Gasification Technologies Council

GASIFICATION

AN INVESTMENT IN OUR ENERGY FUTURE

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One of the most compelling challenges of the 21st Century is finding a way to meet national and global energy needs while minimizing the impact on the environment. There is extensive debate surrounding this issue, but there are certain areas of consensus:

- We need to produce cleaner energy, both from conventional fuel sources and alternative technologies.
- Any energy source must be not only environmentally sound, but also economically viable.
- We need to invest in a variety of technologies and resources to produce clean, abundant, and affordable energy to meet all of our energy needs.

Gasification, a time-tested, reliable and flexible technology, will be an increasingly important component of this new energy equation. An investment in gasification today will yield valuable future returns in clean, abundant, and affordable energy.

Gasification is an environmentally sound way to transform any carbon-based material, such as coal, refinery byproducts, biomass, or even trash, into energy without burning it. Instead, gasification produces a gas by creating a chemical reaction that combines those carbon-based materials (feedstocks) with air or oxygen, breaking them down into molecules and removing pollutants and impurities. What's left is a clean "synthesis gas" (syngas) that can be converted into electricity and valuable products, such as transportation fuels, fertilizers, substitute natural gas, or chemicals.

Gasification has been used on a commercial scale for more than 75 years by the chemical, refining and fertilizer industries and for more than 35 years by the electric power industry. It is currently playing an important role in meeting energy needs in the U.S. and around the world. It will play an increasingly important role as one of the economically attractive manufacturing technologies that will allow us to produce clean, abundant energy. And it is being used in new settings: while gasification has typically been used in industrial applications, it is increasingly being adopted in smaller-scale applications to convert biomass and waste to energy and products.

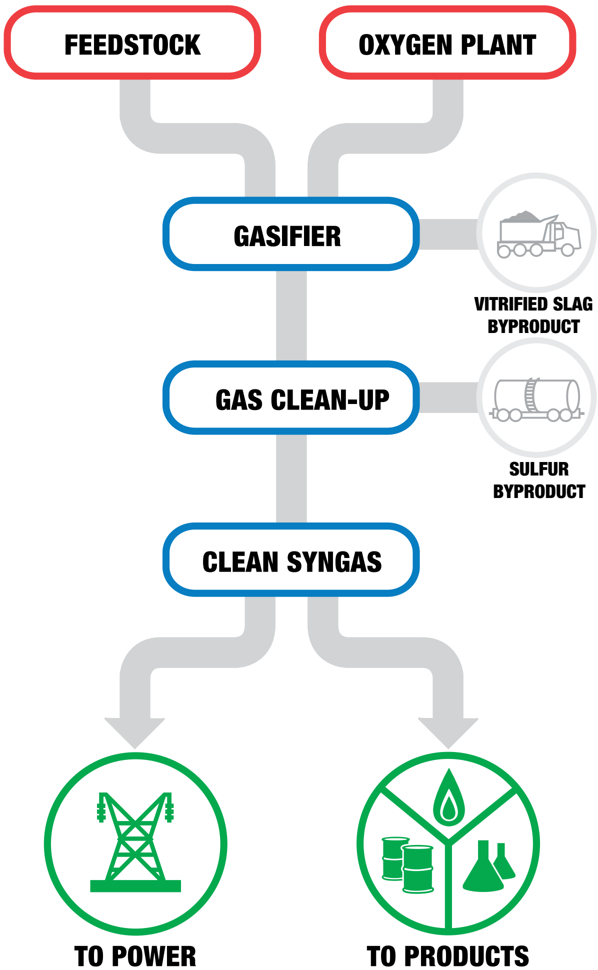
Investment in gasification technology today is an investment in our energy future.

- Gasification is the cleanest, most flexible and reliable way of using fossil fuels. It can convert low-value materials into high-value products, such as chemicals and fertilizers, substitute natural gas, transportation fuels, electric power, steam, and hydrogen.
- It can convert biomass, municipal solid waste and other materials that are normally burned into a clean gas.
- Gasification provides the most cost-effective means of capturing carbon dioxide, a greenhouse gas, when generating power using fossil fuels as a feedstock. This gives the United States and other nations a way to use abundant coal reserves to generate needed electricity in a "carbon-constrained" world.
- Gasification allows us to use domestic resources to generate our energy, instead of relying on high-cost imported petroleum and natural gas from politically unstable regions of the world.
- This technology provides increased domestic investment and jobs in industries that have been in decline because of high energy costs.
- It offers a path to new energy development and use consistent with robust environmental stewardship.
- Gasification provides a way to cleanly convert non-food biomass materials into transportation fuels and electricity.

