

# **Assessment of Replicable Innovative Industrial Cogeneration Applications**

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## **Executive Summary**

U.S. industrial facilities utilize a wide array of thermal process equipment, including:

- Hot water heaters,
- Thermal liquid heaters,
- Ovens,
- Furnaces,
- Kilns,
- Dryers,
- Chillers, and
- Boilers.

In most industrial facilities, process heating is provided by direct or indirect heat exchange from fossil fuel-fired combustion systems. Process heating may also be provided by the direct or indirect use of steam supplied by central boiler systems. Many of these systems could be retrofit to become part of integrated distributed generation (DG) cogeneration systems. Cogeneration, or Combined Heat and Power (CHP) systems, generate electricity on-site using turbines, reciprocating engines, or fuel cells and use the “waste” heat from the prime mover to supply some or all of the energy required by thermal processes. Cogeneration systems have high overall efficiencies and, for some facilities, will have lower life cycle costs than conventional solutions.

There has been considerable interest shown in the distributed generation field over the past 5 years. This market movement has gained credence with the distributed generation equipment manufacturers, and they have made substantial investments in the development of new power generation technologies. However, little is being spent to develop innovative industrial cooling and thermal systems and less on how to integrate distributed generation equipment within manufacturing processes, where the greatest opportunity to use waste heat can be found. Adaptation of innovative cogeneration systems is more advantageous from a national energy and environmental policy standpoint than other distributed generation applications because of the high overall efficiency of these systems.

Conventional large cogeneration systems are well developed, widely deployed, and utilize readily available thermal technologies. Their use and benefits are well documented. The thrust of this effort is to look beyond these beneficial and economically-attractive conventional technologies and identify very replicable and innovative cogeneration approaches integrated with selected industrial process operations.

One of the guiding principals of applying cogeneration is the efficient utilization of all energy input to the process. To accomplish this, thermal energy normally rejected needs to be recovered to the maximum extent possible. This can be achieved by recovering heat from the DG equipment exhaust stream, and for engine system, heat can also be recovered from the water jacket, oil cooler, and aftercooler.

This report provides a market assessment of innovative industrial DG cogeneration systems that are less than 1 MWe. The market assessment was developed by:

- Analyzing industrial thermal processes on an industry-by-industry basis and determining annual energy consumption for each industry/process combination,
- Using a methodology to choose five leading thermal processes that can be easily integrated into a cogeneration system and that offer large energy-saving potential,
- Developing integrated DG cogeneration process schematics, and

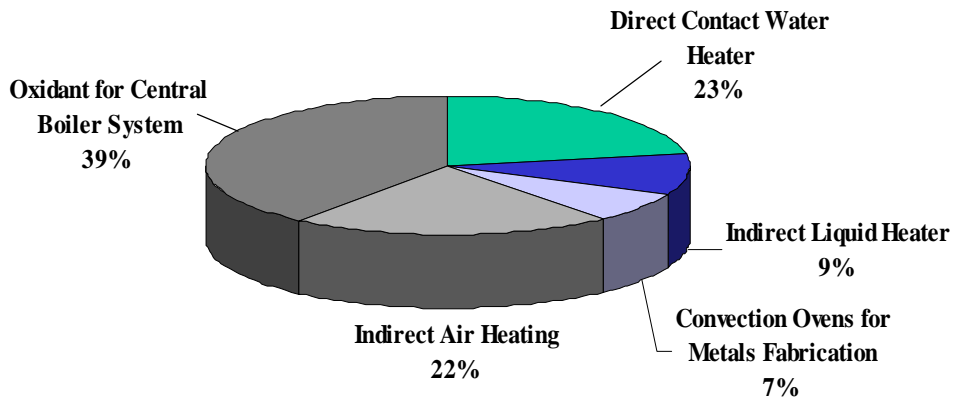
- Assessing the potential market for these systems by comparing their economics with the economics of conventional solutions.

Electricity rates used in this market assessment were based on actual utility electricity rate structures gathered in 1999. Gas rates are based on state average industrial gas rates from 1999, as reported by DOE's Energy Information Administration (EIA). Escalation rates for electricity and gas are based on 1999 EIA regional projections. Using these values eliminates the gas price spikes of 2000 and uncertain projections regarding electricity rates for the West Coast that surfaced in 2000-2001. If emerging energy price trends and escalation rates are incorporated in a subsequent analysis of the industrial cogeneration opportunities examined in this study, market penetration rates would likely change.<sup>1</sup>

The five leading cogeneration systems identified are:

- Direct contact water heaters fed directly with engine/turbine exhaust,
- Indirect liquid heating using air-to-liquid heat exchangers fed with engine/turbine exhaust,
- Convection ovens used for metals fabrication preheating fed directly with engine/turbine exhaust,
- Indirect air heating using air-to-air heat exchanges fed with engine/turbine exhaust, and
- Central boiler systems using turbine exhaust gas as a combustion oxidant.

The market assessment analysis shows 11 GW of economic market potential for these cogeneration applications. Figure 1 shows the total economic market potential by system type.



**Figure 1. Summary Results by System Type - 11 GW Total Economic Market Potential**

Factors that influence economic market potential by system type include:

- Number of facilities in the U.S. with matching thermal processes (there are more facilities with central boiler systems that could be retrofit with cogeneration than potential facilities with convection ovens for metals fabrication),
- Thermal system cogeneration retrofit cost, which affects the total installed cost of the cogeneration system (lower installed cost improves project economics and market potential),
- Existing thermal system efficiency (the lower the existing thermal system efficiency, the more cost-effective the project – indirect air heating efficiency is often below 50%, while convection ovens exceed 85%), and

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<sup>1</sup> Analysis of the impacts of these recently emerging price trends was outside the scope of this effort.



- System sizes for each type (system types where there are more potential facilities with matching thermal processes in the larger size ranges – retrofit, engineering, and installation costs are lower in terms of dollars per kW in the larger sizes).

The 10 states showing the highest economic market potential are shown in Figure 2.

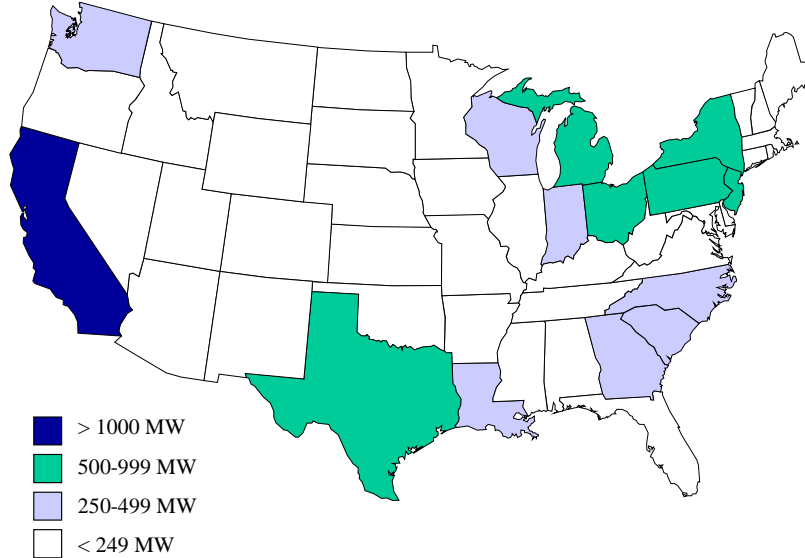


Figure 2. Summary Results by State - 11 GW Total Economic Market Potential

Factors that influence market economic market potential by state include:

- Size of the state and industry mix within the state,
- Industrial electric rates within the state, and
- Industrial natural gas rates within the state.

California has the most applications, because it has the highest number of industrial facilities with matching thermal processes, and also relatively high industrial electricity rates.

Economic market potential broken down by prime mover size range is shown in Figure 3.

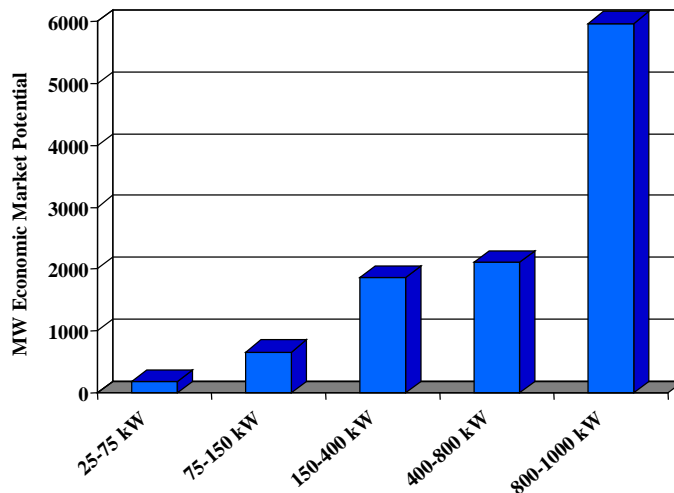
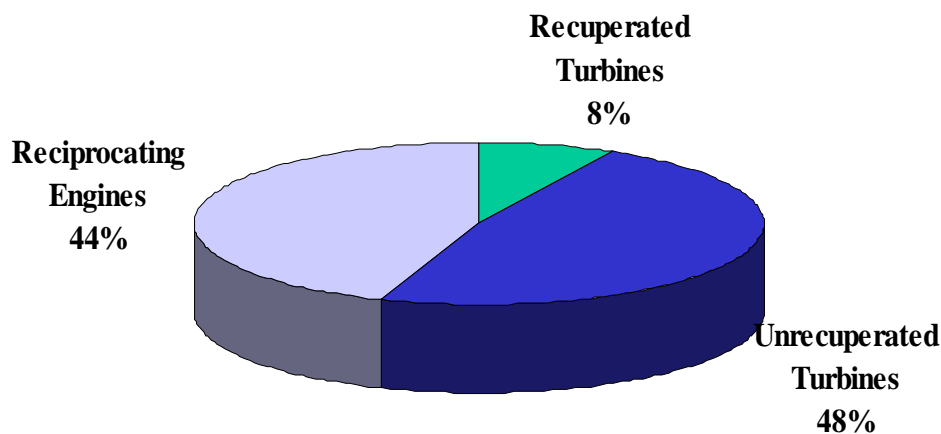


Figure 3. Summary Results by Size Range

Factors that influence market economic market potential by prime mover size range include:

- Number of potential facilities in each size range (most industrial facilities have electric demands greater than 75 kW), and
- Installation costs (costs are lower as the size ranges increase, because retrofit, engineering, and installation costs are lower in terms of dollars per kW, so this favors the larger size ranges).

Economic market potential broken down by prime mover type is shown in Figure 4.



**Figure 4. Summary Results by Prime Mover Type**

Factors that influence market potential that vary by prime mover type include:

- Prime mover electric efficiency (for most size ranges, reciprocating engines have the highest electric efficiency),
- Available usable thermal output from the prime mover (unrecuperated turbines have the highest), and
- Prime mover installed cost (reciprocating engines and unrecuperated turbines are less expensive than recuperated turbines in all size ranges – for example, the installed costs for a 70-100 kW direct contact water heater system using a recuperated turbine is over \$2,400 per kW, but this decreases to under \$1,000/kW in the 800-1000 kW size range),

The results shown in this assessment show the economic market potential. There are a number of barriers that may limit applications of these technologies. Some of these barriers may be regional in nature. The barriers include:

- Product performance and availability,
- Lack of off-the-shelf integrated systems,
- Presence of a supporting market infrastructure,
- Awareness, information and education of end users,
- Demonstration of successful case studies,
- Environmental regulations,
- Planning, zoning, and codes, and
- Tax treatment.

There clearly exists a need for a structured approach to assist with the development and deployment of innovative cogeneration systems in the industrial sector. This approach needs to foster the development of industrial cooling and heating systems that can easily be integrated with distributed generation equipment. The approach should demonstrate these systems in industrial settings and then develop case studies around these demonstrations. These case studies need to include validated and verified data on the systems' operation and performance. In addition, the structured approach also needs to address the potential barriers and how to overcome them.

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## **Introduction**

### **Background**

The U. S. Department of Energy's Office of Power Technologies (OPT) and the Industrial Center, Inc. sponsored this work in keeping with their joint goal to significantly improve the resource efficiency and productivity of industries in the United States. In support of this goal, this project will help industries develop technological solutions to critical energy and environmental challenges. Among the solutions being pursued are innovative applications of distributed generation technologies in industrial and institutional cogeneration applications. These technologies have the potential to reduce national energy use and emissions.

A number of trends have surfaced that may lead to growth in industrial cogeneration including:

1. Global concern over greenhouse gas emissions has meant an increased emphasis placed on total energy efficiency, which would favor combined heat and power over utility central plant generation. This outlook may create interest in changing environmental regulations to be less emission based, and more output based, thus favoring the more efficient cogeneration. Furthermore, creation of a global carbon permit trading market would provide new incentives for cogeneration.
2. Electric utility restructuring has heightened concerns over grid reliability and thus is renewing interest in on-site generation. Stranded cost treatment, including exit fees, threatens to counter this interest by deterring non-grid sources of power.
3. New technologies are surfacing, including microturbines and fuel cells. In addition, a new generation of reciprocating engines is entering the market, with higher efficiencies, decreased costs, and lower emissions. In combination, these technologies provide smaller facilities with an unprecedented set of options from which to potentially satisfy their needs for both thermal and electric energy on-site.

### **Objectives**

The purpose of this study is to assess the market for innovative and replicable applications of small cogeneration technologies in the U. S. industrial sector. Specific objectives of this study are to:

- Review distributed generation technologies in the 25-1000 kWe size range,
- Examine industrial thermal processes that can be integrated with cogeneration systems,
- Select the top five innovative and replicable industrial cogeneration technologies in the 25-1000 kWe size range, and
- Assess the potential market for these technologies.

### **Approach**

This report is the first task of a larger project that will demonstrate innovative applications of industrial cogeneration systems in actual manufacturing facilities. In order to ensure replicability, this first task will assess the market for cogeneration applications in the 25-1000 kWe size range.

This study identifies five highly replicable innovative cogeneration technologies and assesses their domestic market potential. A five-step approach is used to identify these opportunities and estimate the potential market.

**Step 1.** Analyze and group industrial thermal processes into seven broad categories, including:

- Hot water,
- Indirect liquid heating,

- Direct heating and drying,
- Indirect air heating,
- Refrigeration and freezing,
- Dehumidification, and
- Furnaces and boilers.

This is done by examining each specific industry within the manufacturing sector (4 digit Standard industrial classifications (SIC) with SICs 20-39), and looking at each of their significant thermal processes.

**Step 2.** The seven broad categories of thermal processes are broken into more specific categories (e.g., *direct heating and drying* can be broken into subcategories such as *spray drying*) and replicability is assessed by estimating the total U.S. annual energy consumption of each specific process. This is done for each industry at the 4-digit level, and the results are aggregated to obtain totals for each subcategory.

**Step 3.** The top five applications are chosen because of their replicability (energy savings across all applicable SICs) and ease of integration into a cogeneration systems. The five applications selected for the market assessment are:

- Direct contact water heaters,
- Indirect liquid heating,
- Convection ovens used for metals fabrication preheating,
- Indirect air heating, and
- Exhaust gas as an oxidant for central boiler systems.

**Step 4.** Cogeneration system price and performance information is gathered for these five applications.

**Step 5.** An economic analysis (market assessment) is performed to determine the number of potential applications for these five innovative industrial cogeneration systems. The analysis determines the number of facilities, by 4 digit SIC, size range, and state, where using the cogeneration application is more cost effective than purchasing electricity from the grid and using conventional thermal processes.

## Distributed Generation Technologies

A summary of each commercial and near-commercial DG technology is provided below. Included are the technology's history and current status, operational process, and detailed information on industrial cogeneration potential.

