rubber/tire>	12.34		GCV>	36.56	tire steel>	2.28			

Table E-1: Life-Cycle Cost Analysis #1

($0.00 pre-treatment expense, selling prices of $1.20/gal. diesel fuel, $52.40/MWh electricity, $5.42/GJ natural gas, and $65 per ton steel. Case c0d120.)

Life Cycle Cost Anaysis*	**Project Title:**		**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004	**Technology Base:**		5 million tires processed per year				$0.00 per dry ton waste collection costs					$0.03 per gal. fuel price		
Expenses			Present Values in millions US$ rounded to two decimal places											
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost	million US$		**$46.63**	<--------------	10	year financing plan including contingencies	--					-->	end of loan!	
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3 % of capital costs		**Construction in 2005**											
Labor & Supervision	100 % category			($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4 % of capital costs													
Labor & Supervision	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$1.00		($0.01)	($0.02)	($0.04)	($0.05)	($0.04)	($0.04)	($0.04)	($0.03)	($0.03)	($0.03)	($0.02)
Consumption rate	ton/year	67,562												
Fuel costs	$/GJ	$5.42		($0.29)	($0.64)	($1.74)	($2.09)	($1.88)	($1.69)	($1.52)	($1.37)	($1.23)	($1.11)	($1.00)
Consumption rate	GJ /year	528,873												
Feed stock prep. costs	$/ton	$0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Consumption rate	ton/year	67,562												
Taxation	30 % Revenues			(0.50)	(1.21)	(3.51)	(4.41)	(4.15)	(3.90)	(3.67)	(3.45)	(3.25)	(3.06)	(2.88)
Sinking Fund Payments	5 % Capital Value			(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.45)**	**($9.08)**	**($9.52)**	**($9.31)**	**($8.58)**	**($7.90)**	**($7.29)**	**($6.72)**	**($6.20)**	**($2.40)**	**($2.16)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33	$3.13	$2.95
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$1.20		$0.94	$2.28	$6.62	$8.31	$7.82	$7.36	$6.92	$6.51	$6.13	$5.76	$5.42
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year	**million US$**		**0**	**$1.66**	**$4.02**	**$11.71**	**$14.69**	**$13.82**	**$13.00**	**$12.24**	**$11.51**	**$10.83**	**$10.19**	**$9.59**
Discounted Cash Flow	million US$		($6.34)	($7.79)	($5.05)	$2.19	$5.38	$5.24	$5.10	$4.95	$4.79	$4.63	$7.79	$7.43
						Profitability starts!								
Cumulative Cash Flow	million US$		($6.34)	($14.13)	($19.18)	($16.99)	($11.62)	($6.37)	($1.27)	$3.67	$8.46	$13.09	$20.88	$28.31
										Capital costs recovered!				

Table E-2: Life-Cycle Cost Analysis #2

($20.00 pre-treatment expense, selling prices of $1.20/gal. diesel fuel, $52.40/MWh electricity, $5.42/GJ natural gas, $65 per ton steel. Case c20d120)

			2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Life Cycle Cost Anaysis*	**Project Title:**		**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004	**Technology Base:**		5 million tires processed per year				$20.00	per dry ton waste collection costs				$0.03	per gal. fuel price	
	Discount Rate %	10%	1.00000	0.90000	0.81000	0.72900	0.65610	0.59049	0.53144	0.47830	0.43047	0.38742	0.34868	0.31381
	Inflation Rate %	3%	1.00000	0.97000	0.94090	0.91267	0.85873	0.80798	0.76023	0.71530	0.67303	0.63325	0.59583	0.56061
	Effective Rate %	7%	1.00000	0.93000	0.86490	0.80436	0.75682	0.71209	0.67001	0.63041	0.59315	0.55810	0.52511	0.49408
Expenses			Present Values in millions US$ rounded to two decimal places											
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost	million US$		**$46.63**	<-------------	10	year financing plan including contingencies					-->		end of loan!	
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3 % of capital costs		**Construction in 2005**											
Labor & Supervision	100 % category			($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4 % of capital costs													
Labor & Supervision	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$1.00		($0.01)	($0.02)	($0.04)	($0.05)	($0.04)	($0.04)	($0.04)	($0.03)	($0.03)	($0.03)	($0.02)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$5.42		($0.29)	($0.64)	($1.74)	($2.09)	($1.88)	($1.69)	($1.52)	($1.37)	($1.23)	($1.11)	($1.00)
Consumption rate	GJ /year	528873												
Feed stock prep. costs	$/ton	$20.00		(0.14)	(0.30)	(0.82)	(0.99)	(0.89)	(0.80)	(0.72)	(0.65)	(0.58)	(0.52)	(0.47)
Consumption rate	ton/year	67561.5												
Taxation	30 % Revenues			(0.50)	(1.21)	(3.51)	(4.41)	(4.15)	(3.90)	(3.67)	(3.45)	(3.25)	(3.06)	(2.88)
Sinking Fund Payments	5 % Capital Value			(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.58)**	**($9.38)**	**($10.34)**	**($10.30)**	**($9.46)**	**($8.70)**	**($8.01)**	**($7.37)**	**($6.79)**	**($2.92)**	**($2.63)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33	$3.13	$2.95
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$1.20		$0.94	$2.28	$6.62	$8.31	$7.82	$7.36	$6.92	$6.51	$6.13	$5.76	$5.42
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year	**million US$**		**0**	**$1.66**	**$4.02**	**$11.71**	**$14.69**	**$13.82**	**$13.00**	**$12.24**	**$11.51**	**$10.83**	**$10.19**	**$9.59**
Discounted Cash Flow	million US$		($6.34)	($7.93)	($5.36)	$1.37	$4.39	$4.36	$4.30	$4.23	$4.14	$4.05	$7.27	$6.96
						Profitability starts!								
Cumulative Cash Flow	million US$		($6.34)	($14.26)	($19.62)	($18.25)	($13.86)	($9.51)	($5.20)	($0.97)	$3.17	$7.22	$14.49	$21.44
											Capital costs recovered!			