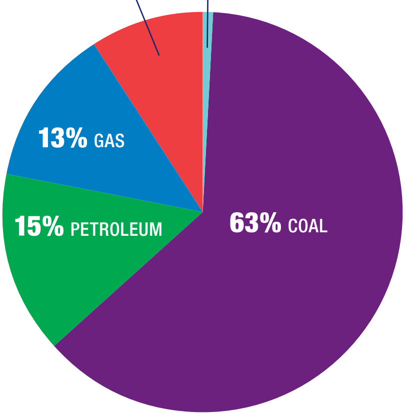
HOW GASIFICATION WORKS

Gasification is a process that converts carbon-containing materials, such as coal, petroleum coke (petcoke — a low-value byproduct of refining), biomass, or various wastes, to a syngas, which can then be used to produce electric power and valuable products such as chemicals, fertilizers, substitute natural gas, hydrogen, and transportation fuels.

THE GASIFICATION PROCESS



FEEDSTOCK



Gasification enables the capture — in an environmentally beneficial manner — of the remaining "value" present in a variety of low-grade hydrocarbon materials, wastes, or biomass, commonly called "feed-stocks". Without gasification, these materials would have to be disposed of, potentially damaging the environment and, equally as important, wasting a valuable source of energy. While traditional feedstocks have included coal and petcoke in large-scale industrial plants, there is an increasing use of municipal solid waste, industrial waste and biomass in smaller scale plants, converting that material to energy.

Gasifiers can be designed to use a single material or a blend of feedstocks:

- **SOLIDS:** All types of coal and petcoke and biomass, such as wood waste, agricultural waste, household waste, and hazardous waste
- **LIQUIDS:** Liquid refinery residuals (including asphalts, bitumen, and oil sands residues) and liquid wastes from chemical plants and refineries
- **GAS:** Natural gas or refinery/chemical off-gas

PLASMA GASIFICATION

Plasma gasification is increasingly being used to convert all types of waste, including municipal solid waste and hazardous waste, into electricity and other valuable products. Plasma is an ionized gas that is formed when an electrical charge passes through a gas. The resultant "flash" from lightning is an example of plasma found in nature. Plasma "torches" and "arcs" generate temperatures that can reach 10,000 degrees F. When used in a gasification plant, these plasma torches and arcs generate this intense heat, which initiates and intensifies the gasification reaction, increasing the rate of those reactions and making gasification more efficient. Plasma gasification has a number of significant benefits: it unlocks the maximum amount of energy from waste. This means that different types of feedstocks, such as municipal solid waste and hazardous waste, can be mixed, avoiding the expensive step of having to sort the feedstock by type before it is fed into the gasifier. These significant benefits make plasma gasification an attractive option for managing different types of wastes.

GASIFIER

The core of the gasification system is the gasifier, a vessel where the feedstock reacts with oxygen (or air) at high temperatures. There are several basic gasifier designs, distinguished by the use of wet or dry feed, the use of air or oxygen, the reactor's flow direction (up-flow, down-flow, or circulating), and the syngas cooling process. Currently, gasifiers are capable of handling up to 3,000 tons/day of feedstock throughput and this will increase in the near future.

After being ground into very small particles – or fed directly (if a gas or liquid) – the feedstock is injected into the gasifier, along with a controlled amount of air or oxygen. Temperatures in a gasifier range from 1,000-3,000 degrees Fahrenheit. The conditions inside the gasifier break apart the chemical bonds of the feedstock, forming syngas.