### Reciprocating Engines

#### History and Status

Reciprocating engines, developed more than 100 years ago, were the first of the fossil fuel-driven DG technologies. Both Otto (spark ignition) and Diesel cycle (compression ignition) engines have gained widespread acceptance in almost every sector of the economy and are in applications ranging from fractional horsepower units powering small hand-held tools to 60 MW baseload electric power plants. Reciprocating engines are machines in which pistons move back and forth in cylinders. Reciprocating engines are a subset of internal combustion engines, which also include rotary engines. Small to medium sized engines are primarily designed for transportation applications and are converted to power generation units with little modification. Larger engines are, in general, designed for power generation, mechanical drive, or marine propulsion. Reciprocating engines are currently available from many manufacturers in all DG size ranges, and can use gasoline, diesel, natural gas, or waste fuels.

#### Operation

Almost all engines used for power generation are four-stroke and operate in four cycles (intake, compression, combustion, and exhaust). The process begins with fuel and air being mixed. Some engines are turbocharged or supercharged to increase engine output, meaning that the intake air is compressed by a small compressor in the intake system. The fuel/air mixture is introduced into the combustion cylinder, then compressed as the piston moves toward the top of the cylinder. In diesel units, the air and fuel are introduced separately with fuel injected after the air is compressed by the piston in the engine. As the piston nears the top of its movement, a spark is produced that ignites the mixture (in most diesel engines, the mixture is ignited by the compression alone). Dual fuel engines use a small amount of diesel pilot fuel in lieu of a spark to initiate combustion of the primarily natural gas fuel. The pressure of the hot, combusted gases drives the piston down the cylinder. Energy in the moving piston is translated to rotational energy by a crankshaft. As the piston reaches the bottom of its stroke the exhaust valve opens and the exhaust is expelled from the cylinder by the rising piston.

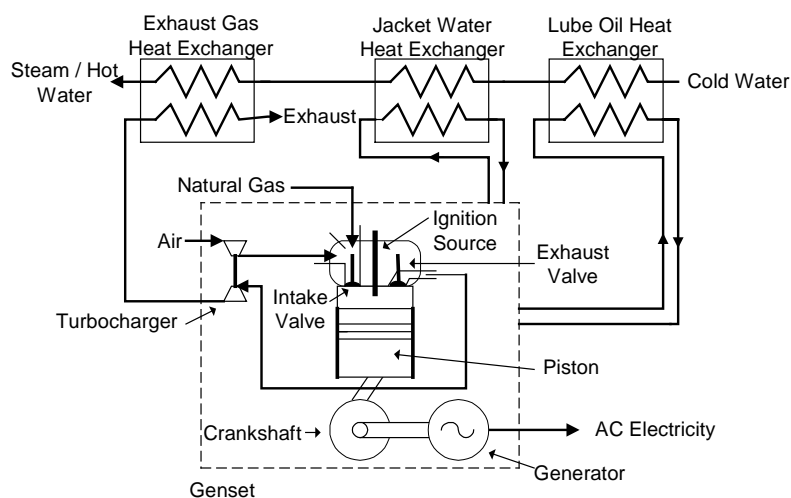


Figure 5. Reciprocating Engine

#### Industrial Cogeneration Potential

Reciprocating engines can be used in three different types of industrial cogeneration applications:

- To produce hot water at around 195° F,
- To produce low temperature steam at around 265° F, and
- To produce heat at higher temperatures, e.g. for drying processes, exhaust gases with temperatures of 930 to 1,000° F can be used directly or by means of a heat exchanger.

The following chart shows the electric efficiencies, thermal output, and potential overall efficiency:

	Electric Efficiency (% LHV)	Thermal Output (% LHV)	Overall Efficiency (% LHV)
Hot Water	31-38	47-54	80-85
Low Temperature Steam	31-38	18-25	80-85*
High Temperature Heat	31-38	18-34	80-85*

\*also includes potential hot water production

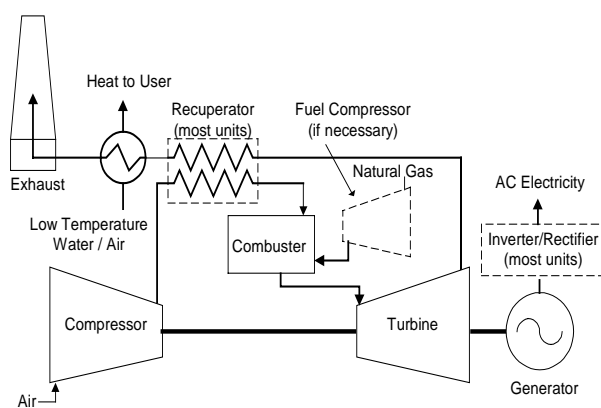
## Microturbines

### History and Status

The technology used in microturbines is derived from aircraft auxiliary power systems, diesel engine turbochargers, and automotive designs. A number of companies are currently field testing demonstration units for small-scale distributed power generation in the 30-400 kW size range. Several units are available commercially, and more are slated to enter the market in 2001 and 2002.

### Operation

Microturbines consist of a compressor, combustor, turbine, and generator. The compressors and turbines are typically radial-flow designs, and resemble automotive engine turbochargers. Most designs are single-shaft and use a high-speed permanent magnet generator producing variable voltage, variable frequency alternating current (AC) power. An inverter is employed to produce 60 Hz AC power. Most microturbine units are currently designed for continuous-duty operation and are recuperated to obtain higher electric efficiencies. Non-recuperated engines have lower electric efficiencies, but higher exhaust temperatures, which makes them better for some industrial cogeneration applications.



**Figure 6. Microturbine**

### Industrial Cogeneration Potential

Microturbines can be used in three different types of industrial cogeneration applications:

- To produce hot water at around 195-205° F,
- To produce low temperature steam at around 265° F, and
- To produce heat at higher temperatures, e.g. for drying processes, exhaust gases with temperatures of 600 to 1,000° F can be used directly or by means of a heat exchanger.

The following charts shows the electric efficiencies, thermal output, and potential overall efficiency for each type of system:

**Recuperated Microturbine**

	Electric Efficiency (% LHV)	Thermal Output (% LHV)	Overall Efficiency (% LHV)
Hot Water	25-27	40-55	65-80
Low Temperature Steam	25-27	40-55	65-80
High Temperature Heat	25-27	50-68	75-93

**Unrecuperated Microturbine**

	Electric Efficiency (% LHV)	Thermal Output (% LHV)	Overall Efficiency (% LHV)
Hot Water	13-15	52-72	65-85
Low Temperature Steam	13-15	52-72	65-85
High Temperature Heat	13-15	72-80	85-93

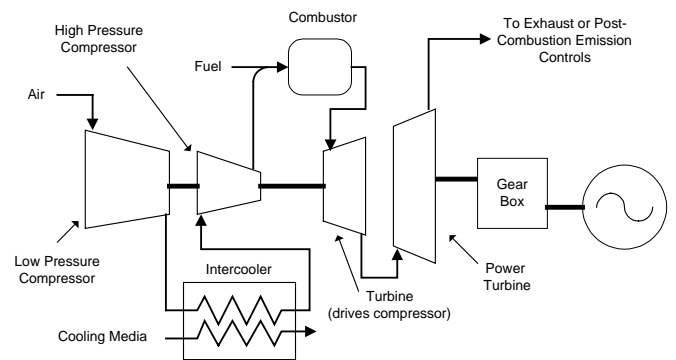
**Industrial Combustion Turbines**

*History and Status*

Combustion turbines have been used for power generation for decades and range in size from units starting at about 1 MW to over 100 MW. Units from 1-15 MW are generally referred to as industrial turbines, a term which differentiates them from larger utility grade turbines and smaller microturbines. Combustion turbines have relatively low installation costs, low emissions, high heat recovery, and infrequent maintenance requirements. With these traits, combustion turbines are typically used for large cogeneration systems, as peakers, and in combined cycle configurations. Industrial turbines sized below 1 MW are rare.

*Operation*

Historically, industrial turbines have been developed as aero derivatives using jet propulsion engines as a design base. Some, however, have been designed specifically for stationary power generation or for compression applications in the oil and gas industries. A combustion turbine is a device in which air is compressed and a gaseous or liquid fuel is ignited. The combustion products expand directly through the blades in a turbine to drive an electric generator. The compressor and turbine usually have multiple stages and axial blading. This differentiates them from smaller microturbines that have radial blades and are single staged. The intercooler shown in Figure 7 is generally reserved for larger units that can economically incorporate this improvement.



**Figure 7. Turbine**

*Industrial Cogeneration Potential*

Industrial turbines can be used in two types of industrial cogeneration applications:

- To produce steam over a range of pressure and temperatures, and



- To produce heat at higher temperatures, e.g. for drying processes, exhaust gases with temperatures of 900 to 1,000° F can be used directly or by means of a heat exchanger.

The following chart shows the electric efficiencies, thermal output, and potential overall efficiency for industrial turbines below 1 MW:

	Electric Efficiency (% LHV)	Thermal Output (% LHV)	Overall Efficiency (% LHV)
Steam	25-27	45-55	70-80
High Temperature Heat	25-27	59-68	84-93

## Phosphoric Acid Fuel Cells

### History and Status

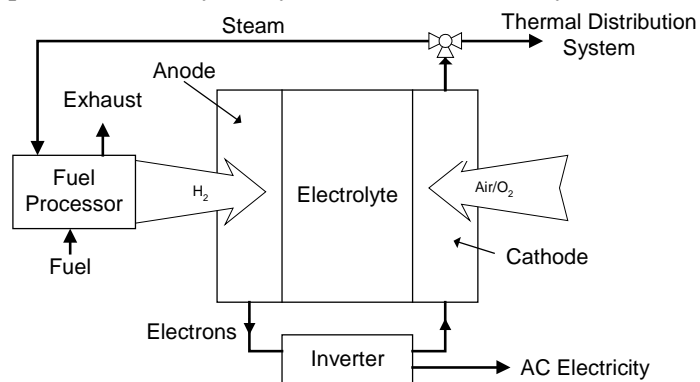
Although the first fuel cell was developed in 1839 by Sir William Grove, the technology was not put to practical use until the 1960's when NASA installed fuel cells to generate electricity on Gemini and Apollo spacecraft. There are many types of fuel cells currently under development, including phosphoric acid, proton exchange membrane, molten carbonate, solid oxide, alkaline, and direct methanol. However, fuel cells are not generally commercially available, except for a 200 kW phosphoric acid unit made by International Fuel Cells.

### Operation

There are many types of fuel cells, but each uses the same basic principle to generate power. A fuel cell consists of two electrodes (an anode and a cathode) separated by an electrolyte. Hydrogen fuel is fed into the anode, while oxygen (or air) enters the fuel cell through the cathode. With the aid of a catalyst, the hydrogen atom splits into a proton (H+) and an electron. The proton passes through the electrolyte to the cathode, and the electrons travel through an external circuit connected as a load, creating a DC current. The electrons continue on to the cathode, where they combine with hydrogen and oxygen, producing water and heat.

The main differences between fuel cell types are in their electrolytic material. Each different electrolyte has both benefits and disadvantages based on materials and manufacturing costs, operating temperature, achievable efficiency, power to volume (or weight) ratio, and other operational considerations. The part of a fuel cell that contains the electrodes and electrolytic material is called the "stack," and is a major component of the cost of the total system. Stack replacement is very costly but becomes necessary when efficiency degrades as stack operating hours accumulate.

Fuel cells require hydrogen for operation. However, it is generally impractical to use hydrogen directly as a fuel source; instead, it is extracted from hydrogen-rich sources such as gasoline, propane, or natural gas using a reformer. Cost effective, efficient fuel reformers that can convert various fuels to hydrogen are necessary to allow fuel cells increased flexibility and commercial feasibility.



**Figure 8. Fuel Cell**

**Industrial Cogeneration Potential**

The phosphoric acid fuel cell can be used in two different types of industrial cogeneration applications:

- To produce hot water at around 140° F, and
- To produce hot water at around 140° F and low temperature steam at 250° F.

The following charts shows the electric efficiencies, thermal output, and potential overall efficiency for the 200 kW phosphoric acid fuel cell:

	Electric Efficiency (% LHV)	Thermal Output (% LHV)	Overall Efficiency (% LHV)
Hot Water	37	50	87
Hot Water Plus Low Temperature Steam	37	50	87

**DG Technology Cost and Performance**

Table 1 shows cost and performance parameters for the each of the generation technologies described. These numbers are used as input data into the model that develops the market assessment presented later in this report. Installation costs and prices for heat recovery equipment depend on the specific thermal application that the generation technology is integrated with, and are presented in later sections of this report.

**Table 1. DG Cost and Performance Tables**

**Recuperated Turbines**

	25-75 kW	75-150 kW	150-400 kW	400-800 kW	800-1000 kW
Packaged Cost (\$/kW)	800	800	700	700	700
Maintenance (\$/kWh)	0.01	0.01	0.009	0.009	0.009
Heat Rate	13,200	13,200	13,200	10,434	10,434
Max. Thermal Output Exhaust (mBtu/hr/kW)	8.94	8.94	8.94	6.76	6.76
Max. Thermal Output Water (mBtu/hr/kW)	0	0	0	0	0

**Unrecuperated Turbines**

	25-75 kW	75-150 kW	150-400 kW	400-800 kW	800-1000 kW
Packaged Cost (\$/kW)	600	600	500	500	350
Maintenance (\$/kWh)	0.01	0.01	0.009	0.009	0.004
Heat Rate	26,246	26,246	26,246	14,519	13,123
Max. Thermal Output Exhaust (mBtu/hr/kW)	21.52	21.52	21.52	10.38	9.05
Max. Thermal Output Water (mBtu/hr/kW)	0	0	0	0	0

**Reciprocating Engines**

	25-75 kW	75-150 kW	150-400 kW	400-800 kW	800-1000 kW
Packaged Cost (\$/kW)	N/A	530	490	435	390
Maintenance (\$/kWh)	N/A	0.01	0.0085	0.008	0.0075
Heat Rate	N/A	11,000	10,340	9,750	8,980
Max. Thermal Output Exhaust (mBtu/hr/kW)	N/A	3.54	2.91	2.35	1.62
Max. Thermal Output Water (mBtu/hr/kW)	N/A	3.5	3.5	3.5	3.5

**Phosphoric Acid Fuel Cells**

	25-75 kW	75-150 kW	150-400 kW	400-800 kW	800-1000 kW
Packaged Cost (\$/kW)	N/A	N/A	3300	3300	3300
Maintenance (\$/kWh)	N/A	N/A	0.015	0.015	0.015
Heat Rate	N/A	N/A	9,235	9,235	9,235
Max. Thermal Output Exhaust (mBtu/hr/kW)	N/A	N/A	0	0	0
Thermal Water Output (mBtu/hr/kW)	N/A	N/A	4.5	4.5	4.5

Initial screening ruled out applications using fuel cells. Because of their high capital costs, they cannot currently compete either with other DG technologies or with conventional thermal technologies combined with purchased electricity from the grid. The remainder of this report will focus on turbine- (including microturbine) and reciprocating engine-based cogeneration technologies.

## **Potential Industrial Thermal Applications to Integrate with Cogeneration DG Systems**

The section describes the generic industrial applications that can use waste thermal energy. For each generic industrial application, there is a general description, process uses, and details on cogeneration integration. A diagram of the generic process integrated with a microturbine is also included.

### **Hot Water/Direct Contact Water Heaters**

#### **General**

Process hot water often represents the single largest Btu/hr energy requirement for a manufacturer. Development of highly efficient heat exchange concepts for this purpose has resulted in the 'direct contact water heating' scheme. Fundamentally, by raining water down a 'packed' column, which also is the stack for combustion products (natural gas), near ideal heat transfer is achieved. Exhaust leaves the system cooled to less than 10°F above the cool water inlet, and the water is able to reclaim well above 90% of the exhaust energy.