Table E-3: Life-Cycle Cost Analysis #3

($40.00 pre-treatment expense, selling prices of $1.20/gal. diesel fuel, $52.40/MWh electricity, $5.42/GJ natural gas, $65 per ton steel. Case c40d120)

Life Cycle Cost Anaysis*		**Project Title:**	**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004		**Technology Base:**	5 million tires processed per year				$40.00 per dry ton waste collection costs					$0.03 per gal. fuel price		
	Discount Rate %	10%	1.00000	0.90000	0.81000	0.72900	0.65610	0.59049	0.53144	0.47830	0.43047	0.38742	0.34868	0.31381
	Inflation Rate %	3%	1.00000	0.97000	0.94090	0.91267	0.85873	0.80798	0.76023	0.71530	0.67303	0.63325	0.59583	0.56061
	Effective Rate %	7%	1.00000	0.93000	0.86490	0.80436	0.75682	0.71209	0.67001	0.63041	0.59315	0.55810	0.52511	0.49408
Expenses			Present Values in millions US$ rounded to two decimal places											
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost	million US$		**$46.63**	<--------------	10	year financing plan including contingencies --->							end of loan!	
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3 % of capital costs		**Construction in 2005**											
Labor & Supervision	100 % category			($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4 % of capital costs													
Labor & Supervision	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$1.00		($0.01)	($0.02)	($0.04)	($0.05)	($0.04)	($0.04)	($0.04)	($0.03)	($0.03)	($0.03)	($0.02)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$5.42		($0.29)	($0.64)	($1.74)	($2.09)	($1.88)	($1.69)	($1.52)	($1.37)	($1.23)	($1.11)	($1.00)
Consumption rate	GJ /year	528873												
Feed stock prep. costs	$/ton	$40.00		(0.27)	(0.61)	(1.64)	(1.97)	(1.77)	(1.60)	(1.44)	(1.29)	(1.16)	(1.05)	(0.94)
Consumption rate	ton/year	67561.5												
Taxation	30 % Revenues			(0.50)	(1.21)	(3.51)	(4.41)	(4.15)	(3.90)	(3.67)	(3.45)	(3.25)	(3.06)	(2.88)
Sinking Fund Payments	5 % Capital Value			(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.72)**	**($9.69)**	**($11.16)**	**($11.28)**	**($10.35)**	**($9.50)**	**($8.72)**	**($8.02)**	**($7.37)**	**($3.45)**	**($3.10)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33	$3.13	$2.95
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$1.20		$0.94	$2.28	$6.62	$8.31	$7.82	$7.36	$6.92	$6.51	$6.13	$5.76	$5.42
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year	**million US$**		**0**	**$1.66**	**$4.02**	**$11.71**	**$14.69**	**$13.82**	**$13.00**	**$12.24**	**$11.51**	**$10.83**	**$10.19**	**$9.59**
Discounted Cash Flow	million US$		($6.34)	($8.06)	($5.66)	$0.55	$3.41	$3.47	$3.50	$3.51	$3.50	$3.47	$6.74	$6.49
						Profitability starts!								
Cumulative Cash Flow	million US$		($6.34)	($14.40)	($20.06)	($19.51)	($16.11)	($12.64)	($9.13)	($5.62)	($2.12)	$1.34	$8.09	$14.57
													Capital costs recovered!	