The syngas consists primarily of hydrogen and carbon monoxide and, depending upon the specific gasification technology, smaller quantities of methane, carbon dioxide, hydrogen sulfide, and water vapor. The ratio of carbon monoxide to hydrogen depends in part upon the hydrogen and carbon content of the feedstock and the type of gasifier used, but can also be adjusted or "shifted" downstream of the gasifier through use of catalysts. This ratio is important in determining the type of product to be manufactured (electricity, chemicals, fuels, hydrogen). For example, a refinery would use a syngas consisting primarily of hydrogen, important in producing transportation fuels. Conversely, a chemical plant uses syngas with roughly equal proportions of hydrogen and carbon monoxide, both of which are basic building blocks for the broad range of products that they produce. These include consumer and agricultural products such as medications, fertilizer, and plastics. This inherent flexibility of the gasification process means that it can produce one or more products from the same process. Typically, 70–85% of the carbon in the feedstock is converted into the syngas.

OXYGEN PLANT

Most gasification systems use almost pure oxygen (as opposed to air) to help facilitate the reaction in the gasifier. This oxygen (95–99% purity) is generated in a plant using proven cryogenic (ultra-low temperature) technology. The oxygen is then fed into the gasifier at the same time as the feedstock, ensuring that the chemical reaction is contained in the gasifier.

SYNGAS CLEAN-UP

The raw syngas produced in the gasifier contains trace levels of impurities that must be removed prior to its ultimate use. After the syngas is cooled, virtually all the trace minerals, particulates, sulfur, mercury, and unconverted carbon are removed using commercially proven cleaning processes common to the chemical and refining industries. For feedstocks (such as coal) containing mercury, more than 90% of the mercury can be removed from the syngas using relatively small and commercially available activated carbon beds.

CARBON DIOXIDE

Carbon dioxide can also be removed in the syngas clean-up stage using a number of commercial technologies. In fact, carbon dioxide is routinely removed with a commercially proven process in gasification-based ammonia, hydrogen, and chemical manufacturing plants. Gasification-based ammonia plants already capture/separate approximately 90% of their carbon dioxide and gasification-based methanol plants capture approximately 70%. The gasification process offers the most cost-effective and efficient means of capturing carbon dioxide during the energy production process.

BYPRODUCTS

Most solid and liquid feed gasifiers produce a glass-like byproduct called slag, composed primarily of sand, rock, and minerals contained in the gasifier feedstock. This slag is non-hazardous and can be used in roadbed construction, cement manufacturing or in roofing materials. Also, in most gasification plants, more than 99% of the sulfur is removed and recovered either as elemental sulfur or sulfuric acid.

WHO USES GASIFICATION

Gasification was first used in the chemical, refining, and fertilizer industries and then adopted in the 1980s by the electric power industry. Products generated by gasification today are used to fertilize crops, to heat and light homes and offices, and in consumer products as varied as LCD and LED screens, over-the-counter medications, and hand tools.

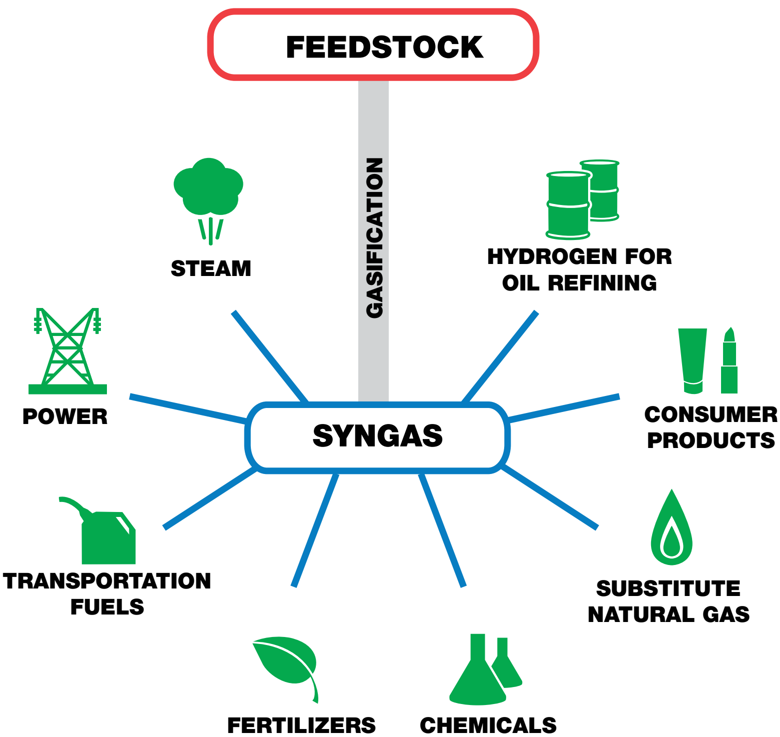
Currently, there are more than 132 large-scale gasification plants — with more than 392 gasifiers — operating worldwide. A number of these large-scale gasification plants are located in the United States. (Visit www.gasification.org/USA-Gasification.jpg)