#### **Process Uses**

Abundance, availability, safety and experience make hot water a first choice for manufacturing processes requiring:

1. Washing/flushing
  - Equipment "clean-down" and sanitizing in food industries (meat, dairy, sugar refining, etc.), and pharmaceutical and "bio" processes.
  - Continuous washing operations in raw food preparation (cane/beet sugars, meat, etc.), textiles, wood/paper pulp, removing oils and other excess matter (paint, dust etc.) in metals fabrication and molded plastics industries (auto parts, sheet metal, cans, food/beverage containers, etc.), and in synthetic rubber and fiber manufacturing.
  - Flushing process piping and batch equipment (paint blenders, fermentation vessels, etc.), particularly for operations using the same process lines/equipment to produce slightly varying products (paints, candy slurries, pharmaceuticals, etc.).
2. Solvents for raw material preparation, leaching, separations/extractions, and emission control operations. Water is typically chosen when these systems handle general solid inorganics, acids, generally polar fluids, and crystalline salts.
3. Crystallization/fermentation/reaction media for industries including wine/malt-beverage, dairy, pharmaceutical, and inorganic chemicals.
4. Heating jackets for vessels/operations below ~230°F including chocolate tempering, crystallizers, and storage vessels/mixers containing viscous materials.

Hot water generated from direct contact with natural gas derived combustion exhaust has been approved for food manufacturers including dairy, meat plants, and beverages.

#### **Integrating for Cogeneration**

To address heat transfer, either more packing media, or extending the height of the column (or both) may be necessary to maintain normal operation (with retrofit systems). Pressure drop and thus back-pressure imposed on the generating system will be a key design element. Special consideration to ensure that no process water enters back into the DG unit's exhaust system is also crucial for practical implementation.

Many industrial facilities may not have a constant hot water demand. However two profiles may describe the demand well (e.g., normal production operation, and "clean-down" or full capacity day shifts with

part capacity night shifts). In the latter case, a bypass-recuperator option on a turbine-based cogeneration scheme can be integrated with a variable flow water tower to switch between profiles. Assuming precise hot-water energy requirements are known, a recuperator with bypass can be designed to maintain total system efficiency by diverting some or all of the exhaust past the (turbine) recuperator to boost the hot water delivery to the desired level.

### Currently Available Systems

There are currently two off-the-shelf small industrial cogeneration systems available in the marketplace to generate hot water. The first system is a microturbine-based solution that works like the indirect liquid heating system described later in this report. An air-to-water heat exchanger is used with the turbine exhaust gases to heat water.

The second system is a standard reciprocating engine cogeneration system. These systems use liquid-to-water heat exchangers on the water jacket cooling fluid, the lubricating oil system, and sometimes on the aftercoolers. Some of these systems also use an air-to-water heat exchanges on the engine exhaust.

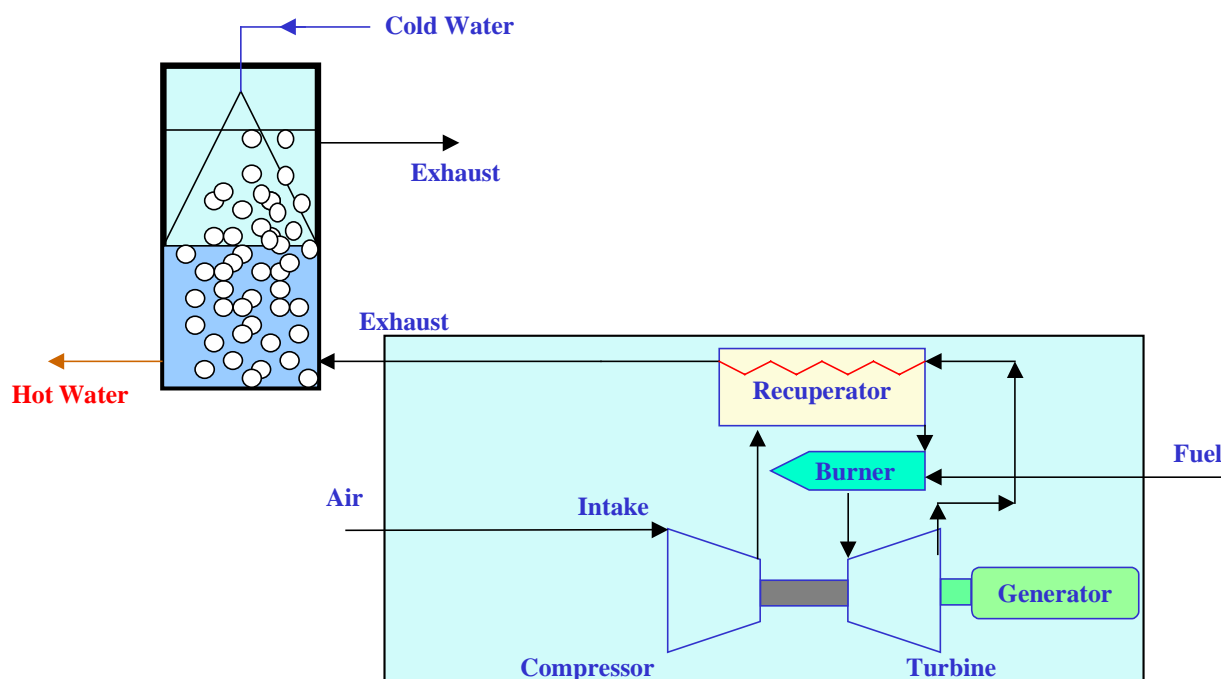


Figure 9. Direct Contact Water Heater System

## Indirect Heating of Thermal Fluids

### General

Many operations, requiring energy delivery to a liquid-phase (and/or fluid) stream, require a physical barrier between the fossil burn (energy release) and the process stream. The barrier reduces heat transfer efficiency, but is often necessary. Traditional systems depend upon heat delivery via heat exchangers, fire-tube schemes (heating coils, or multi-pass fluid heaters) and other methods. Many of these systems use flame induced, radiant based heating to rapidly deliver well over 50% of the required energy.

### Process Uses

Situations involving high (and/or variable) pressure systems, separation/purification operations, multi-phase operations, systems impeded by oxidation (or other possibly reactive/degrading components of

combustion), and/or strictly maintained closed-loop systems are common boundaries to direct heating of process streams. More specific operations and their manufacturing environments include:

1. Purification, recovery, and separations.
  - Chemicals/refinery distillation (reboilers, etc.), and flash evaporators (polymer processing, slurry separations/purification, brine treatment, etc.).
2. Pressurized process streams (chemical reactors, etc.).
3. Processes/products sensitive to oxidation, other reaction-driven degradation, and/or general fouling (chemical, food, pharmaceutical processing, etc.).
4. Vat or batch systems maintaining a heated fluid (paint/dye blenders, food deep fryers, refinery-bottoms storage and subsequent processing, reactor/fermentation vessels, crystallizers, etc.).
5. Thermal fluid, closed-loop-heating systems for processes, often including those already mentioned, requiring especially high and smoothly controlled temperature profiles.
  - Systems requiring high temperatures over large areas such as calcium chloride crystallizers.
  - Pipe line tracing.
    - Distillation and reactor feed lines whereby preheating feed components simplifies the energy delivery and/or chemistry complexity of that downstream operation.
    - Heat tracing viscous material (crude, confectionery, polymer melts, etc.) pipelines to reduce electric driven pumping.
  - Tool heating (including plastics/rubber extruders, molds), paper mill platens and rollers, metal fabrication equipment, laminate setting, and others.
  - General polymer processing. Polymer processing plants may require high temperature (> 400°F) energy delivery to several unit operations because of high “pure” polymer melting points (maintained for extrusion, molding, etc.), and endothermic and/or equilibrium limited reactions (whereby light byproducts, often water, must be continuously evaporated and removed for effective/efficient reactor output). Polyester and Nylon 6,6 are good examples of major international commodities often utilizing thermal fluids systems throughout their production cycle.

### **Integrating for Cogeneration**

The wide variety of thermal “fluid” heating applications mentioned above reflects the broad scope in unit operations, engineering techniques, and process chemistries involved in this concept category. For this section, three general interconnection (with cogeneration) systems will be discussed.

1. Systems not relying on radiant energy delivery.

Systems currently delivering heat to a process fluid via combustion exhaust energy only (or other forced convection media), either through a series of tubes, vessel/pipe jacket, or compact heat exchanger (shell and tube, plate unit, etc.) can be easily adapted to receive cogeneration based thermal energy. Because the majority of a DG unit’s thermal output is in the form of hot exhaust, the key concerns would be matching the temperature, gas volume, and pressure parameters to those experienced prior to cogeneration integration. This may require little or no rebuilding of the process heat exchange equipment, but needs to consider the operating tolerance of the DG unit.

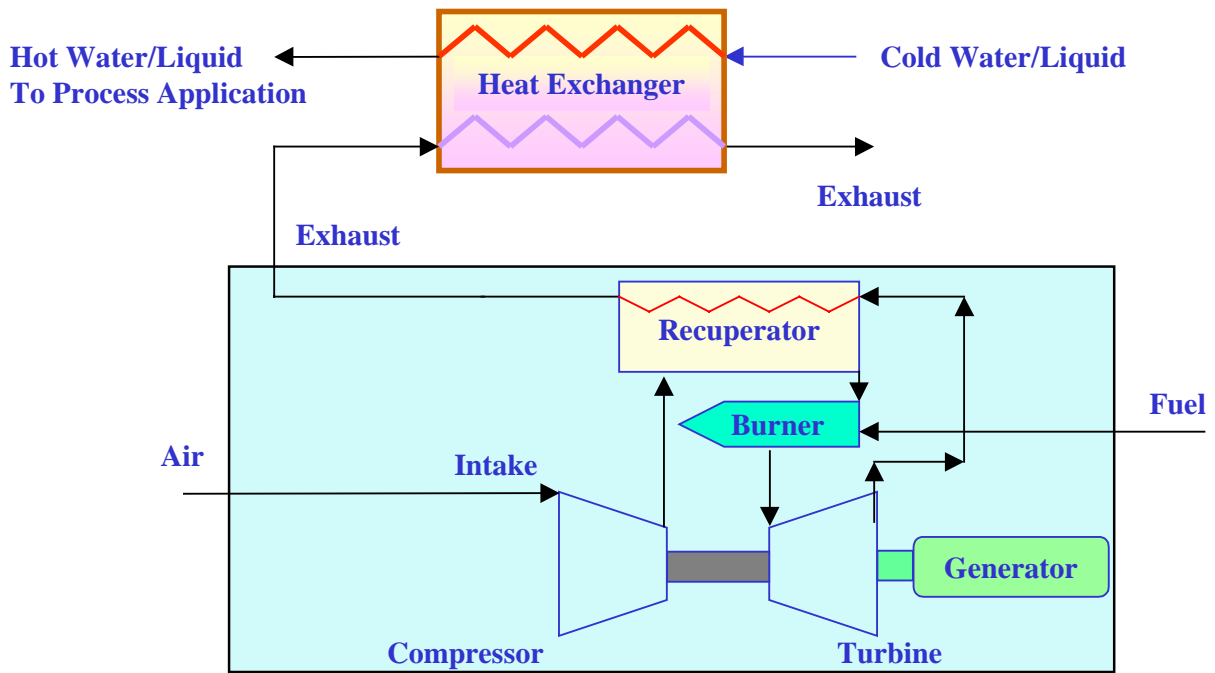
2. Systems relying on radiant (flame induced) energy transfer.

Unless there is little radiant energy transfer contribution (relative to the entire quantity delivered by the process operation) and/or the flame temperatures are low (< 1500°F), even an unrecuperated turbine cannot match the heat transfer characteristics expected in the existing process heat transfer unit. Several combinations may then compete on a cost benefit and space based analysis. Many systems delivering a majority of the energy via high temperature, flame induced radiation leave a significant amount of the unit volume for flame (radiant rays) “space” only. If this space were utilized to generate more passes (fluid tubing), thereby increasing heat

transfer area, the operation could be more readily fit by a cogeneration scheme. It may be the case that the original heat transfer unit cannot be properly modified. However, if the feed line to the heater unit is relatively low temperature (70-300°F), a heat exchanger extracting cogeneration energy prior to entering the main heater could result in a sizable turn down of fuel delivery to that unit. Another option would be the use of duct burners to increase the fuel gas temperature to the required levels.

3. Closed loop, thermal fluid heating systems.

The previous two interconnection categories represent traditional methods of heat transfer to process fluid streams/systems. The second is more common, but also requires a great deal more case by case analysis, because of the variety of techniques and principles incorporated in radiant heat transfer different from those available from cogeneration exhaust (not considering “reburn” technologies). Thermal fluid heating systems however, represent a stronger possibility for a more heterogeneous cogeneration-based heat delivery, retrofit and/or interface system. From a cogeneration standpoint, the only concern is maintaining total heat transfer characteristics to the heat transfer fluid on return from the process unit(s). In other words, a 400,000 Btu/hr Dowtherm® based operation can use the same heater design regardless of whether the system is heating/controlling a polymer reactor or a paper laminate machine. This would allow for more repetitious cogeneration designs across broad categories of process operations and manufacturing sectors.



**Figure 10. Indirect Fluid Heater System**

**Direct Heating/Drying**

**General**

Direct heating and drying refers to combustion products mixing directly with the process environment (typically process solids and a forced “air” stream). Because radiation transfer is rapid, typically at high temperature, and ceases upon reaching a boundary (the outer layer of process matter), it is often undesirable and unnecessary. Therefore, natural and forced convection heat transfer engineering may

dominate dryer design. There are a wide variety of process dryers, kilns, calciners, ovens, etc. that incorporate an even greater range of combinations in forced convection, radiation, and conduction (through the material) heat transfer principles to satisfy the product requirements. In all cases, however, the heat energy supplied to a system must perform the following four tasks:

1. Heat the dryer feed to the “light” component’s vaporization temperature.
2. Vaporize and/or free the liquid/byproducts above the solids’ surface.
3. Heat the solids to the final desired temperature, and for the desired duration of time.
4. Heat the vapor to the final desired temperature.

### **Process Uses**

Numerous factors, including production throughput, local steam, natural gas and electricity prices, emissions restrictions, and equipment cost considerations, often result in similar solids being dried in very different ways. However, common direct drying/heating operations and their typical product/process applications include:

1. Bringing variable water-weight percent feeds to a desired initial processing concentration.
  - Mined raw materials and/or prepared mixes fed to cement, gypsum, ceramics, and lime processes require crushing, sizing, and drying. Rotary dryers, impact dryers, drum dryers, and others are used to handle large volume, variable composition slurries. Water removal to organize/homogenize process streams for inorganic chemicals manufacture is also common.
2. More complete drying of slurries containing finer solids within certain size/weight specifications is carried out using spray dryers, thin-film dryers, and drum dryers.
  - Within the Stone, Clay, Glass and Cement manufacturing sector (SIC 32), fine dry powders are desirable for handling, packing, and/or to produce a more consistent product. Specific products include kaolin clay, fluid cracking catalysts and ceramics that may also use this step to introduce property enriching additives/binders to the material.
  - Emulsion PVC and PVP polymer processes often employ spray drying to rapidly remove water without degrading product.
  - Milk/dairy powders.
  - Organic and inorganic dry soaps, detergents, dyes and pigments.
3. Pre-heating/drying materials.
  - Metals fabrication and/or scrap metal industries use direct heat to remove volatile impurities (oils, plastics, paints, etc.) and/or to reduce energy demand of central furnace operations.
  - Large kilns, calciners, and ovens (primarily in SIC 32) also benefit from preheated feeds, often containing preheat sections as part of the primary unit (tunnel kilns, etc.).
  - Coke processes may preheat coal feeds to reduce moisture content.
  - Glass and mineral wool industries utilize many preheat techniques to reduce energy demands or increase throughput on central furnaces systems.
4. Drying and heating meant to relieve chemically bound light components and/or otherwise modify solid structure. Rotary kilns, shaft kilns, kettle calciners, flash calciners, brick ovens/houses, tunnel kilns, regenerative kilns, and others are included in this grouping.
  - Kilns and ovens used for bricks, ceramics, etc. where residence times in hot and dry conditions may last hours to days to obtain desired final qualities in appearance and structure.
  - Kilns and calciners used to produce/process gypsum, plasters, cements, limestone, etc. where energy not only thoroughly removes any remaining water, but also frees intimate impurities, and forces various reactions often resulting in the release of carbon and sulfur oxides. Along with those operations in SIC 32, both the pulp & paper and beet sugar industries use these lime kiln technologies.
5. Drying to remove water (and/or other solvents/chemicals) added, left, or produced during processing.
  - Starch, stalk and husk dryers, and fruit peel and feed dryers, used in beet and cane sugar manufacturing, grain mill products, and other SIC 20 manufacturing sectors.