Table E-4: Life-Cycle Cost Analysis #4

($0.00 pre-treatment expense, selling prices of $2.40/gal. diesel fuel, $52.40/MWh electricity, $5.42/GJ natural gas, $65 per ton steel. Case c0d240)

Life Cycle Cost Anaysis*	**Project Title:**		**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004	**Technology Base:**		2000 tons/day of waste wood - Riverside area				$0.00 per dry ton waste collection costs					$0.06 per gal. fuel price		
Expenses			Present Values in millions US$ rounded to two decimal places											
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost	million US$		**$46.63**	<--------------	10	year financing plan including contingencies	----------	----------	----------	----------	----------	---------->	end of loan!	
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3 % of capital costs		**Construction in 2005**											
Labor & Supervision	100 % category			($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4 % of capital costs													
Labor & Supervision	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$5.42		($0.11)	($0.24)	($0.64)	($0.77)	($0.70)	($0.63)	($0.56)	($0.51)	($0.46)	($0.41)	($0.37)
Consumption rate	GJ /year	195705												
Feed stock prep. costs	$/ton	$0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Consumption rate	ton/year	67561.5												
Taxation	30 % Revenues			(0.78)	(1.89)	(5.50)	(6.90)	(6.49)	(6.11)	(5.75)	(5.41)	(5.09)	(4.79)	(4.50)
Sinking Fund Payments	5 % Capital Value			(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.26)**	**($8.66)**	**($8.39)**	**($7.95)**	**($7.35)**	**($6.80)**	**($6.30)**	**($5.83)**	**($5.40)**	**($1.68)**	**($1.51)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33	$3.13	$2.95
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$2.40		$1.88	$4.55	$13.25	$16.62	$15.64	$14.71	$13.84	$13.02	$12.25	$11.53	$10.85
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year	**million US$**		**0**	**$2.60**	**$6.30**	**$18.33**	**$23.00**	**$21.64**	**$20.36**	**$19.16**	**$18.02**	**$16.96**	**$15.96**	**$15.01**
Discounted Cash Flow	million US$		($6.34)	($6.67)	($2.36)	$9.94	$15.05	$14.29	$13.56	$12.86	$12.20	$11.56	$14.28	$13.50
						Profitability starts!								
Cumulative Cash Flow	million US$		($6.34)	($13.00)	($15.36)	($5.42)	$9.63	$23.92	$37.47	$50.33	$62.53	$74.09	$88.37	$101.87
							Capital costs recovered!							

Table E-5: Life-Cycle Cost Analysis #5

($20.00 pre-treatment expense, selling prices of $2.40/gal. diesel fuel, $52.40/MWh electricity, $5.42/GJ natural gas, $65 per ton steel. Case c20d240)

Life Cycle Cost Anaysis*		**Project Title:**	**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004		**Technology Base:**	2000 tons/day of waste wood - Riverside area			$20.00	per dry ton waste collection costs					$0.06	per gal. fuel price	
Expenses			Present Values in millions US$ rounded to two decimal places											
		Project Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost		million US$	**$46.63**	<--------------	10	year financing plan including contingencies --------------------------------------->							end of loan!	
Payments		**Interest Rate %** 6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3	% of capital costs	**Construction in 2005**											
Labor & Supervision	100	% category		($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4	% of capital costs												
Labor & Supervision	50	% category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50	% category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$5.42		($0.11)	($0.24)	($0.64)	($0.77)	($0.70)	($0.63)	($0.56)	($0.51)	($0.46)	($0.41)	($0.37)
Consumption rate	GJ /year	195705												
Feed stock prep. costs	$/ton	$20.00		(0.14)	(0.30)	(0.82)	(0.99)	(0.89)	(0.80)	(0.72)	(0.65)	(0.58)	(0.52)	(0.47)
Consumption rate	ton/year	67561.5												
Taxation	30	% Revenues		(0.78)	(1.89)	(5.50)	(6.90)	(6.49)	(6.11)	(5.75)	(5.41)	(5.09)	(4.79)	(4.50)
Sinking Fund Payments	5	% Capital Value		(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year		**million US$**	**($6.34)**	**($9.40)**	**($8.96)**	**($9.21)**	**($8.94)**	**($8.24)**	**($7.60)**	**($7.01)**	**($6.48)**	**($5.98)**	**($2.20)**	**($1.98)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
		Plant Capacity Factor	0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
		Operating hours per year	0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33	$3.13	$2.95
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$2.40		$1.88	$4.55	$13.25	$16.62	$15.64	$14.71	$13.84	$13.02	$12.25	$11.53	$10.85
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year		**million US$**	**0**	**$2.60**	**$6.30**	**$18.33**	**$23.00**	**$21.64**	**$20.36**	**$19.16**	**$18.02**	**$16.96**	**$15.96**	**$15.01**
Discounted Cash Flow		million US$	($6.34)	($6.80)	($2.66)	$9.12	$14.06	$13.40	$12.76	$12.14	$11.55	$10.98	$13.76	$13.03
						Profitability starts!								
Cumulative Cash Flow		million US$	($6.34)	($13.14)	($15.80)	($6.68)	$7.39	$20.78	$33.54	$45.69	$57.24	$68.21	$81.97	$95.00
							Capital costs recovered!							