In addition to these traditional industrial uses, an increasing number of cities are now considering using gasification to transform their municipal solid waste into power and products—instead of putting it in landfills, which can contaminate groundwater and decompose into methane, a powerful greenhouse gas. (Visit www.gasification.org/page_1.asp?a=79)

GASIFICATION APPLICATIONS AND PRODUCTS

Hydrogen and carbon monoxide, the major components of syngas, are the basic building blocks of a number of other products, such as fuels, chemicals and fertilizers. In addition, a gasification plant can be designed to produce more than one product at a time (co-production or "polygeneration"), such as electricity, and chemicals (e.g., methanol or ammonia).

GASIFICATION FOR PRODUCTS



Chemicals and Fertilizers

Modern gasification has been used in the chemical industry since the 1930s. Typically, the chemical industry uses gasification to produce methanol as well as chemicals — such as ammonia and urea — which form the foundation of nitrogen-based fertilizers and to produce a variety of plastics. The majority of the operating gasification plants worldwide are designed to produce chemicals and fertilizers. (Visit www.gasification.org/page_1.asp?a=25&b=1)

Substitute Natural Gas

Gasification can also be used to create substitute natural gas (SNG) from coal. Using a "methanation" reaction, the coal-based syngas — mostly carbon monoxide and hydrogen — can be converted to methane. Almost chemically identical to conventional natural gas, the resulting SNG can be transported in existing natural gas pipeline networks and used to generate electricity, produce chemicals/fertilizers, or heat homes and businesses. SNG will enhance domestic fuel security by displacing imported natural gas that is likely to be supplied in the form of Liquefied Natural Gas (LNG).

Hydrogen for Oil Refining

Hydrogen, one of the two major components of syngas, is used to produce high-quality gasoline, diesel fuel, and jet fuel, meeting the requirements for clean fuels in state and federal clean air regulations. Hydrogen is also used to upgrade heavy crude oil. Refineries can gasify low-value residuals, such as petroleum coke, asphalts, tars, and some oily wastes from the refining process to generate both the required hydrogen and the power and steam needed to run the refinery.

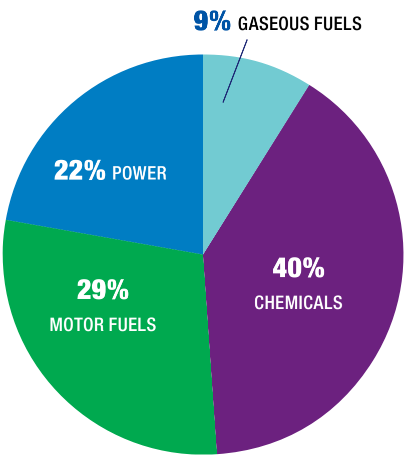
Transportation Fuels

Gasification is the foundation for converting coal and other solid feedstocks and natural gas into transportation fuels, such as gasoline, ultra-clean diesel fuel, jet fuel, naphtha, and synthetic oils. Two basic paths are employed in converting coal to motor fuels via gasification. In the first, the syngas undergoes an additional process, the Fischer-Tropsch (FT) reaction, to convert it to a liquid petroleum product. The FT process, with coal as a feedstock, was invented in the 1920s, used by Germany during World War II, and has been utilized in South Africa for decades. Today, it is also used in Malaysia and the Middle East with natural gas as the feedstock.

In the second process, so-called Methanol to Gasoline (MTG), the syngas is first converted to methanol (a commercially used process) and the methanol is then converted to gasoline by reacting it over catalysts. A commercial MTG plant successfully operated in the 1980s and early 1990s in New Zealand and projects are currently under development in China and the U.S.