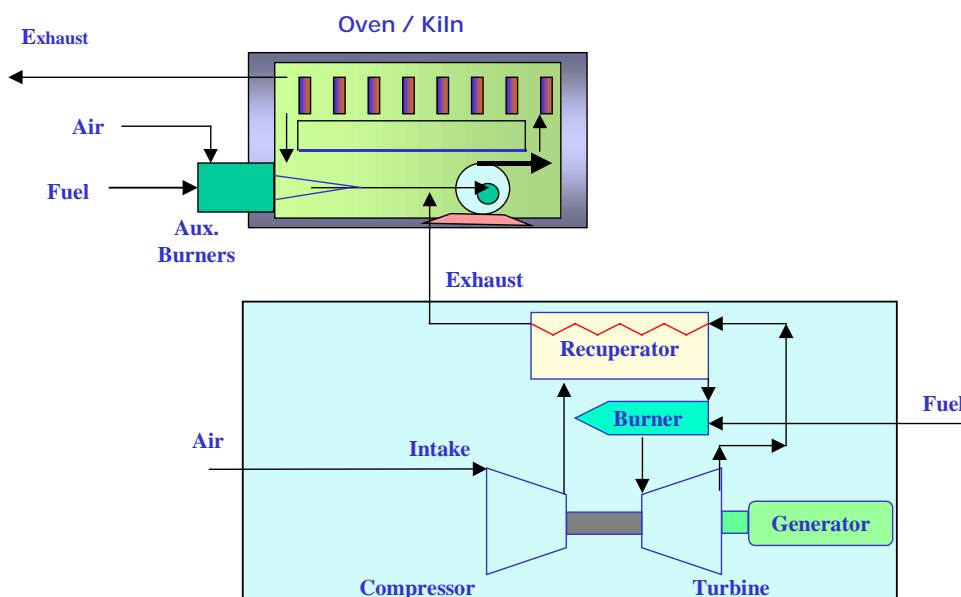
- Convection dryers in textile manufacturing.
  - Veneer and other lumber/wood-furniture dryers.
  - Pulp dryers, coated and tissue paper dryers in SIC 26.
  - Dryers including conveyor and tray dryers used in non & cellulosic fibers (rayon, acrylics, etc.) processing, polymer rubbers manufacture, for pharmaceuticals, and latex.
6. Granulators, fluidized bed systems, rotary dryers, and tower dryers often used for producing finished grains, sugar, and fertilizer.

### **Integrating for Cogeneration**

Many kilns and calciners depend on high temperature (1000-2000°F) exhaust and radiant heating sections that could not be supplied by cogeneration exhaust alone. However, preheating operations can take advantage of cogeneration. Although many “direct” preheating systems recover stack gas from onsite furnaces and central calciners/dryers, the gas often requires filtering or other treatment to remove particles, sulfurous gases, and other components that can otherwise deteriorate equipment and cause health concerns. Sites with successful existing preheating not derived from cogeneration may see additional turndown (on the primary unit’s fuel feed) without high retrofit costs if the system can handle an extra volume of exhaust (from a cogeneration scheme) and assuming temperature conditions are similar to the existing preheater’s hot gas feed. Drying operations at facilities without processing furnaces, (e.g., calciners) could completely supplement a non-radiant based dryer. However, some direct dryers burn cheap fuels (e.g. wood, pulp waste, coal) and so emissions considerations may drive the final decision.

In all cases, drying systems can contain a complex array of blowers and fans to promote improved heat transfer and efficiency. Back pressures on the DG unit may require controls and monitoring at each dryer entry point (of hot gases into the system) depending on the design.

Note: Typical unit operations literature may define direct drying to include solids receiving energy from any heated gas (combustion products/air mixtures, and hot air only are two of the most common media). This report distinguishes between the two, not because the process solid experiences different heat transfer profiles (it, essentially, does not), but because the integration of the cogeneration equipment is different.



**Figure 11. Direct Heating/Drying System**

## Indirect Air/Gas Heating

### General

Air heaters or inert gas heaters are commonly considered when products, process operations, or the facility environment are potentially compromised by using direct drying/heating systems. Because issues including plant layout, local regulations, and fuel type affect these considerations, many of the processes in this section and the preceding section are served by both indirect and direct heating.

### Process Uses

Two general processing categories are considered:

1. Food products cooking, baking, and drying.
  - Roasters used in coffee and cocoa processing.
  - Baking ovens used for breads, cakes, etc.
  - Toasting and drying systems for cereals.
2. Finish drying and curing systems.
  - Dryers following painting and or final cleaning operations in furniture and metals fabrication industries (transportation & industrial equipment, beverage cans, etc.).
  - Dryers used in finishing periodicals and newspaper production processes.

### Integrating for Cogeneration

Air heaters are often industrial versions of fired furnaces used in HVAC systems. Although many of the operations mentioned above require only modest heat (200-600°F), the heater itself may have radiation-induced “hot side” temperatures above 1500°F. A new type of heat exchanger may be needed for some applications.

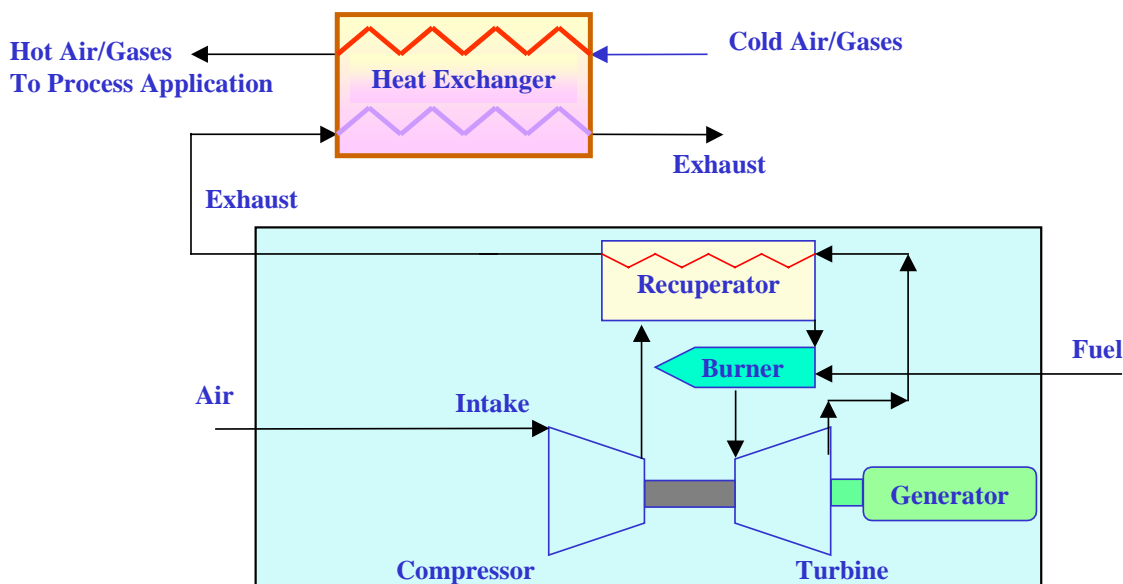


Figure 12. Indirect Air/Gas Heating System

## Refrigeration/Freezing (absorption cooling)

### General

Refrigeration/freezing refers to a direct process end use in which energy is used to lower the temperature of substances involved in the manufacturing process. Conventional equipment includes industrial chillers and absorption cooling equipment.

### Process Uses

Major applications of industrial cooling include:

- Refrigerated storage of unfrozen foods,
- Frozen foods,
- Refrigeration to change the chemical structure of food,
- Freeze drying,
- Industrial process air conditioning, and
- Refrigeration in the petroleum and chemicals industries (reaction heat removal, gas separations, condensation of gases, separations, solidifications, humidity control, etc.).

### Integration for Cogeneration

Absorption cooling systems require a source of heat. For an ammonia-water cooling system, the heat is required to separate the water and ammonia. In conventional absorption systems, this heat is supplied by steam heat exchangers, an electrical heater or a gas fired heater. For cogeneration systems, this heat can be supplied by using a heat exchanger where clean exhaust gases from a turbine or other type of prime mover is used as a heat source. The heating gases may have to be mixed with air or other gases to maintain desired heating gas temperature. Such a system will reduce or eliminate heat input for the overall system.

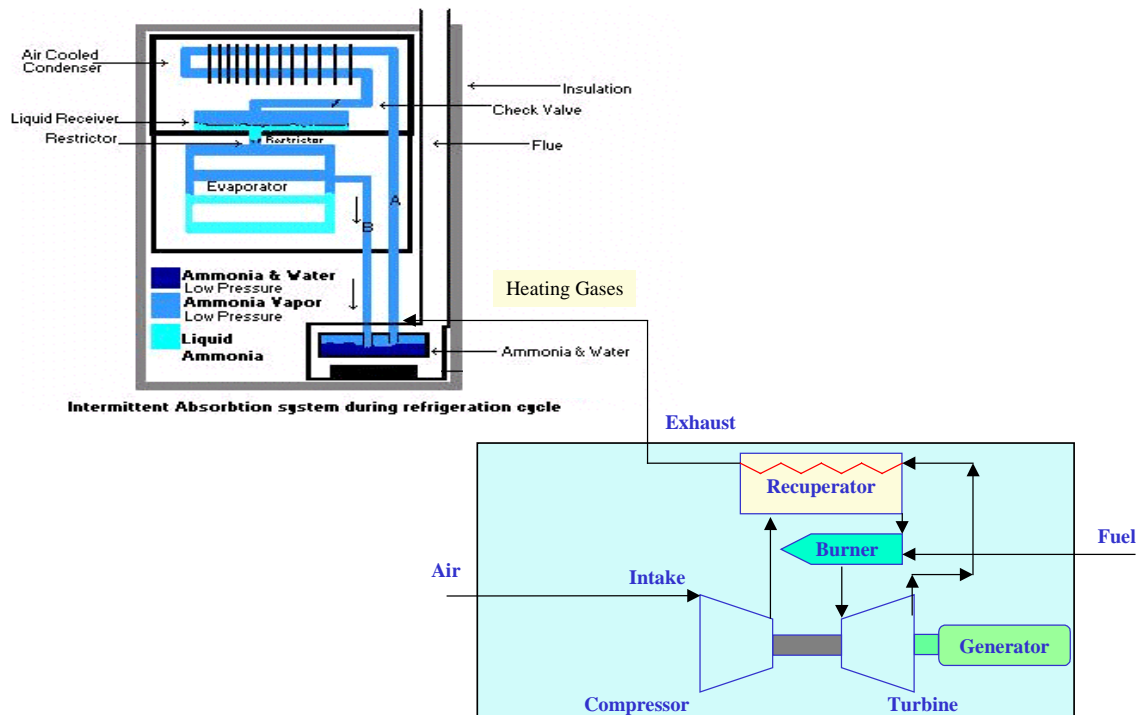


Figure 13. Refrigeration/Freezing System

## Dehumidification

### General

Desiccant-based dehumidification systems are used extensively for removing moisture from moist air or gases in many industrial applications. Some typical industries where such systems are used include chemical, pharmaceutical, food, semi-conductor manufacturing, and vacuum processing. These systems are also used for climate control applications in commercial buildings. Operation of these systems includes a regeneration step where hot air (or other gases) are used to remove moisture from saturated desiccant media.

### Process Uses

Major applications of dehumidification in the manufacturing sector include:

- Pharmaceutical processing,
- Candy coating,
- Storage and packing,
- Conveying of hygroscopic powders,
- Composite manufacturing,
- Semiconductor manufacturing,
- Printing operations,
- Corrosion prevention,
- Molding operations, and
- Drying operations.

### Integration for Cogeneration

In the cogeneration system, clean exhaust gases will be mixed with ambient air to raise the temperature to the desired value. Currently, a variety of heating methods and media are used for supplying hot regenerative air. The heating methods include heating by electricity, steam, or a fuel (usually gas) fired burner. Application of such a scheme may require redesign of the regenerative air system for a retrofit application. For a newer application, such changes can be accounted for during the design phase of the project.

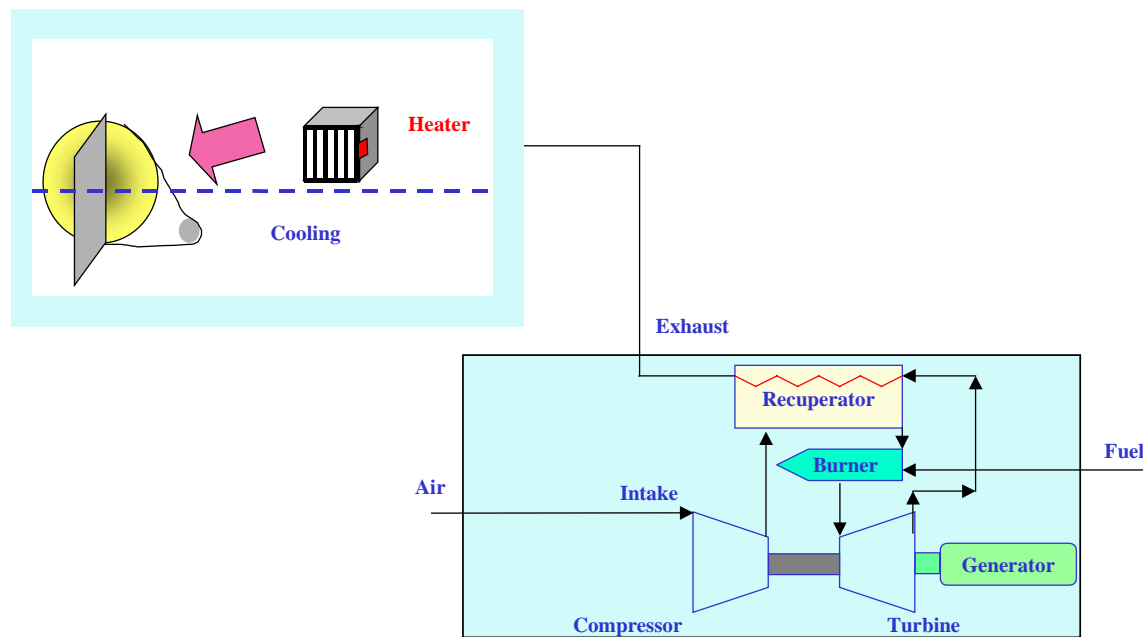


Figure 14. Dehumidification System

## **Use of Exhaust Gas as an Oxidant (including boiler systems)**

### **General**

Combustion reactions are highly exothermic. However, their reactants (fuel and oxidant) continuously absorb considerable energy to reach proper combustion temperatures. Exhaust gases from a prime mover, particularly from a gas turbine (because of its high oxygen content), provide an excellent preheated oxidant. These gases can be considered as an oxidant source for combustion of fossil fuels used in most heating applications including steam generators or boilers.

### **Processes Uses**

Applications for using exhaust gases as an oxidant include:

- Central boiler systems,
- Waste VOC incineration systems,
- Kilns,
- Calciners,
- Large ovens,
- Large heat treating operations,
- Large furnaces,
- Forging operations,
- Tempering operations,
- Annealing operations, and
- Cupolas.

### **Integration of Cogeneration Systems**

Many engineering techniques addressing the principle of preheating the combustion reactant feed (especially the oxidant, because its volume generally dominates the reactant mixture) are in practice.

Three categories represent a majority of these techniques:

1. Using the stack exhaust to indirectly (e.g., with a shell and tube exchanger) heat the air/oxidant feed line.
2. Burner tip techniques that often incorporate ceramics to maintain the final mixing chamber at extremely high temperature, thereby heating the reactants immediately prior to ignition.
3. Using high temperature, high oxygen content, waste-heat streams as a combustion reactant/oxidant (as the DG cogeneration system would offer).