Table E-6: Life-Cycle Cost Analysis #6

($40.00 pre-treatment expense, selling prices of $2.40/gal. diesel fuel, $52.40/MWh electricity, $5.42/GJ natural gas, $65 per ton steel. Case c40d240)

Life Cycle Cost Anaysis*		**Project Title:**	**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004		**Technology Base:**	2000 tons/day of waste wood - Riverside area			$40.00	per dry ton waste collection costs				$0.06	per gal. fuel price		
Expenses			Present Values in millions US$ rounded to two decimal places											
		Project Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost		million US$	**$46.63**	<--------------	10	year financing plan including contingencies						-->	end of loan!	
Payments		**Interest Rate %** 6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3	% of capital costs	**Construction in 2005**											
Labor & Supervision	100	% category		($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4	% of capital costs												
Labor & Supervision	50	% category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50	% category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$5.42		($0.11)	($0.24)	($0.64)	($0.77)	($0.70)	($0.63)	($0.56)	($0.51)	($0.46)	($0.41)	($0.37)
Consumption rate	GJ /year	195705												
Feed stock prep. costs	$/ton	$40.00		(0.27)	(0.61)	(1.64)	(1.97)	(1.77)	(1.60)	(1.44)	(1.29)	(1.16)	(1.05)	(0.94)
Consumption rate	ton/year	67561.5												
Taxation	30	% Revenues		(0.78)	(1.89)	(5.50)	(6.90)	(6.49)	(6.11)	(5.75)	(5.41)	(5.09)	(4.79)	(4.50)
Sinking Fund Payments (for replacement of components/plant)	5	% Capital Value		(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
TOTAL EXPENSES for each year		**million US$**	**($6.34)**	**($9.53)**	**($9.27)**	**($10.03)**	**($9.92)**	**($9.13)**	**($8.40)**	**($7.73)**	**($7.12)**	**($6.56)**	**($2.73)**	**($2.45)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
		Plant Capacity Factor	0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
		Operating hours per year	0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33	$3.13	$2.95
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$2.40		$1.88	$4.55	$13.25	$16.62	$15.64	$14.71	$13.84	$13.02	$12.25	$11.53	$10.85
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year		**million US$**	**0**	**$2.60**	**$6.30**	**$18.33**	**$23.00**	**$21.64**	**$20.36**	**$19.16**	**$18.02**	**$16.96**	**$15.96**	**$15.01**
Discounted Cash Flow		million US$	($6.34)	($6.94)	($2.97)	$8.30	$13.08	$12.51	$11.96	$11.42	$10.90	$10.40	$13.23	$12.56
						Profitability starts!								
Cumulative Cash Flow		million US$	($6.34)	($13.27)	($16.24)	($7.94)	$5.14	$17.65	$29.61	$41.04	$51.94	$62.34	$75.57	$88.13
							Capital costs recovered!							

Table E-7: Life-Cycle Cost Analysis #7

($0.00 pre-treatment expense, selling prices of $1.20/gal. diesel fuel, $104.80/MWh electricity, $5.42/GJ natural gas, $65 per ton steel. Case c0d120e2x)

			2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Life Cycle Cost Anaysis*		**Project Title:**	**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004		**Technology Base:**	2000 tons/day of waste wood - Riverside area			$0.00 per dry ton waste collection costs					$0.03 per gal. fuel price			
Expenses			Present Values in millions US$ rounded to two decimal places											
		Project Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost		million US$	**$46.41**	<--------------	#REF!	year financing plan including contingencies -->							end of loan!	
Payments		**Interest Rate %** 6%	($6.31)	($5.86)	($5.45)	($5.07)	($4.77)	($4.49)	($4.23)	($3.98)	($3.74)	($3.52)		
Operating Costs		3 % of capital costs	**Construction in 2005**											
Labor & Supervision		100 % category		($1.39)	($1.25)	($1.13)	($1.02)	($0.91)	($0.82)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs		4 % of capital costs												
Labor & Supervision		50 % category		($0.93)	($0.84)	($0.75)	($0.68)	($0.61)	($0.55)	($0.49)	($0.44)	($0.40)	($0.36)	($0.32)
Materials		50 % category		($0.93)	($0.84)	($0.75)	($0.68)	($0.61)	($0.55)	($0.49)	($0.44)	($0.40)	($0.36)	($0.32)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$5.42		($0.11)	($0.24)	($0.64)	($0.77)	($0.70)	($0.63)	($0.56)	($0.51)	($0.46)	($0.41)	($0.37)
Consumption rate	GJ /year	195705												
Feed stock prep. costs	$/ton	$0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Consumption rate	ton/year	67561.5												
Taxation		30 % Revenues		(0.65)	(1.58)	(4.59)	(5.76)	(5.42)	(5.10)	(4.80)	(4.51)	(4.25)	(4.00)	(3.76)
Sinking Fund Payments		5 % Capital Value		(2.09)	(1.88)	(1.69)	(1.52)	(1.37)	(1.23)	(1.11)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year		**million US$**	**($6.31)**	**($9.22)**	**($8.62)**	**($8.35)**	**($7.92)**	**($7.32)**	**($6.77)**	**($6.27)**	**($5.81)**	**($5.38)**	**($1.67)**	**($1.51)**
Capital Value of Plant			**$46.41**	**$41.77**	**$37.60**	**$33.84**	**$30.45**	**$27.41**	**$24.67**	**$22.20**	**$19.98**	**$17.98**	**$16.18**	**$14.57**
Sinking Fund Cumulative Value				**$2.09**	**$3.97**	**$5.66**	**$7.18**	**$8.55**	**$9.79**	**$10.90**	**$11.90**	**$12.79**	**$13.60**	**$14.33**
Revenues			**Construction in 2005**											
		Plant Capacity Factor	0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
		Operating hours per year	0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$104.80		$1.02	$2.47	$7.19	$9.02	$8.49	$7.99	$7.52	$7.07	$6.65	$6.26	$5.89
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$1.20		$0.94	$2.28	$6.62	$8.31	$7.82	$7.36	$6.92	$6.51	$6.13	$5.76	$5.42
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year		**million US$**	**0**	**$2.17**	**$5.26**	**$15.31**	**$19.20**	**$18.07**	**$17.00**	**$15.99**	**$15.05**	**$14.16**	**$13.32**	**$12.54**
Discounted Cash Flow		million US$	($6.31)	($7.05)	($3.36)	$6.95	$11.28	$10.74	$10.22	$9.72	$9.24	$8.78	$11.65	$11.03
						Profitability starts!								
Cumulative Cash Flow		million US$	($6.31)	($13.36)	($16.78)	($9.76)	$1.52	$12.26	$22.49	$32.21	$41.45	$50.24	$61.89	$72.92
							Capital costs recovered!							