Transportation Fuels from Oil Sands

PRODUCT DISTRIBUTION



The "oil sands" in Alberta, Canada are estimated to contain as much recoverable oil (in the form of bitumen) as the vast oil fields in Saudi Arabia. However, to convert this raw material to saleable products requires extracting the oil sands and refining the resulting bitumen to transportation fuels. The mining process requires massive amounts of steam to separate the bitumen from the sands and the refining process demands large quantities of hydrogen to upgrade the "crude oil" to finished products. Residuals from the upgrading process include petcoke, de-asphalted bottoms, vacuum residuals, and asphalt/asphaltenes – all of which contain unused energy that can be gasified.

Traditionally, oil sand operators have utilized natural gas to produce the steam and hydrogen needed for the mining, upgrading, and refining processes. However, one oil sands production site in Canada now employs gasification and a number of additional operators have plans to gasify bitumen residues to supply the necessary steam and hydrogen. Not only will gasification displace expensive natural gas as a feedstock, it will enable the extraction of usable energy from what is otherwise a waste product (e.g., petcoke). In addition, black water from the mining and refining processes can be recycled to the gasifiers using a wet feed system, reducing fresh water usage and waste water management costs. This is not inconsequential since traditional oil sand operations consume large volumes of water.

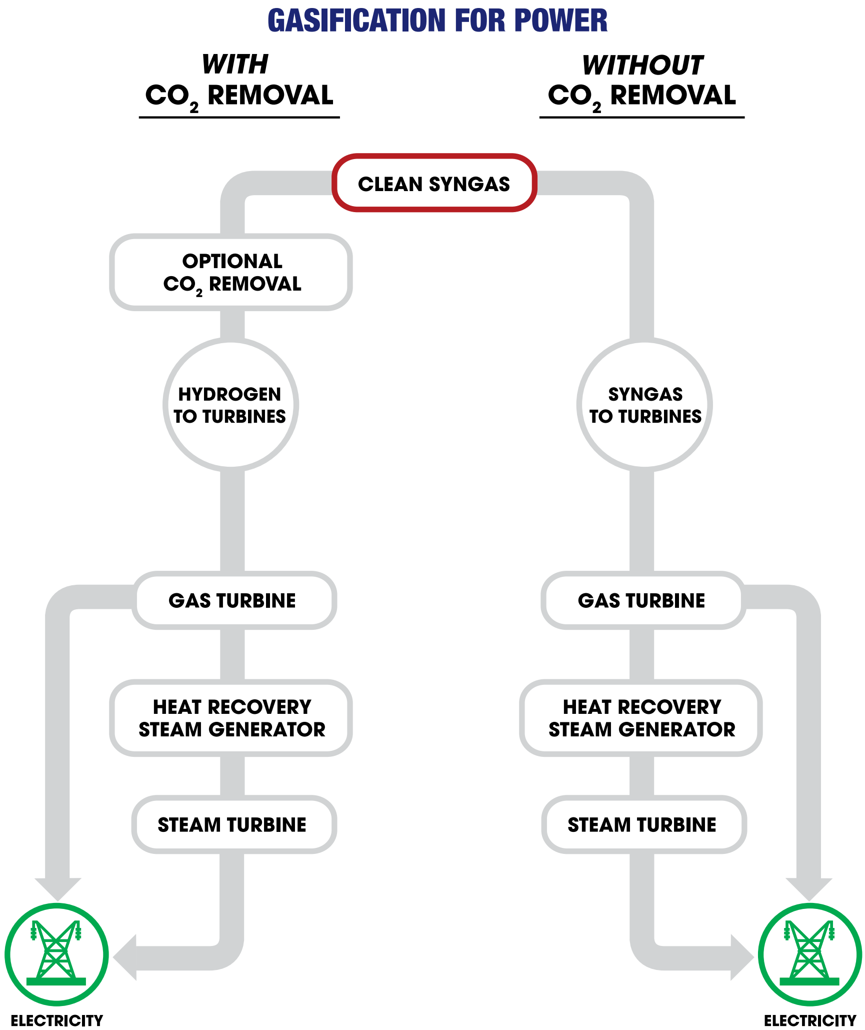
Power Generation with Gasification

As stated above, coal can be used as a feedstock to produce electricity from gasification. This particular coal-to-power technology allows the continued use of ample domestic supplies of coal without the high level of air emissions associated with conventional coal-burning technologies.