In general the cogeneration based oxidant system is highly competitive for these options when:

1. The process operation is operated such that its own exhaust is either low in temperature or low in excess oxygen.
2. The process operation uses coal (or other fuels releasing soot and sulfur in the exhaust) as a fuel. In such cases cogeneration offers both a relatively clean preheated feed (so as not to foul the burner equipment) and also reduces the amount of sulfur and particulate released (by reducing the amount of coal needed).

If a system's burner was initially designed for low temperature air feeds, more heat durable components may be needed to handle a hot oxidant. The difference in oxygen content also needs careful consideration to properly engineer the combustion system.

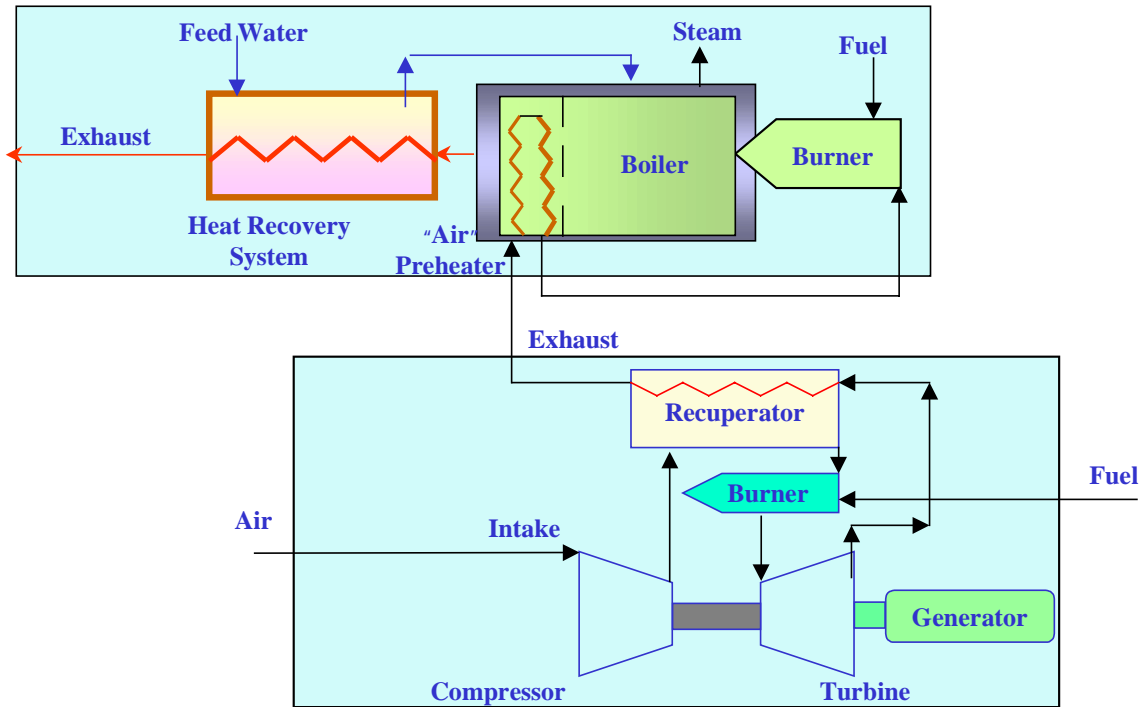


Figure 15. Exhaust Gas as an Oxidant System for Boiler Systems

### General Cogeneration Integration Considerations

Integration into a specific manufacturing facility will always require further site-specific analyses. However, there are several general considerations pertinent to determining how a specific existing operation is altered (from an engineering perspective) when driven or partially supported through cogeneration.

1. *Heat transfer rates* to the process media are often reduced when using exhaust (the typical heat media from a cogeneration unit) as opposed to a burner-based operation (e.g., a process furnace). Though the quantity of heat energy available from a DG unit is often sufficient to maintain a process operation from an energy balance standpoint, the dynamics (temperature and energy transfer profiles) can be significantly different. This is because high temperature (1500-4000°F), luminous flames induce radiant based heating (rays of energy moving at the speed of light), whereas cogenerated exhaust energy ranges from 450-1100°F and moves via convection-conduction only. A common remedy is an increase in the heat transfer area (and therefore the equipment size).
2. *Batch systems* and other operations with non-constant temperature/energy requirements, including fermentation, reactor, and mixing vessels, are often dependent upon dynamic heating systems to accommodate “cold” start-ups, and varying endo/exo-therms and temperature profiles. These systems are not always ideal for cogeneration schemes.
3. *Auxiliary burners*, or maintaining the existing burner system (depending on its flexibility), can increase the flexibility and therefore applications of cogeneration systems. The primary driver for investing in a distributed generation (leading to a cogeneration option) unit is the electricity output. Constant electrical delivery typically results in constant heat delivery (although variations in heat recuperation, fuel feed, etc. can allow for some flexibility). However, for a process such as the batch systems addressed above, there may be a row of three burners heating the vessel. If a “batch” cycle

ran one hour, needing all three burners for the first 20 minutes, and one or two thereafter, a steady cogenerated heat stream could replace the “one or two” burners needed constantly, while the third would remain to maintain the initial per-batch heat requirement.

4. *Controls systems* monitoring and maintaining operations incorporating a cogeneration scheme may need to be modified or completely re-engineered. Automated control systems on a typical burner based system will monitor one or more parameters of the process and then adjust fuel/oxidant feeds to the burner accordingly. If a system is heated via exhaust from a cogeneration scheme, the control system might include a by-pass system (e.g., a recuperator) or on/off auxiliary burner concepts.

## Generic Thermal Process by Industry

Table 2 shows the applicability of each generic thermal process to each manufacturing sector.

**Table 2. Thermal Processes by Industry**

Industry	Direct Contact Water Heater	Indirect Liquid Heating	Direct Heating Drying	Indirect Air/Gas Heating	Refrig Freeze	Dehumidification	Exhaust Gas Oxidant (non-boiler)	Exhaust Gas Oxidant (boiler)
20 – Food	X	X	X	X	X	X	X	X
21 – Tobacco			X		X			X
22 – Textiles	X		X	X				X
23 – Apparel	X							X
24 – Wood	X		X					X
25 – Furniture	X							X
26 – Paper	X	X	X				X	X
27 – Printing	X	X	X		X		X	
28 – Chemical	X	X	X	X	X	X	X	X
29 – Petroleum		X	X		X	X	X	X
30 - Rubber Plastics	X	X	X	X	X			X
31 – Leather	X							X
32 - Stone Clay Glass	X	X	X				X	X
33 - Prim Metals	X	X	X		X	X	X	X
34 - Fab Metals	X	X	X	X			X	
35 – Machinery	X	X	X				X	
36 – Electronics	X							
37 – Transport	X							
38 – Measuring Equipment	X							X
39 - Misc.	X							

Table 3 shows significant thermal processes by 4-digit SIC, describes each process step in more detail, and gives an indication of temperature ranges for each process.





*Assessment of Replicable Innovative Industrial Cogeneration Applications*

**Table 3. Thermal Processes by Industry**

SIC	Industry Sector	Direct Contact Water Heater		Indirect Liquid Heating		Direct Heating Drying		Indirect Air/Gas Heating		Refrigeration/Freezing		Dehumidification		Exhaust Gas Oxidant	
		Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F
2221-62	Textile mill products	Dye and wash	140			Singeing	400	Singeing	401						
2221-62	Textile mill products	Washing	180			Drying	250								
2400	Lumber & wood products													Supplemental burn (low emissions)	
2421	Saw mills etc.					Kiln drying	120-180								
2430	Plys & structural			Molds/Presses (thermal fluids)											
2499	Fiberboard					Stabilization/drying	350								
2500	Furniture													VOCs reduction (paints, solvents, etc.)	
2600	Paper & allied products														
2600	Non-integrated finishing plants													VOCs reduction	
2611	Pulp Mills (Kraft, sulfite and mechanical process)	Washing of pulp stock	900-100			Drying	151-240							Lime kilns	1200
2620-30	Paper (paper board) mills – integrated plants	Washing of pulp stock	90-101			Drying	151-240							Lime kilns	1200
2670	Coated & laminated			Laminate setting/ finish cure (thermals)											
2710-20-30-40-50	Newspaper, Periodicals, books, misc. publishing & general printing	General washing	100-120			Drying	150-200			Air Cooling	40-60			Thermal oxidizers	1400-1600
2750	Commercial printing – gravure			Finish drying/curing (thermal)											
2812	Alkalies and Chlorine			Brine heater	160					Chlorine condenser				Lime kiln	1600-1800
2812	Alkalies and					Drying	180							Calcliner for	650

*Assessment of Replicable Innovative Industrial Cogeneration Applications*

**Table 3. Thermal Processes by Industry**

SIC	Industry Sector	Direct Contact Water Heater		Indirect Liquid Heating		Direct Heating Drying		Indirect Air/Gas Heating		Refrigeration/Freezing		Dehumidification		Exhaust Gas Oxidant	
		Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F
	Chlorine													NAHCO3	
	Anhydrous caustic soda			Evaporators (thermal)	700										
2813	H2 generation – steam reformer			Ammine solution reactivator	220									Reformer heating	1500-1600
2813	H2 generation – steam reformer													CO converter	800
2816	Inorganic pigments	Washing	120-140			Pigment (spray) dryer	325 - 1200			Chilled water	40			Ti O2 Heater & Vaporizer	1120
2816	Inorganic pigments													O2 Heater	1120
2819	Inorganic chemicals	Ore leaching	180			Drying	250-350							Calciner – TiO2	1500
	Sodium tripolyphosphate					Spray dryer									
2821	Plastic resins			Hot oil for heating	400-450	Drying	250-350								
2821	PVP & PVC emulsion					Spray dryers	300-400								
2821	LDPE, polystyrene			Various equipment (thermal fluids)	600-800										
2821	PTA			Preheat hydrogeneration feed (thermals)	700									CTA & vent gas (VOCs) incineration	
2822	Synthetic Rubber					Storage heating	200-250			Emulsion reactor	40				
2822	Synthetic Rubber					Drying	180			Chilled water for extruders mixers etc.	40				
2822	Synthetic Rubber	Preheaters (Ethylene)	120			Pre-heaters (Ethylene)	120								
2823	Manmade fibers	Hot water for washing – fibers	180-200			Drying	120-200								
2823	Manmade fibers	Pulp preheating	90-100			Pulp preheating	90-100								
2824	Organic fibers					Drying	120							Reactor heating	450-500
2824	Polyester, nylon 6-6			Melters, evaps, etc. (thermals)	400-1000	Melter	320							Polymer melter	450
2824	Polyester, nylon 6-6					Drying	150							Polymerizer	540



*Assessment of Replicable Innovative Industrial Cogeneration Applications*

**Table 3. Thermal Processes by Industry**

SIC	Industry Sector	Direct Contact Water Heater		Indirect Liquid Heating		Direct Heating Drying		Indirect Air/Gas Heating		Refrigeration/Freezing		Dehumidification		Exhaust Gas Oxidant	
		Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F
	processing						450								
2911	Reforming													Heating	1100-1400
2911	Alkylation									Vapor condens.	-10 – 40	Dehumid of feed	Ambient		
2911	Recovery boiler													CO burning	1000-1600
2950	Asphalt			Heating	250-350	Drying process	250-400							VOC reduction	
2990	Misc. petroleum			Heating	250-350									VOC reduction	
3069	Fabricated rubber			Thermal fluids	350-600	Drying	120-150			Chilled water	40				
3069	Plastics products			Thermal fluids	350-600	Lamin., cast, mold	250-350			Chilled water	40				
3069	Tire recycling			Melting											
3221 3222	Glass					Cullet drying preheating	250-1000							Annealing	900-1000
3221 3222	Glass													Tempering	1300-1600
3221 3222	Glass													Laminating heating	1000-1100
3229	Fiber glass					Curing ovens	350-650							Curing ovens	350-650
3240	Cement	Hot water	120-140											Dryers, clinkers	
3250 3260	Clay products	Hot water	120-140			Spray dryers	300-1100								
3270	Concrete, gypsum, plaster	Hot water	120-140											Lime kilns	
3296	Mineral wool			Curing		Curing ovens	350-650							Curing ovens	350-650
3296	Mineral wool													Cupolas	
3310	Coke from coal					Pre-drying coal									
3310 3312	Blast furnaces steel mills	Pickling	160	Pickling	160	Scrap drying preheating	350-600	Blast furnace stove air preheat	200-800			Blast furnace dehumid.	75-90	Scrap preheat	1000-1200
3310 3312	Blast furnaces steel mills					Load preheating	250-600							Direct fired furnaces	600-2500
3310 3312	Blast furnaces steel mills					Ladle drying	300-400								
3313	Electromet. Products					Ore drying	300-400							Preheating kilns	1200-1600

**Table 3. Thermal Processes by Industry**

SIC	Industry Sector	Direct Contact Water Heater		Indirect Liquid Heating		Direct Heating Drying		Indirect Air/Gas Heating		Refrigeration/Freezing		Dehumidification		Exhaust Gas Oxidant		
		Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	Process Step	Temp °F	
3321	Iron foundries					Mold drying	500-600									
3321	Iron foundries					Core baking	400-450									
3321	Iron foundries					Sand reclamation	800-1200									
3321	Iron foundries					Heat treating tempering	300-900							Heat treating hardening forging	300-1600	
3334	Primary Al													Anode baking	500-2000	
3341	Secondary Al					Scrap drying preheating	350-600							Melting furnace	1250-1350	
3341	Secondary Al					Solution treatment furnaces	350-400			Quench medium cooling	40-60			Direct fired homogen. Furnaces	350-1000	
3341	Zinc					Sweating furnace	1000							Melting furnace	1000	
3341	Zinc					Mold preheating	250-400							Distillation furnace	2400	
3341	Copper					Scrap drying preheating	350-600							Sweating furnace	1000-1100	
3341	Copper													Melting refining furnace	2000-2400	
3353	Al sheet, plate, foil			Preheat with thermal fluids										Melting refining furnace	1200-1400	
3353	Al sheet, plate, foil					Annealing	400-700							Annealing	400-1000	
3460	Forging					Preheat	600-1400							Preheat	600-1400	
3460	Forging					Annealing	400-700							Heat treatment	1000-1600	
3479	Metal coating					Sheet drying	150-200									
35	Machinery					Paint drying	200-350								Heat treatment	1000-1600
35	Machinery			Parts washing and rinsing	140-160	Parts drying	160-200								VOC reduction (painting)	
36	Electronics											Clean rooms	Ambient			

## Selecting the Top 5 Cogeneration Applications

The seven broad categories of thermal applications were broken into more specific categories (e.g., breaking *direct heating and drying* into subcategories such as *spray drying*) so that replicability could be estimated by approximating the total U.S. annual energy consumption of each specific process. Table 4 ranks the specific thermal process categories by total U.S. annual energy consumption.