Table E-8: Life-Cycle Cost Analysis #8

($40.00 pre-treatment expense, selling prices of $2.40/gal. diesel fuel, $104.80/MWh electricity, $5.42/GJ natural gas, $65 per ton steel. Case c40d240e2x)

			2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Life Cycle Cost Anaysis*	**Project Title:**		**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004	**Technology Base:**		2000 tons/day of waste wood - Riverside area				$40.00 per dry ton waste collection costs					$0.06 per gal. fuel price		
Expenses			Present Values in millions US$ rounded to two decimal places											
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost	million US$		**$46.63**	<--------------	10	year financing plan including contingencies -->							end of loan!	
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3 % of capital costs		**Construction in 2005**											
Labor & Supervision	100 % category			($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4 % of capital costs													
Labor & Supervision	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$5.42		($0.11)	($0.24)	($0.64)	($0.77)	($0.70)	($0.63)	($0.56)	($0.51)	($0.46)	($0.41)	($0.37)
Consumption rate	GJ /year	195705												
Feed stock prep. costs	$/ton	$40.00		(0.27)	(0.61)	(1.64)	(1.97)	(1.77)	(1.60)	(1.44)	(1.29)	(1.16)	(1.05)	(0.94)
Consumption rate	ton/year	67561.5												
Taxation	30 % Revenues			(0.93)	(2.26)	(6.58)	(8.25)	(7.77)	(7.31)	(6.87)	(6.47)	(6.09)	(5.73)	(5.39)
Sinking Fund Payments	5 % Capital Value			(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.53)**	**($9.27)**	**($10.03)**	**($9.92)**	**($9.13)**	**($8.40)**	**($7.73)**	**($7.12)**	**($6.56)**	**($2.73)**	**($2.45)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$104.80		$1.02	$2.47	$7.19	$9.02	$8.49	$7.99	$7.52	$7.07	$6.65	$6.26	$5.89
	ton/year	10362.6												
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43	$0.40	$0.38
	gal/year	8062973.32												
Fuel sales	$/gal	$2.40		$1.88	$4.55	$13.25	$16.62	$15.64	$14.71	$13.84	$13.02	$12.25	$11.53	$10.85
	MWth/yr	77071.53												
Heat sales	$/MWth	$19.51		$0.15	$0.35	$1.03	$1.29	$1.22	$1.14	$1.08	$1.01	$0.95	$0.90	$0.84
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year	**million US$**		**0**	**$3.11**	**$7.54**	**$21.93**	**$27.51**	**$25.88**	**$24.35**	**$22.91**	**$21.56**	**$20.29**	**$19.09**	**$17.96**
Discounted Cash Flow	million US$		($6.34)	($6.43)	($1.73)	$11.90	$17.59	$16.76	$15.96	$15.18	$14.44	$13.72	$16.36	$15.51
						Profitability starts!								
Cumulative Cash Flow	million US$		($6.34)	($12.76)	($14.49)	($2.59)	$14.99	$31.75	$47.71	$62.89	$77.33	$91.05	$107.41	$122.92
							Capital costs recovered!							