**Table 4. U.S. Annual Energy Consumption for Each Process**

Technology Group	Process Step Aided	SIC	Product	Tbtu per year	
(1) exhaust as oxidant	heating	2911	atm & vacuum distillation	113.50	
	methane reformer	2873	ammonia	71.49	
	H2 feedstock reformers	2911	refineries	66.17	
	heating	2911	catalytic reforming	52.00	
	heating	2911	coking	25.75	
	lime kilns	2611-30	paper mills integrated	22.00	
	reformer heating	2813	merchant inorganics gases	22.00	
	reformer	2869	methanol	17.74	
	melting/refining furnace	3353	aluminum sheet, foil, etc	5.55	
	slab/billet/etc. preheat	3354	aluminum sheet, foil, etc	2.99	
	melting furnace	3341	secondary aluminum	2.27	
	annealing	3221	container glass	1.64	
	preheating kilns	3313	electrometallurgical prods	1.45	
	tempering	3211	flat glass	1.20	
	heating	2911	vis breaking	1.00	
	Lime kiln	2063	beet sugar	0.76	
	Annealing	3211	flat glass	0.38	
	Laminating/heating	3211	flat glass	0.18	
				<b>Category (1) Total</b>	<b>408.06</b>
	(2) direct contact water heater	Pulp wash	2620-30	integrated paper mills	227.43
Mingle, melt, etc		2060	sugar & confectionery	48.16	
pickling op.		3312	blast furnace steel	32.37	
container wash		2834	pharmaceutical	22.00	
process water		2082	malt beverages	21.26	
dye/wash		2200	textile	18.28	
pulp wash		2611	pulp mills	13.77	
ore leaching		2819	inorganic chemicals	6.06	
washing		2026	fluid milk processing	3.92	
				<b>Category (2) Total</b>	<b>393.25</b>
(3) indirect liquid heating - thermal fluid systems	setting laminates	2670	coated & laminated paper	49.24	
	isomerization/separations	2865	para xylene	31.43	
	molds/cures	3080	misc plastic products	24.74	
	various	2824	nylon 6,6	23.20	
	hot rolls	3350	nonferrous roll/draw	16.12	
	recovery, purify	2834	pharmaceutical preps	14.21	
	molds/cures	3010	tires & tubes	12.74	
	hydrogenation feed	2821	terephthalic acid (PTA)	11.70	
	separations/recovery	2865	styrene	10.73	

*Assessment of Replicable Innovative Industrial Cogeneration Applications*

Technology Group	Process Step Aided	SIC	Product	Tbtu per year
	high T calenders/rollers	2600	pulp finishing	10.00
	fryer	2096	potato/corn chips	9.97
	heater/melter	2824	polyester fiber	9.47
	hot rolls/ink press	2754	gravure, comm. printing	5.84
	various	2821	LD polyethylene	4.24
	various	2821	polystyrene	4.17
	curing/finishing	3296	fiberglass insulation	2.68
	evaps/crystallizers	2819	calcium chloride, anhyd.	2.16
	storage/pumping	2950	asphalt	1.16
	evaps/crystallizers	2812	caustic soda, anhydrous	0.64
	fryer	2099	french fries	0.61
	melters/heaters	2869	caprolactam	0.56
	storage/pumping	2080	beverages	0.48
	fryer	2092	prepared fish	0.45
	fryer	2051	doughnuts	0.39
	storage/pumping	2060	sugar and confectionery	0.28
	storage/pumping	2070	fats and oils	0.19
	fryer	2051	snack pies	0.10
	storage/pumping	2850&91	paints & allied products	0.06
				<b>Category (3) Total</b>
(4) exhaust as oxidant - mixing with combustion air &/or apart of an air/fuel staging scheme all for energy savings and lower emissions	dryers and clinkers	3240	cement manufacture	41.50
	Kilns	3270	lime (dolomite, etc)	21.60
	central furnaces/boilers & dryers	2400	lumber and wood products	4.24
	cupolas	3296	mineral wool	0.40
	central boilers	2600	pulp mills	116.40
				<b>Category (4) Total</b>
(5) indirect air heating - process 'ovens'	baking ovens	2050	bakery goods	33.68
	finish drying (paint)	3700	transportation equipment	30.00
	finish drying and curing	3470	coating, engraving etc	18.09
	finish drying	3500	industrial machinery	18.00
	finish drying (paint) and curing	3411	metal cans	17.08
	coffee roaster	2090	coffee manufacture	3.29
	cocoa roaster	2060	chocolate manufacture	3.10
	finish drying	3600	electronics, etc.	3.00
				<b>Category (5) Total</b>
(6) direct dry - spray drying	Spray drying	3255	kaolin clay	37.60
	Spray drying	2023	dried milk	9.79
	Spray drying	3253	ceramic slips	9.32
	Spray drying	2841	soaps & detergents	9.30
	Spray drying	2816	inorganic pigments	4.75
	Spray drying	2819	Na tripolyphosphate	1.76
	Spray drying	3255	fluid cracking catalysts	0.80
	Spray drying	2865	inorganic dyes/pigments	0.50
	Spray drying	2821	emulsion PVC	0.30
	Spray drying	2821	PVP	0.01
				<b>Category (6) Total</b>



*Assessment of Replicable Innovative Industrial Cogeneration Applications*

Technology Group	Process Step Aided	SIC	Product	Tbtu per year
(7) direct dry - conveyor	drying	2822	PBR	16.44
	drying	2822	BR	13.00
	drying	2822	PI	4.89
	drying	2822	EPR	2.27
	drying	2822	SBR	2.04
				<b>Category (7) Total</b>
(8) direct dry - metals drying	parts drying	3479	metal services	21.56
	scrap/load dry/preheat	3312	blast furnace steel	8.30
	scrap dry/preheat	3341	secondary aluminum	4.69
	ore drying	3313	electrometallurgicals	0.73
	scrap dry/preheat	3341	copper	0.34
				<b>Category (8) Total</b>
(9) indirect liquid heating - chemicals reactor	cracker furnace, recovery, etc	2869	vinyl chloride monomer	23.50
	reactor furnace	2869	methanol	6.00
			<b>Category (9) Total</b>	<b>29.50</b>
(10) indirect liquid heating - chemical separations	distillation, recovery equipment	2865	p-xylene	3.69
	distillation, recovery equipment	2865	styrene	7.00
	distillation, recovery equipment	2869	acetic acid	10.24
	distillation, recovery equipment	2869	propylene oxide	3.30
	heaters and separation equip.	2869	acrylonitrile	1.00
	heaters and separation equip.	2869	caprolactam	0.67
	heaters	2824	olefin fibers	1.00
				<b>Category (10) Total</b>
(11) preheating VOC exhaust prior to incineration	distillation & reactors off vents	2800	organic chemicals	11.81
	solvents, laminates, inks	2600	non-integrated paper finishing mills	2.43
	finishing' process vents	2821-24	resins and manmade fibers	1.79
	VOCs off paint-label dryers	30	plastic/rubber products finishing	1.45
	VOCs off finishing op's	3710	motor vehicles	1.18
	cleaning/paints solvent VOCs	3400	fabricated metal products	0.83
	VOCs off dryers, storage, etc	2950/90	asphalt roofing materials	0.76
	odors, cleaning solvents	2000	foods manufacture	0.74
	solvent, paint, coating	2500	furniture finishing	0.66
	solvents, laminates	2700	printing/publishing establishments	0.31
	coating/finishing solvents	2200	textile manufacturing	0.24
	general VOCs reduction	2851	paints & varnishes	0.11
	glues, solvents	2400	lumber and wood products	0.11
	paints	3600	electronics, etc.	0.09
				<b>Category (11) Total</b>
(12) direct dry - curing	curing ovens	3296	mineral wool, etc	10.11
	curing ovens	3229	fiber glass	7.92
			<b>Category (12) Total</b>	<b>18.03</b>
(13) direct dry - kiln	kiln dryer	2063	beet sugar	16.23
			<b>Category (13) Total</b>	<b>16.23</b>

*Assessment of Replicable Innovative Industrial Cogeneration Applications*

<b>Technology Group</b>	<b>Process Step Aided</b>	<b>SIC</b>	<b>Product</b>	<b>Tbtu per year</b>
(14) direct dry	drying	2834	pharmaceutical preps	12.71
			<b>Category (14) Total</b>	<b>12.71</b>
(15) refrigeration and freezing	cool after pasteurizing & storage	2026	fluid milk processing	4.67
	cooling, fermentation, etc	2082	malt beverages	3.22
	cooling & refrigeration	2822	synthetic rubber	1.29
	storage	2100	tobacco products	0.12
			<b>Category (15) Total</b>	<b>9.30</b>
(16) direct dry - pulp drying	infrared drying	2600	paper finishing mills	2.00
			<b>Category (16) Total</b>	<b>2.00</b>
(17) direct dry - storage conditioning	storage heating	2822	SBR	0.75
			<b>Category (17) Total</b>	<b>0.75</b>
(18) direct dry	ethylene preheaters	2822	EPR	0.44
			<b>Category (18) Total</b>	<b>0.44</b>
(19) direct dry - granulators/dryers	granulator/dryers	2063	beet sugar	0.25
	granulator/dryers	2062	cane sugar refining	0.09
			<b>Category (19) Total</b>	<b>0.35</b>
(20) desiccant based dehumidification	space conditioning	2060	sugar & confect. prods.	
	QC	2834	pharmaceutical prep	
	feed dehumidification	2911	alkylation step	
	blast-furnace air feed	3312	steel mills (blast based)	
			<b>Category (20) Total</b>	<b>Data not available</b>

Central boiler systems are not included in Table 4, but initial estimations show they offer the largest energy savings opportunity. The top five applications were determined in terms of replicability (energy savings across all applicable SICs), innovation, and ease of integration into a cogeneration systems. The five cogeneration systems that will be analyzed in the market assessment are:

- Direct contact water heaters,
- Indirect liquid heating,
- Convection ovens used for metals fabrication preheating,
- Indirect air heating, and
- Exhaust gas as an oxidant for central boiler systems.

## Market Assessment Model Input Parameters

A number of input parameters are required by the model to estimate the economic market potential for each application. The following tables summarize these parameters for each application.

### Direct Contact Water Heaters

For this application, a direct contact water heater fired with the turbine/engine exhaust is replacing a conventional water heater. For the reciprocating engine-driven system, engine jacket cooling water is also used to supply hot water.

**Table 5. Direct Contact Water Heater – Input Parameters**

	Size Range (kW)				
	25-75	75-150	150-400	400-800	800-100
<b>Recuperated Turbine</b>					
Installed Cost (\$/kW)	2,410	1,565	1,203	1,053	994
Heat Rate (Btu/kW)	13,200	13,200	13,200	10,434	10,434
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.009
Usable Exhaust Energy (mBtu/hr/kW)	7.5	7.5	7.5	5.72	5.72
<b>Unrecuperated Turbine</b>					
Installed Cost (\$/kW)	2,070	1,318	978	838	620
Heat Rate (Btu/kW)	26,246	26,246	26,246	14,519	13,123
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.004
Usable Exhaust Energy (mBtu/hr/kW)	20.80	20.80	20.80	8.62	8.62
<b>Reciprocating Engine</b>					
Installed Cost (\$/kW)	N/A	1,237	961	772	671
Heat Rate (Btu/kW)	N/A	11,006	10,340	9,748	8,978
O&M (\$/kWh)	N/A	0.01	0.0085	0.008	0.0075
Usable Exhaust Energy (mBtu/hr/kW)	N/A	3.33	2.58	2.16	1.45
Usable Cooling Water Energy (mBtu/hr/kW)	N/A	3.5	3.5	3.5	3.5
Existing Thermal System Eff.	0.85				

## Indirect Liquid Heating

For this application, an indirect liquid heating system fired with turbine/engine exhaust replaces a conventional burner-fed system. For the reciprocating engine driven system, engine jacket cooling water is used to supply hot water to other applications at the site.

**Table 6. Indirect Liquid Heating – Input Parameters**

	Size Range (kW)				
	25-75	75-150	150-400	400-800	800-100
<b>Recuperated Turbine</b>					
Installed Cost (\$/kW)	1,700	1,196	950	870	839
Heat Rate (Btu/kW)	13,200	13,200	13,200	10,434	10,434
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.009
Usable Exhaust Energy (mBtu/hr/kW)	5.08	5.08	5.08	4.54	4.54
<b>Unrecuperated Turbine</b>					
Installed Cost (\$/kW)	1,380	954	728	657	467
Heat Rate (Btu/kW)	26,246	26,246	26,246	14,519	13,123
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.004
Usable Exhaust Energy (mBtu/hr/kW)	17.94	17.94	17.94	8.46	7.32
<b>Reciprocating Engine</b>					
Installed Cost (\$/kW)	N/A	874	711	590	518
Heat Rate (Btu/kW)	N/A	11,006	10,340	9,748	8,978
O&M (\$/kWh)	N/A	0.01	0.0085	0.008	0.0075
Usable Exhaust Energy (mBtu/hr/kW)	N/A	2.83	2.09	1.79	1.18
Usable Cooling Water Energy (mBtu/hr/kW)	N/A	3.5	3.5	3.5	3.5
Existing Thermal System Eff.	0.66				

## Convection Ovens

For this application, a convection oven system direct-fired with the turbine/engine exhaust replaces a conventional burner-fed system. For the reciprocating engine driven system, engine jacket cooling water is used to supply hot water to other applications at the site.

**Table 7. Convection Oven – Input Parameters**

	Size Range (kW)				
	25-75	75-150	150-400	400-800	800-100
<b>Recuperated Turbine</b>					
Installed Cost (\$/kW)	1,050	905	764	743	735
Heat Rate (Btu/kW)	13,200	13,200	13,200	10,434	10,434
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.009
Usable Exhaust Energy (mBtu/hr/kW)	5.08	5.08	5.08	4.54	4.54
<b>Unrecuperated Turbine</b>					
Installed Cost (\$/kW)	810	691	557	538	377
Heat Rate (Btu/kW)	26,246	26,246	26,246	14,519	13,123
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.004
Usable Exhaust Energy (mBtu/hr/kW)	17.94	17.94	17.94	8.46	7.32
<b>Reciprocating Engine</b>					
Installed Cost (\$/kW)	N/A	615	542	473	421
Heat Rate (Btu/kW)	N/A	11,006	10,340	9,748	8,978
O&M (\$/kWh)	N/A	0.01	0.0085	0.008	0.0075
Usable Exhaust Energy (mBtu/hr/kW)	N/A	2.83	2.09	1.79	1.18
Usable Cooling Water Energy (mBtu/hr/kW)	N/A	3.5	3.5	3.5	3.5
Existing Thermal System Eff.	0.88				

## Indirect Air Heating

For this application, an indirect air heating system using an air to air heat exchanger fired with the turbine/engine exhaust replaces a conventional burner-fed system. For the reciprocating engine driven system, engine jacket cooling water is used to supply hot water to other applications at the site.

**Table 8. Indirect Air Heating – Input Parameters**

	Size Range (kW)				
	25-75	75-150	150-400	400-800	800-100
<b>Recuperated Turbine</b>					
Installed Cost (\$/kW)	1,641	1,176	940	865	836
Heat Rate (Btu/kW)	13,200	13,200	13,200	10,434	10,434
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.009
Usable Exhaust Energy (mBtu/hr/kW)	5.08	5.08	5.08	4.54	4.54
<b>Unrecuperated Turbine</b>					
Installed Cost (\$/kW)	1,341	943	722	654	469
Heat Rate (Btu/kW)	26,246	26,246	26,246	14,519	13,123
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.004
Usable Exhaust Energy (mBtu/hr/kW)	17.94	17.94	17.94	8.46	8.46
<b>Reciprocating Engine</b>					
Installed Cost (\$/kW)	N/A	864	706	589	517
Heat Rate (Btu/kW)	N/A	11,006	10,340	9,748	8,978
O&M (\$/kWh)	N/A	0.01	0.0085	0.008	0.0075
Usable Exhaust Energy (mBtu/hr/kW)	N/A	2.83	2.09	1.79	1.18
Usable Cooling Water Energy (mBtu/hr/kW)	N/A	3.5	3.5	3.5	3.5
Existing Thermal System Eff.	0.48				

## Exhaust Gas as an Oxidant to Boiler Systems

For this application, exhaust gases from the turbines are used as an oxidant for the boiler burners and are retrofitted to conventional boilers.

**Table 9. Exhaust Gas as an Oxidant to Boiler Systems – Input Parameters**

	Size Range (kW)				
	25-75	75-150	150-400	400-800	800-100
<b>Recuperated Turbine</b>					
Installed Cost (\$/kW)	2,195	1,454	1,127	998	948
Heat Rate (Btu/kW)	13,200	13,200	13,200	10,434	10,434
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.009
Usable Exhaust Energy (mBtu/hr/kW)	8.73	8.73	8.73	6.4	6.4
<b>Unrecuperated Turbine</b>					
Installed Cost (\$/kW)	1,865	1,210	904	785	576
Heat Rate (Btu/kW)	26,246	26,246	26,246	14,519	13,123
O&M (\$/kWh)	0.01	0.01	0.009	0.009	0.004
Usable Exhaust Energy (mBtu/hr/kW)	21.33	21.33	21.33	10.28	8.96
Existing Thermal System Eff.	0.85				

*Installed Costs* are based on packaged generator cost (shown earlier in the report), thermal system retrofit, engineering, and installation. Cost is also based on the following assumptions.