Table E-9: Life-Cycle Cost Analysis #9

($40.00 pre-treatment expense, selling prices of $2.40/gal. diesel fuel, $104.80/MWh electricity, $10.84/GJ natural gas, $130 per ton steel. Case c40d240(egs)2x)

Life Cycle Cost Anaysis*		**Project Title:**	**CE-CERT Generic Tire Gasification Co-production Plant**									
* UCR CE-CERT copyright 2004		**Technology Base:**	2000 tons/day of waste wood - Riverside area				$40.00 per dry ton waste collection costs					$0.06
Expenses			Present Values in millions US$ rounded to two decimal places									
		Project Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Capital Cost		million US$	**$46.63**	<--------------	10	year financing plan including contingencies			-->			
Payments		**Interest Rate %** 6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)
Operating Costs		3 % of capital costs	**Construction in 2005**									
Labor & Supervision		100 % category		($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)
Maintenance Costs		4 % of capital costs										
Labor & Supervision		50 % category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)
Materials		50 % category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)
Feed materials costs and fees												
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5										
Fuel costs	$/GJ	$21.68		($0.42)	($0.95)	($2.58)	($3.09)	($2.78)	($2.51)	($2.25)	($2.03)	($1.83)
Consumption rate	GJ /year	195705										
Feed stock prep. costs	$/ton	$40.00		(0.27)	(0.61)	(1.64)	(1.97)	(1.77)	(1.60)	(1.44)	(1.29)	(1.16)
Consumption rate	ton/year	67561.5										
Taxation		30 % Revenues		(1.00)	(2.41)	(7.03)	(8.81)	(8.29)	(7.80)	(7.34)	(6.91)	(6.50)
Sinking Fund Payments		5 % Capital Value		(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)
(for replacement of components/plant)												
TOTAL EXPENSES for each year		**million US$**	**($6.34)**	**($9.85)**	**($9.98)**	**($11.96)**	**($12.24)**	**($11.21)**	**($10.28)**	**($9.42)**	**($8.64)**	**($7.93)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**
Revenues			**Construction in 2005**									
		Plant Capacity Factor	0	10%	25%	75%	100%	100%	100%	100%	100%	100%
		Operating hours per year	0	800	2000	6000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64										
Power sales	$/MWeh	$104.80		$1.02	$2.47	$7.19	$9.02	$8.49	$7.99	$7.52	$7.07	$6.65
	ton/year	10362.6										
Steel sales	$/ton	130		$0.13	$0.32	$0.92	$1.16	$1.09	$1.02	$0.96	$0.91	$0.85
	gal/year	8062973.32										
Fuel sales	$/gal	$2.40		$1.88	$4.55	$13.25	$16.62	$15.64	$14.71	$13.84	$13.02	$12.25
	MWth/yr	77071.53										
Heat sales	$/MWth	$39.02		$0.29	$0.71	$2.06	$2.58	$2.43	$2.29	$2.15	$2.02	$1.90
Waste Disposal fees	$/wton											
Waste	wet ton/yr											
TOTAL REVENUES for each year		**million US$**	**0**	**$3.32**	**$8.05**	**$23.42**	**$29.38**	**$27.64**	**$26.01**	**$24.47**	**$23.03**	**$21.67**
Discounted Cash Flow		million US$	($6.34)	($6.53)	($1.93)	$11.46	$17.14	$16.43	$15.73	$15.05	$14.38	$13.73
						Profitability starts!						
Cumulative Cash Flow		million US$	($6.34)	($12.87)	($14.80)	($3.35)	$13.79	$30.22	$45.95	$61.00	$75.38	$89.11
						Capital costs recovered!						

Table E-10: Life-Cycle Cost Analysis #10

($20.00 pre-treatment expense, selling prices of $1.20/gal. diesel fuel, $52.40/MWh electricity, $10.84/GJ natural gas, $130 per ton steel. Case c20d120(gs)2x)

Life Cycle Cost Anaysis*	**Project Title:**		**CE-CERT Generic Tire Gasification Co-production Plant**										
* UCR CE-CERT copyright 2004	**Technology Base:**		2000 tons/day of waste wood - Riverside area				$20.00	per dry ton waste collection costs				$0.03	per gal. fuel price
	Effective Rate %	7%	1.00000	0.93000	0.86490	0.80436	0.75682	0.71209	0.67001	0.63041	0.59315	0.55810	0.52511	0.49408
Expenses			Present Values in millions US$ rounded to two decimal places											
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost	million US$		**$46.63**	<--------------	10	year financing plan including contingencies -->							end of loan!	
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3 % of capital costs		**Construction in 2005**											
Labor & Supervision	100 % category			($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4 % of capital costs													
Labor & Supervision	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$10.84		($0.21)	($0.48)	($1.29)	($1.55)	($1.39)	($1.25)	($1.13)	($1.01)	($0.91)	($0.82)	($0.74)
Consumption rate	GJ /year	195705												
Feed stock prep. costs	$/ton	$20.00		(0.14)	(0.30)	(0.82)	(0.99)	(0.89)	(0.80)	(0.72)	(0.65)	(0.58)	(0.52)	(0.47)
Consumption rate	ton/year	67561.5												
Taxation	30 % Revenues			(0.56)	(1.36)	(3.96)	(4.97)	(4.67)	(4.40)	(4.14)	(3.89)	(3.66)	(3.45)	(3.24)
Sinking Fund Payments	5 % Capital Value			(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
(for replacement of components/plant)														
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.50)**	**($9.20)**	**($9.85)**	**($9.71)**	**($8.94)**	**($8.23)**	**($7.58)**	**($6.98)**	**($6.44)**	**($2.61)**	**($2.35)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33	$3.13	$2.95
	ton/year	10362.6												
Steel sales	$/ton	130		$0.13	$0.32	$0.92	$1.16	$1.09	$1.02	$0.96	$0.91	$0.85	$0.80	$0.76
	gal/year	8062973.32												
Fuel sales	$/gal	$1.20		$0.94	$2.28	$6.62	$8.31	$7.82	$7.36	$6.92	$6.51	$6.13	$5.76	$5.42
	MWth/yr	77071.53												
Heat sales	$/MWth	$39.02		$0.29	$0.71	$2.06	$2.58	$2.43	$2.29	$2.15	$2.02	$1.90	$1.79	$1.69
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year	**million US$**		**0**	**$1.87**	**$4.54**	**$13.20**	**$16.56**	**$15.58**	**$14.66**	**$13.79**	**$12.98**	**$12.21**	**$11.49**	**$10.81**
Discounted Cash Flow	million US$		($6.34)	($7.63)	($4.66)	$3.35	$6.85	$6.64	$6.43	$6.22	$5.99	$5.77	$8.88	$8.46
						Profitability starts!								
Cumulative Cash Flow	million US$		($6.34)	($13.97)	($18.63)	($15.29)	($8.44)	($1.79)	$4.64	$10.85	$16.85	$22.62	$31.50	$39.96
									Capital costs recovered!					