- In all cases, except direct contact water heating, the system will be retrofitted to an existing host system.
- A "standard" engineering package is available for the replicable applications. This package includes a bill of material, component sizing methodology or tool, and a list of suppliers for necessary components.
- Installation of the system does not require significant changes in installation drawings and design.
- Installation does not require major structural change for the host system or the plant itself.
- It will not be necessary to spend significant resources for permits or variances from the regulatory agencies or utility companies.

In each case the hardware cost estimates are based on information obtained from the equipment or hardware supplier. Installation cost includes cost of minor changes of standardized installation engineering drawings and labor cost for the retrofit. This cost is obtained from several sources such as the equipment supplier, engineering consulting companies and installation contractors.

In case of direct contact water heater, a new water heater is used to accommodate larger mass flow compared to that in case of a direct fired unit, where a small burner is used to supply heat. The installation cost includes water piping, safety system installation, controls and other hardware.

Direct injection of gases in an oven requires installation of duct work to an existing oven, a pressure control system, and a gas by-pass system together with modification to the oven walls to allow for the gas introduction.



For the indirect (water) liquid and gas heating system, the system cost includes purchase of an appropriate heat exchanger, exhaust gas connections, the fluid exit-entry connections, and associated control system.

In case of boiler applications, the cost includes modifications to the existing burner and air supply system to allow for introduction of turbine exhaust gases, proper piping systems, changes in the control system for air-fuel ratio, and pressure control system if necessary.

The cost numbers for hardware and installation should be considered as “typical”, and should not be used as "standard" costs. The cost can vary significantly depending on the type of host process and its operating parameters, location of the system, and age of the system. It is necessary to carry out such a cost analysis for each individual application.

Engineering cost is based on the assumption that a "standard" engineering package is available for the replicable applications. This package includes a bill of material, component sizing methodology or tool and a list of suppliers for necessary components.

**Heat Rate** and **O&M** data is based on data from equipment manufacturers.

**Usable Exhaust Energy** is calculated by making a comparison between the performances of two self-standing systems, (i) gas turbine and (ii) process heating system - termed as the "host" system, with an integrated system in which turbine exhaust gases are used to supply additional process heat and reduce heat input in the host system. Turbine performance data is supplied by manufacturers and is used to calculate the following parameters for the turbine exhaust gases:

- Mass flow rate,
- Heat content,
- Oxygen content, and
- Power generated by the turbine.

In case of the host system, the following parameters are used to calculate heat demand and efficiency of the system:

- Process temperature,
- Process heat demand,
- Process exhaust gas oxygen (or excess air used for combustion), and
- Combustion air temperature.

Heat (fuel) consumption calculations for the host system used in the combined system assume that net heat supplied to the process is the same as in the case of the self standing heating system. These calculations involve heat balance for the host system, accounting for additional heat from the turbine exhaust gases and allowances for efficiency of the host system.

## **Market Assessment Methodology**

The analysis was performed using Resource Dynamics Corporation's DIStributed Power Economic Rationale SElection (DISPERSE) model, which estimates the achievable economic potential for cogeneration by comparing the on-site generation economics with competing grid prices. The analysis determines whether on-site cogeneration appears to be more cost effective than purchasing from the grid, and also which technology and size appears to be the most economic for a given application. This model has been developed over the past ten years, and has been applied on a variety of projects for utilities, equipment manufacturers, and research organizations. The following key inputs are used by the model:

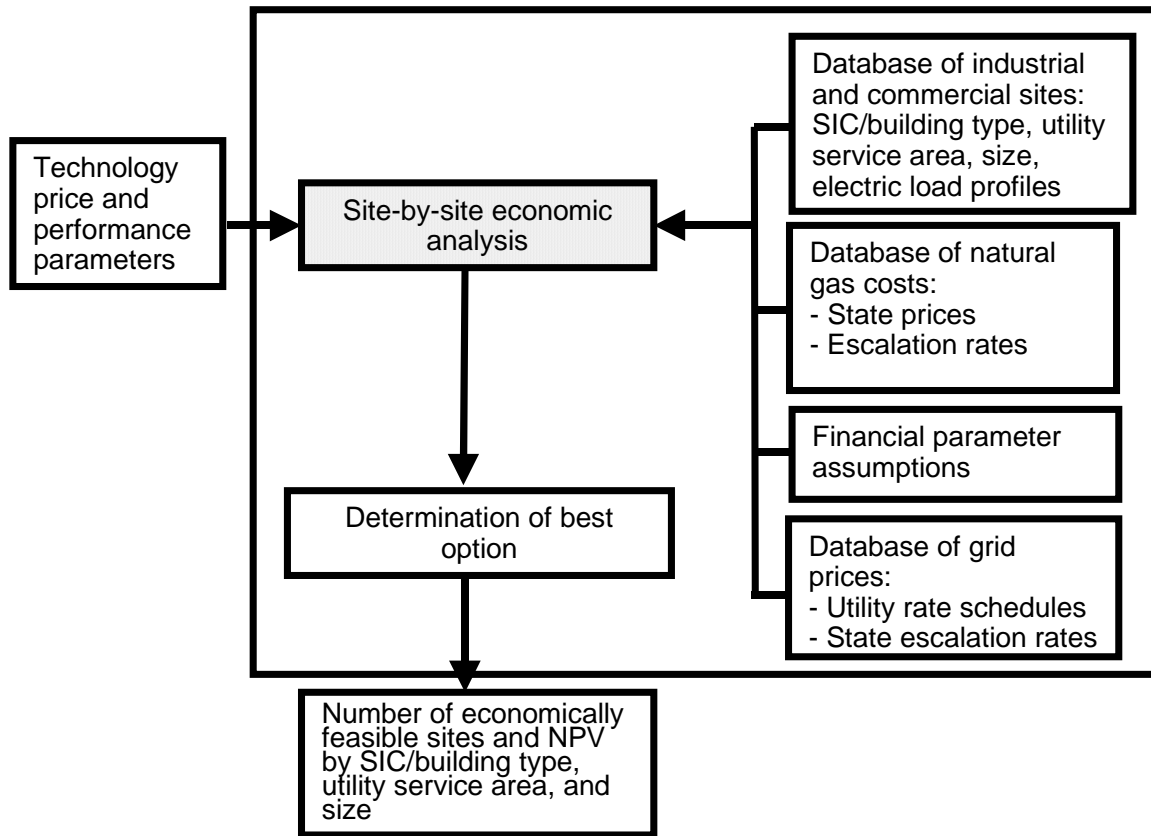
1. **Technology price and performance parameters.** The model requires price and performance data on the mix of technologies that are available for each cogeneration application being analyzed. This data includes the technology's installed cost, fuel type, heat rate, electrical efficiency, useable thermal output, fixed and variable operating and maintenance costs, and other key parameters.
2. **Database of industrial sites.** Data on industrial sites by SIC, size, and utility service area come from the County Business Patterns.
3. **Database of fuel prices.** Natural gas costs are based on state prices for the industrial sector, as reported by the Department of Energy's Energy Information Administration (EIA). Base rates are from 1999. Natural gas escalation rates are based on regional EIA projections from the 1999 Annual Energy Outlook. Using 1999 base and escalation rates eliminates the price spikes of 2000. Rates range from a high of \$8.24/MCF for Hawaii to a low of \$1.25/MCF for Alaska. Annual escalation rates range from a high of 5.72% for states in the Mountain region to a low of 0.58% for states in New England.
4. **Financial parameter assumptions.** Ownership parameters are based on RDC experience with typical DG projects and expectations for financial structures of projects in the future.
5. **Site characteristics.** Site characteristics include electric and thermal load profiles from RDC databases.
6. **Database of grid prices.** Rate schedules of the 68 largest electric utilities (in terms of GWh sales to industrial customers) representing over two-thirds of deliveries to the industrial sectors were utilized and are shown in Table 11. Rate structures are from 1999. Customers in counties not served by the largest utilities were assigned a regional rate schedule derived from schedules of major utilities within that region. Escalation rates are based on regional EIA projections from the Supplement to the Annual Energy Outlook, as projected in 1999. Backup charges are included at \$50/kW annually (or \$4.20/kW/month). Since actual rate structures were used, rates differ depending on customer size and load profile. For a customer in SIC 20 (Food) with a peak demand of 1.5 MW, rates range from just over \$0.03/kWh in low priced areas to over \$0.08/kWh. Annual escalation rates range from 0.48% to a high of 2.35%.
7. **Financial parameter assumptions.** Table 10 contains a list of financial assumptions. A project life of 10 years is assumed, reflecting the anticipated life of smaller DG projects and conservative financial planning from customers. Units are expected to be funded by the customer from their operations. Taxes and insurance are included, as well as costs of standby power. There are no sales of excess electricity back to the grid.

**Table 10. Financial Parameter Assumptions**

Project Length (years)	10
Federal Income Tax (%)	35
State Income Tax (%)	5
Property Tax and Insurance (%)	2
Discount Rate (%)	8

The model run begins with a database of industrial sites, which are organized by utility service area, SIC code, and size. In addition, based on the site SIC code/building type, a load profile (both thermal and electric) that is representative of that segment is assigned. The size of the facility is used to scale up or down the magnitude of the load profile.

Using data on number of facilities in each size range in each utility service area, the number of potential applications is determined. Results are aggregated and summarized to show key information on where the potential applications are. Figure 16 provides an overview of the model inputs, analysis, and outputs.



**Figure 16. DISPERSE Model**

Using this information, combined with the unit price and performance data, the model performs a life-cycle cost economic analysis, based on the unit life, electric utility rate schedules, and state fuel prices. The model determines whether the cogeneration system can beat the base case in which all power is purchased from the host utility. The best technology option is selected based on highest net present value (NPV). This process occurs for each group of sites within each

combination of the same utility service area/size range/sector in the database of industrial sites, and the results are then aggregated to obtain market potential.

To give an example of the competing grid prices and natural gas prices that were used in the assessment, for a customer in SIC 20 (Food) in Illinois Power Company's service territory with a peak demand of 700 kW, competing grid prices were \$0.055/kWh and gas prices were \$4.06/MCF. Annually escalation rates were 1.33% for electricity and 3.66% for gas.

**Table 11. Utilities Included in DISPERSE**

Alabama Power Co	Oklahoma Gas & Elec Co
Appalachian Power Co	Pacific Gas & Electric Co
Baltimore Gas & Electric Co	PacifiCorp
Carolina Power & Light Co	PECO Energy Co
Central Power & Light Co	Pennsylvania Electric Co
Cincinnati Gas & Elec Co	Potomac Edison Co
Cleveland Electric Illum Co	PP&L Inc
Commonwealth Edison Co	PSI Energy Inc
Connecticut Light & Pwr Co	Pub Service Co of Colorado
Consumers Energy Co	Pub Svc Co of Oklahoma
Dayton Power & Light Co	Pub Svc Co of New Mexico
Detroit Edison Co	Pub Svc Electric & Gas Co
Duke Energy Corp	Puget Sound Energy Inc
Entergy Arkansas Inc	Sacramento Municipal Util
Entergy Gulf States Inc	Salt River Project
Entergy Louisiana Inc	San Antonio Pub Svc Bd
Florida Power and Light	South Carolina Elec&Gas
Florida Power Corp	S. Carolina Pub Svc Auth
Georgia Power Co	Southern California Edison
Green River Electric Corp	Southwestern Electric Pwr
Houston Lighting & Pwr Co	Texas Utilities Electric Co
Idaho Power Co	Toledo Edison Co
IES Utilities Inc	Tucson Electric Power Co
Illinois Power Co	Union Electric Co
Indiana Michigan Power Co	Virginia Electric & Pwr Co
Indianapolis Pwr & Light Co	West Penn Power Co
Kentucky Utilities Co	Wisconsin Electric Pwr Co
Massachusetts Electric Co	Wisconsin Pwr & Light Co
Memphis City of	
Metropolitan Edison Co	
MidAmerican Energy Co	
Minnesota Power Inc	
Mississippi Pwr Company	
Monongahela Power Co	
Nevada Power Co	
Niagara Mohawk Pwr Corp	
Northern Indiana Pub Serv	
Northern States Power Co	
Ohio Edison Co	
Ohio Power Co	

## Market Assessment Results

The model used to assess the total potential market for these system solutions shows the following economic market potential:

**Table 12. Summary Results by System Type**

Cogeneration Package Systems	Economic Market Potential (MWe)
Direct Contact Water Heater	2,435
Indirect Liquid Heaters	1,010
Convection Ovens for Metal Fab. Preheating	760
Indirect Air Heating	2,332
Central Boiler Systems	4,251
<b>Total</b>	<b>10,789</b>

The 10 states showing the highest economic market potential are:

**Table 13. Summary Results by State**

State	Economic Market Potential (MWe)
California	1,862
Texas	689
New Jersey	637
Michigan	624
New York	589
Ohio	516
Pennsylvania	501
Louisiana	410
Georgia	364
North Carolina	335
<b>Total</b>	<b>6,527</b>

Economic market potential broken down by prime mover size range is:

**Table 14. Summary Results by Size Range**

Size Range	Economic Market Potential (MWe)
25-75 kW	181
75-150 kW	664
150-400 kW	1,868
400-800 kW	2,106
800-1000 kW	5,970
<b>Total</b>	<b>10,789</b>

Economic market potential broken down by prime mover type is:

**Table 15. Summary Results by Prime Mover Type**

Prime Mover Type	Economic Market Potential (MWe)
Recuperated Turbines	829
Unrecuperated Turbines	5,166
Reciprocating Engines	4,794
<b>Total</b>	<b>10,789</b>

Economic market potential for the top four digit SIC codes by size range and top four-digit SIC codes by state are shown in Table 16.