Table E-11: Life-Cycle Cost Analysis #11

($20.00 pre-treatment expense, selling prices of $0.60/gal. diesel fuel, $26.20/MWh electricity, $2.71/GJ natural gas, $32.50 per ton steel. Case c20d060(egs).5x)

Life Cycle Cost Anaysis*	**Project Title:**		**CE-CERT Generic Tire Gasification Co-production Plant**											
* UCR CE-CERT copyright 2004	**Technology Base:**		2000 tons/day of waste wood - Riverside ar		$20.00 per dry ton waste collection costs					$0.01 per gal. fuel price				
Expenses			Present Values in millions US$ rounded to two decimal places											
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Capital Cost	million US$		**$46.63**	-------------	10	year financing plan including contingencies			-----	-----	-----	-----	end of loan!	
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)		
Operating Costs	3	% of capital costs	**Construction in 2005**											
Labor & Supervision	100	% category		($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)	($0.54)	($0.49)
Maintenance Costs	4	% of capital costs												
Labor & Supervision	50	% category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Materials	50	% category		($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)	($0.36)	($0.33)
Feed materials costs and fees														
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5												
Fuel costs	$/GJ	$2.71		($0.05)	($0.12)	($0.32)	($0.39)	($0.35)	($0.31)	($0.28)	($0.25)	($0.23)	($0.21)	($0.18)
Consumption rate	GJ /year	195705												
Feed stock prep. costs	$/ton	$20.00		(0.14)	(0.30)	(0.82)	(0.99)	(0.89)	(0.80)	(0.72)	(0.65)	(0.58)	(0.52)	(0.47)
Consumption rate	ton/year	67561.5												
Taxation	30	% Revenues		(0.25)	(0.60)	(1.76)	(2.20)	(2.07)	(1.95)	(1.84)	(1.73)	(1.62)	(1.53)	(1.44)
Sinking Fund Payments (for replacement of components/plant)	5	% Capital Value		(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)	(0.81)	(0.73)
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.35)**	**($8.84)**	**($8.89)**	**($8.55)**	**($7.89)**	**($7.29)**	**($6.73)**	**($6.22)**	**($5.75)**	**($2.00)**	**($1.80)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**	**$16.26**	**$14.63**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**	**$13.67**	**$14.40**
Revenues			**Construction in 2005**											
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64												
Power sales	$/MWeh	$26.20		$0.25	$0.62	$1.80	$2.26	$2.12	$2.00	$1.88	$1.77	$1.66	$1.57	$1.47
	ton/year	10362.6												
Steel sales	$/ton	32.5		$0.03	$0.08	$0.23	$0.29	$0.27	$0.26	$0.24	$0.23	$0.21	$0.20	$0.19
	gal/year	8062973.32												
Fuel sales	$/gal	$0.60		$0.47	$1.14	$3.31	$4.15	$3.91	$3.68	$3.46	$3.26	$3.06	$2.88	$2.71
	MWth/yr	77071.53												
Heat sales	$/MWth	$9.76		$0.07	$0.18	$0.51	$0.65	$0.61	$0.57	$0.54	$0.51	$0.48	$0.45	$0.42
Waste Disposal fees	$/wton													
Waste	wet ton/yr													
TOTAL REVENUES for each year	**million US$**		**0**	**$0.83**	**$2.01**	**$5.85**	**$7.34**	**$6.91**	**$6.50**	**$6.12**	**$5.76**	**$5.42**	**$5.10**	**$4.80**
Discounted Cash Flow	million US$		($6.34)	($8.52)	($6.83)	($3.03)	($1.21)	($0.98)	($0.79)	($0.61)	($0.47)	($0.34)	$3.10	$3.00
													Profitability starts!	
Cumulative Cash Flow	million US$		($6.34)	($14.85)	($21.68)	($24.71)	($25.92)	($26.90)	($27.69)	($28.30)	($28.77)	($29.11)	($26.01)	($23.01)
														Capital costs not recovered in 11 years!