**Table 16. Detailed Results by SIC/State (10 Sub-tables)**

**Direct Contact Water Heating Systems**

SIC	Sector Description	Total MWs	MW Potential per DG Size Range				
			25 - 75 kW	75 - 150 kW	150 - 400 kW	400 - 800 kW	800 - 1000kW
2819	Inorganic Chemicals, NEC	263	0.0	3.6	9.7	30.7	219.2
3465	Automotive Stampings	157	0.0	6.6	18.7	60.0	71.2
2026	Fluid Milk	110	0.1	4.4	13.4	63.3	28.4
2834	Pharmaceutical Preparations	106	0.7	7.4	20.0	29.4	48.6
3089	Plastic Products, NEC	102	0.0	7.3	11.5	41.2	42.0
2037	Frozen Fruits, Vegetables, & Juices	95	0.0	0.0	8.6	0.0	86.6
2086	Soft Drinks & Carbonated Water	75	0.3	8.2	22.0	31.8	12.6
3312	Steel Works & Mills	75	0.0	0.1	0.5	2.8	71.2
3471	Fabricated Metals: Plating, Polishing	67	0.4	23.4	36.0	0.0	7.4
2011	Meat Packing Plants	66	0.2	2.9	5.3	10.4	47.0
2676	Sanitary Paper Products	56	0.0	1.2	3.2	9.9	41.8
3625	Electronics: Relays & Controls	55	0.0	0.8	7.7	6.5	40.4
2048	Prepared Animal Feeds	55	0.9	0.0	40.1	12.0	1.5
3674	Semiconductors	52	0.0	1.9	1.3	9.4	39.1
2262	Finishers of Synthetic Fibers & Silk	50	0.0	1.2	3.4	24.1	21.4

SIC	Top Five States, per SIC, by Total Number of Potential Units									
2819	CA	41	NJ	31	LA	26	SC	25	TX	23
3465	MI	165	OH	43	IN	20	NY	8	PA	6
2026	CA	42	NY	26	MA	17	PA	14	TX	13
2834	NJ	46	CA	39	NY	35	CT	20	PA	10
3089	CA	147	NJ	91	AZ	17	CO	8	SC	6
2037	CA	27	ID	22	WA	20	FL	12	OR	8
2086	CA	45	NY	18	TX	14	GA	12	NJ	11
3312	PA	19	MI	9	TX	7	NY	6	IN	6
3471	CA	177	NY	40	CT	30	NJ	29	MI	28
2011	CA	12	TX	9	NE	7	CO	5	PA	5
2676	GA	8	WA	8	PA	8	WI	8	CA	7
3625	CA	33	WI	17	NY	15	NJ	6	OH	5
2048	CA	47	TX	20	NY	20	GA	16	AR	10
3674	CA	58	AZ	9	NJ	3	WA	0	OH	0
2262	SC	22	NC	12	NJ	10	MA	9	CA	6

**Indirect Fluid Heating Systems€**

SIC	Sector Description	Total MWs	MW Potential per DG Size Range				
			25 - 75 kW	75 - 150 kW	150 - 400 kW	400 - 800 kW	800 - 1000kW
3080	Plastic Products	218	1.7	17.0	33.4	92.4	75.4
2670	Converted Paper & Paperboard	214	3.3	30.5	66.8	58.8	58.4
2834	Pharmaceuticals	109	1.8	7.0	20.8	32.6	48.9
3350	NonFerrous: Rolling, Drawing, Extruding	77	0.0	0.0	13.2	26.2	37.2
2430	Veneer, Ply, & Structural Wood	69	0.7	0.0	37.9	15.7	15.0
2650	Paperboard Boxes	36	0.0	5.4	23.2	4.2	3.0
2096	Potato & Corn Chips	33	0.9	2.9	5.8	6.4	18.2
2080	Beverages	32	0.0	0.0	9.5	0.0	22.2
2754	Commercial Printing: Gravure	28	0.1	2.4	2.2	8.4	15.2
2620	Paper Mills	21	0.0	0.0	0.0	0.4	20.1
2676	Sanitary Paper Products	56	0.0	1.2	3.2	9.9	41.8
3625	Electronics: Relays & Controls	55	0.0	0.8	7.7	6.5	40.4
2048	Prepared Animal Feeds	55	0.9	0.0	40.1	12.0	1.5
3674	Semiconductors	52	0.0	1.9	1.3	9.4	39.1
2262	Finishers of Synthetic Fibers & Silk	50	0.0	1.2	3.4	24.1	21.4

SIC	Top Five States, per SIC, by Total Number of Potential Units									
3080	CA	267	NJ	163	NY	49	AZ	29	WI	23
2670	CA	104	NY	63	NJ	62	PA	53	OH	49
2834	NJ	71	CA	39	NY	35	CT	20	NC	11
3350	CA	29	NY	20	NJ	16	AZ	10	IN	6
2430	CA	56	AZ	28	WI	20	UT	12	ID	11
2650	NJ	43	CA	37	NY	21	UT	8	CT	7
2096	CA	18	PA	12	TX	5	OH	5	NY	5
2080	CA	28	NJ	12	CO	7	AZ	5	UT	2
2754	CA	8	NY	6	GA	6	VA	5	IN	4
2620	WI	12	CA	3	NJ	3	WA	1	OH	1
2676	GA	8	WA	8	PA	8	WI	8	CA	7
3625	CA	33	WI	17	NY	15	NJ	6	OH	5
2048	CA	47	TX	20	NY	20	GA	16	AR	10
3674	CA	58	AZ	9	NJ	3	WA	0	OH	0
2262	SC	22	NC	12	NJ	10	MA	9	CA	6

**Convection Oven Systems€**

SIC	Sector Description	Total MWs	MW Potential per DG Size Range				
			25 - 75 kW	75 - 150 kW	150 - 400 kW	400 - 800 kW	800 - 1000kW
3714	Motor Vehicle Parts	197	0.3	5.5	8.6	35.3	147.1
3312	Steel Works & Mills	127	0.2	0.9	1.4	7.1	116.9
3728	Aircraft Parts, NEC	36	0.2	4.0	3.6	9.4	19.1
3452	Bolts, Nuts, Screws, etc	28	4.2	0.0	14.4	3.6	5.5
3599	Indust./Comm. Equipment, NEC	25	2.0	10.3	13.0	0.1	0.0
3841	Surgical & Medical Instruments	24	0.0	2.9	5.1	5.4	10.1
3462	Iron & Steel Forgings	20	0.1	0.8	1.9	2.4	14.9
3499	Fabricated Metal Products, NEC	20	0.8	5.1	6.9	3.2	3.8
3443	Fabricated Plate Work	17	0.8	3.7	8.3	2.5	2.1
3531	Construction Equipment	15	0.1	0.0	7.1	2.2	5.3
2676	Sanitary Paper Products	56	0.0	1.2	3.2	9.9	41.8
3625	Electronics: Relays & Controls	55	0.0	0.8	7.7	6.5	40.4
2048	Prepared Animal Feeds	55	0.9	0.0	40.1	12.0	1.5
3674	Semiconductors	52	0.0	1.9	1.3	9.4	39.1
2262	Finishers of Synthetic Fibers & Silk	50	0.0	1.2	3.4	24.1	21.4

SIC	Top Five States, per SIC, by Total Number of Potential Units									
3714	MI	118	CA	69	NY	31	OH	28	IN	25
3312	PA	36	OH	18	IN	11	MI	11	TX	10
3728	CA	63	AZ	12	NJ	8	CT	6	UT	4
3452	CA	72	CT	16	NJ	15	NY	10	OH	8
3599	CA	91	NJ	59	AZ	20	CT	10	OH	9
3841	CA	41	UT	7	NJ	6	CT	4	CO	3
3462	CA	8	WI	7	OH	7	TX	4	MI	3
3499	CA	37	NJ	12	NY	9	UT	7	PA	6
3443	CA	34	NJ	13	OK	11	NY	6	UT	5
3531	WI	10	OK	7	CA	5	PA	3	NJ	2
2676	GA	8	WA	8	PA	8	WI	8	CA	7
3625	CA	33	WI	17	NY	15	NJ	6	OH	5
2048	CA	47	TX	20	NY	20	GA	16	AR	10
3674	CA	58	AZ	9	NJ	3	WA	0	OH	0
2262	SC	22	NC	12	NJ	10	MA	9	CA	6



**Indirect Air Heating Systems€**

SIC	Sector Description	Total MWs	MW Potential per DG Size Range				
			25 - 75 kW	75 - 150 kW	150 - 400 kW	400 - 800 kW	800 - 1000kW
3411	Metal Cans	151	0.5	1.5	4.2	21.2	124.1
3479	Coating & Engraving, NEC	136	7.4	41.7	31.3	40.2	15.9
3625	Electronics: Relays & Controls	130	0.0	4.3	13.5	19.5	92.8
3714	Motor Vehicle Parts	115	0.0	1.7	5.3	13.8	94.3
3564	Indust./Comm. Fans, Blowers, etc	111	0.4	2.8	10.6	28.3	68.5
2752	Commercial Printing: Lithographic	96	2.8	26.4	34.7	17.4	14.2
3711	Motor Vehicle Bodies	93	0.3	2.4	2.4	7.7	80.4
3585	HVAC & Refrigeration Units	88	0.7	0.0	22.2	21.4	43.6
3469	Metal Stampings, NEC	77	5.2	19.9	30.7	13.8	7.0
2051	Bread/Bakery Products	76	5.2	0.0	42.8	20.4	7.4
3674	Semiconductors	68	0.0	2.1	5.3	18.9	41.6
2048	Prepared Animal Feeds	66	0.1	0.0	48.1	16.0	1.5
3429	Hardware, NEC	59	1.9	5.0	11.5	17.2	23.1
3444	Sheet Metalwork	58	26.8	0.0	27.2	2.8	1.0
3679	Electronics Components, NEC	51	0.0	4.4	17.1	11.6	17.6

SIC	Top Five States, per SIC, by Total Number of Potential Units									
3411	CA	37	OH	18	IL	13	GA	9	WI	9
3479	CA	153	MI	72	NY	50	OH	46	MA	38
3625	CA	52	NY	37	WI	24	MA	17	OH	15
3714	CA	46	MI	45	OH	16	NY	13	AZ	9
3564	CA	21	NY	16	OH	14	NC	13	WI	11
2752	CA	212	NY	72	NJ	60	WI	29	AZ	24
3711	MI	29	OH	17	GA	7	CA	7	IN	6
3585	TX	19	NY	18	GA	17	CA	15	NJ	12
3469	CA	103	CT	51	NJ	37	NY	29	OH	25
2051	CA	124	NY	27	NJ	22	TX	13	UT	12
3674	CA	78	AZ	12	NJ	3	ID	2	NM	2
2048	TX	30	CA	27	AR	22	NY	20	GA	16
3429	CA	46	CT	21	MI	16	NY	10	IN	8
3444	CA	281	NY	54	NJ	52	WA	43	MA	39
3679	CA	94	NJ	23	NY	12	CO	11	AZ	10

**Exhaust Gas As Oxidant Systems€**

SIC	Sector Description	Total MWs	MW Potential per DG Size Range				
			25 - 75 kW	75 - 150 kW	150 - 400 kW	400 - 800 kW	800 - 1000kW
2911	Petroleum Refining	638	1.4	0.0	58.0	0.0	578.1
2621	Paper Mills	604	0.6	0.0	38.3	0.0	564.6
2869	Industrial Organic Chemicals, NEC	382	0.0	18.2	28.3	146.5	188.5
3312	Steel Works & Mills	322	1.7	0.0	37.4	0.0	283.0
2821	Plastic Mat'ls, Resins, & Elastomers	248	1.1	0.0	26.8	43.3	177.0
2819	Industrial Inorganic Chemicals, NEC	244	0.0	8.6	0.0	72.4	162.5
2631	Paperboard Mills	207	0.2	0.0	16.9	25.6	164.3
2611	Pulp Mills	190	0.3	0.0	4.4	34.5	150.9
3711	Motor Vehicle Bodies	94	0.2	0.0	24.3	0.0	69.6
2436	Softwood Veneer & Plywood	80	0.0	0.0	16.8	0.0	63.1
2812	Alkalies & Chlorine	72	0.0	0.0	0.1	0.0	72.1
2824	Manmade NonCellulosic Fibers	71	0.0	0.0	6.3	16.3	48.6
3714	Motor Vehicle Parts	51	0.0	8.8	9.8	23.4	8.7

SIC	Top Five States, per SIC, by Total Number of Potential Units									
2911	TX	160	CA	154	LA	138	PA	56	NJ	34
2621	ME	82	NY	61	WI	49	MI	42	MN	39
2869	TX	192	LA	128	NJ	82	AR	32	NY	28
3312	PA	98	OH	65	IN	36	MI	31	TX	28
2821	TX	95	LA	47	NJ	40	MI	36	SC	34
2819	CA	43	LA	39	TX	34	NJ	33	NC	28
2631	GA	32	WA	19	LA	19	VA	16	OR	15
2611	GA	72	FL	58	NC	39	WA	35	AK	17
3711	MI	40	OH	21	GA	11	CA	10	NJ	8
2436	OR	33	LA	21	AR	16	WA	15	TX	11
2812	NY	12	LA	11	TX	10	KS	7	WY	6
2824	SC	36	NC	21	VA	15	GA	10	AL	9
3714	MI	63	CA	18	IN	17	OH	15	NY	12

## Sensitivity Analysis

Installed costs for the innovative cogeneration equipment decrease in terms of dollars per kW as the equipment size increases. This is because packaged reciprocating engine and turbines prices, thermal system retrofit, engineering, and installation costs decrease in terms of dollars per kW as the equipment size increase. As an example, the installed cost for the 25-75 kW indirect air heating system using a recuperated turbine is \$1,641/kW, but in the 800-1000 kW size range is only \$836/kW.

Thermal system retrofit, engineering, and installation cost were determined by specifying a base case for the smallest size range, and then using a multiplier to estimate costs for larger size ranges. The equation takes the following form: cost multiplier (absolute \$) = (size multiplier)<sup>n</sup>, where n is between 0.20 to 0.60. A sensitivity analysis was performed using n = 0.75 for retrofit, engineering, and installation. This lead to a smaller decrease in installed cost as the equipment size increased. For example, the 25-75 kW indirect air heating system using a recuperated turbine is \$1,641/kW, but in this sensitivity analysis now decrease to \$1,043/kW in the 800-1000 kW size range (instead of \$836/kW). The following tables show the results using this less aggressive installed cost reduction scenario.

**Table 17. Less Aggressive Installed Cost Reduction - System Type**

Cogeneration Package Systems	Economic Market Potential (MWe)
Direct Contact Water Heater	1,741
Indirect Liquid Heaters	835
Convection Ovens for Metal Fabrication Preheating	648
Indirect Air Heating	1,865
Oxidant for Central Boiler Systems	2,865
<b>Total</b>	<b>7,954</b>

The 10 states showing the highest economic market potential are (sensitivity analysis):

**Table 18. Less Aggressive Installed Cost Reduction - State**

State	Economic Market Potential (MWe)
California	1,649
New Jersey	607
New York	486
Texas	440
Michigan	419
Pennsylvania	383
Ohio	338
Louisiana	278
Wisconsin	258
Georgia	224
Other States	2,873
<b>Total</b>	<b>7,954</b>

Economic market potential broken down by prime mover size range is (sensitivity analysis):

**Table 19. Less Aggressive Installed Cost Reduction - Size Range**

<b>Size Range</b>	<b>Economic Market Potential (MWe)</b>
25-75 kW	149
75-150 kW	439
150-400 kW	1,193
400-800 kW	1,280
800-1000 kW	4,893
<b>Total</b>	<b>7,954</b>

Economic market potential broken down by prime mover type is (sensitivity analysis):

**Table 20. Less Aggressive Installed Cost Reduction - Prime Mover**

<b>Prime Mover Type</b>	<b>Economic Market Potential (MWe)</b>
Recuperated Turbines	478
Unrecuperated Turbines	4,023
Reciprocating Engines	3,454
<b>Total</b>	<b>7,954</b>

## **Conclusions**

This assessment shows there is a potentially significant market for small innovative industrial cogeneration technologies. These units can beat conventional solutions in:

- Applications where the thermal systems retrofit cost is low,
- Larger sizes applications, because retrofit, engineering, and installation costs are lower in terms of \$ per kW than in the smaller sizes,
- Applications where most or all of the waste heat is being used,
- Applications where the existing thermal system efficiency is low, and
- Applications in areas with high electric rates.

Lowering the installed cost for the smaller size ranges (especially installation and retrofit) would increase the market potential even further.

## **Benefits**

Innovative industrial cogeneration systems can help industrial end users reduce air emissions, lower costs, and make their plants more competitive. This study examined retrofit opportunities, but economic benefits to end users would likely be greater if innovative cogeneration solutions were adopted in plants with failed thermal equipment that needed to be replaced anyway.

From a national perspective, innovative industrial cogeneration solutions will provide the following benefits:

- Increased overall system efficiency for some processes in the industrial sector,
- Reduced air emissions,
- A more competitive industrial base, and
- Reduced demand on the electricity grid.

This report gives important information to cogeneration project developers and technology funders such as the U.S. Department of Energy on the overall magnitude of the market and also provides critical data on the top application types, size ranges, and states.

## **Barriers**

The results shown in this assessment show the economic market potential. There are a number of barriers that may limit applications of these technologies. Some of these barriers may be regional in nature. The barriers include:

- Product performance and availability,
- Lack of off-the-shelf integrated systems,
- Presence of a supporting market infrastructure,
- Awareness, information and education of end users,
- Demonstration of successful case studies,
- Environmental regulations,
- Planning, zoning, and codes, and
- Tax treatment.

There clearly exists a need for a structured approach to assist with the development and deployment of innovative cogeneration systems in the industrial sector. This approach needs to foster the development of industrial cooling and heating systems that can easily be integrated with distributed generation

equipment. The approach should demonstrate these systems in industrial settings and then develop case studies around these demonstrations. These case studies need to include validated and verified data on the systems' operation and performance. In addition, the structured approach also needs to address the potential barriers and how to overcome them.

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