Table E-12: Life-Cycle Cost Analysis #12

($20.00 pre-treatment expense, selling prices of $0.60/gal. diesel fuel, $52.40/MWh electricity, $2.71/GJ natural gas, and $65 per ton steel. Case c20d060(g).5x)

Life Cycle Cost Anaysis*	**Project Title:**		**CE-CERT Generic Tire Gasification Co-production Plant**									
* UCR CE-CERT copyright 2004	**Technology Base:**		2000 tons/day of waste wood - Riverside area				$20.00 per dry ton waste collection costs					$0.01
Expenses			Present Values in millions US$ rounded to two decimal places									
	Project Year		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Capital Cost	million US$		**$46.63** <--------------		10	year financing plan including contingencies -->						
Payments	**Interest Rate %**	6%	($6.34)	($5.89)	($5.48)	($5.10)	($4.79)	($4.51)	($4.24)	($3.99)	($3.76)	($3.54)
Operating Costs	3 % of capital costs		**Construction in 2005**									
Labor & Supervision	100 % category			($1.40)	($1.26)	($1.13)	($1.02)	($0.92)	($0.83)	($0.74)	($0.67)	($0.60)
Maintenance Costs	4 % of capital costs											
Labor & Supervision	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)
Materials	50 % category			($0.93)	($0.84)	($0.76)	($0.68)	($0.61)	($0.55)	($0.50)	($0.45)	($0.40)
Feed materials costs and fees												
Catalysts & chemicals	$/ton	$0.10		($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)	($0.00)
Consumption rate	ton/year	67561.5										
Fuel costs	$/GJ	$1.36		($0.03)	($0.06)	($0.16)	($0.19)	($0.17)	($0.16)	($0.14)	($0.13)	($0.11)
Consumption rate	GJ /year	195705										
Feed stock prep. costs	$/ton	$20.00		(0.14)	(0.30)	(0.82)	(0.99)	(0.89)	(0.80)	(0.72)	(0.65)	(0.58)
Consumption rate	ton/year	67561.5										
Taxation	30 % Revenues			(0.34)	(0.81)	(2.36)	(2.97)	(2.79)	(2.63)	(2.47)	(2.33)	(2.19)
Sinking Fund Payments	5 % Capital Value			(2.10)	(1.89)	(1.70)	(1.53)	(1.38)	(1.24)	(1.12)	(1.00)	(0.90)
(for replacement of components/plant)												
TOTAL EXPENSES for each year	**million US$**		**($6.34)**	**($9.32)**	**($8.78)**	**($8.73)**	**($8.36)**	**($7.72)**	**($7.13)**	**($6.59)**	**($6.10)**	**($5.64)**
Capital Value of Plant			**$46.63**	**$41.97**	**$37.77**	**$33.99**	**$30.59**	**$27.54**	**$24.78**	**$22.30**	**$20.07**	**$18.07**
Sinking Fund Cumulative Value				**$2.10**	**$3.99**	**$5.69**	**$7.22**	**$8.59**	**$9.83**	**$10.95**	**$11.95**	**$12.85**
Revenues			**Construction in 2005**									
	Plant Capacity Factor		0	10%	25%	75%	100%	100%	100%	100%	100%	100%
	Operating hours per year		0	800	2000	6000	8000	8000	8000	8000	8000	8000
	MWeh/yr	100255.64										
Power sales	$/MWeh	$52.40		$0.51	$1.24	$3.60	$4.51	$4.24	$3.99	$3.76	$3.54	$3.33
	ton/year	10362.6										
Steel sales	$/ton	65		$0.07	$0.16	$0.46	$0.58	$0.54	$0.51	$0.48	$0.45	$0.43
	gal/year	8062973.32										
Fuel sales	$/gal	$0.60		$0.47	$1.14	$3.31	$4.15	$3.91	$3.68	$3.46	$3.26	$3.06
	MWth/yr	77071.53										
Heat sales	$/MWth	$9.76		$0.07	$0.18	$0.51	$0.65	$0.61	$0.57	$0.54	$0.51	$0.48
Waste Disposal fees	$/wton											
Waste	wet ton/yr											
TOTAL REVENUES for each year	**million US$**		**0**	**$1.12**	**$2.71**	**$7.88**	**$9.89**	**$9.31**	**$8.76**	**$8.24**	**$7.75**	**$7.29**
Discounted Cash Flow	million US$		($6.34)	($8.20)	($6.07)	($0.84)	$1.53	$1.59	$1.62	$1.65	$1.66	$1.65
										Profitability starts!		
Cumulative Cash Flow	million US$		($6.34)	($14.54)	($20.61)	($21.45)	($19.92)	($18.34)	($16.71)	($15.06)	($13.41)	($11.76)
												Capital costs nc

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