In the U.S., two coal-based IGCCs have been in operation for more than a decade. The 262 megawatt Wabash River Coal Gasification Repowering Project (Wabash) in Indiana began commercial operation in November 1995. Tampa Electric Company's 250 megawatt Polk Power Station near Mulberry, Florida, began operating in 1996.

IGCC Power Plants

An Integrated Gasification Combined Cycle (IGCC) power plant combines the gasification process with a "combined cycle" power block (consisting of one or more gas turbines and a steam turbine). Clean syngas is combusted in high efficiency gas turbines to produce electricity. The excess heat from the gas turbines and from the gasification reaction is then captured, converted into steam, and sent to a steam turbine to produce additional electricity.



Gas Turbines

In IGCC — where power generation is the focus — the clean syngas is combusted (burned) in high efficiency gas turbines to generate electricity with very low emissions. The gas turbines used in these plants are similar to jet engines and are slight modifications of proven, natural gas combined-cycle gas turbines that have been specially adapted for use with syngas. For IGCC plants that include carbon dioxide capture, these gas turbines are adapted to operate on syngas with higher levels of hydrogen. Although modern state-of-the-art gas turbines are commercially ready for this "higher hydrogen" syngas, work is ongoing in the United States to develop the next generation of even more efficient gas turbines ready for carbon dioxide capture-based IGCC.

Heat Recovery Steam Generator

The heat recovery steam generator (HRSG) captures heat in the hot exhaust from the gas turbines and uses it to generate additional steam that is used to make more power in the steam turbine portion of the combined-cycle unit.

Steam Turbines

In most IGCC plant designs, steam recovered from the gasification process is superheated in the HRSG to increase overall efficiency output of the steam turbines, hence the name Integrated Gasification Combined Cycle. This IGCC combination, which includes a gasification plant, two types of turbine generators (gas and steam), and the HRSG is clean and efficient. (Visit www.gasification.org/IGCC-Table.jpg)

WASTE-TO-ENERGY GASIFICATION

Municipalities are spending millions of dollars each year to dispose of solid waste that, in fact, contains valuable unused energy. In addition to the expense of collecting this waste, they must also contend with increasingly limited landfill space, the environmental impacts of landfilling, and stringent bans on the use of incinerators. Given these challenges, municipalities are increasingly looking to gasification as a solution to help transform this waste into energy. Gasification can convert municipal and other wastes (such as construction and demolition wastes) that cannot be recycled into electric power or other valuable products, such as chemicals, fertilizers, and substitute natural gas. Instead of paying to dispose of these wastes, municipalities are generating income from these waste products, since they are valuable feedstocks for a gasifier. Gasifying municipal and other waste streams reduces the need for landfill space, decreases the generation of methane (a potent greenhouse gas), and reduces the potential for groundwater contamination from landfills.

It is important to note that gasification does not compete with recycling. In fact, it complements existing recycling programs. Many materials, including a wide range of plastics, cannot currently be recycled or recycled any further. Such materials are ideal feedstocks for the gasification process. And, as populations grow, the amount of waste generated also increases. So even as recycling rates increase, the amount of waste being generated is growing at a faster rate. All of this waste contains energy which gasification can recover.

BIOMASS GASIFICATION

In addition to using the traditional feedstocks coal and petcoke, gasifiers can be designed to utilize biomass, such as yard and crop waste, biosolids, "energy crops", such as switch grass, and waste and residual pulp/paper plant materials as feedstock. Municipalities, as well as the paper and agricultural industries, are looking for ways to reduce the disposal costs associated with these wastes, and for technologies to produce electricity and other valuable products from these waste materials. While still in its infancy, biomass gasification shows a great deal of promise. A key advantage of gasification is that it can convert "non-food" biomass materials, such as corn stalks and wood wastes, to alcohols. Biomass gasification does not remove food-based biomass, such as corn, from the economy, unlike typical fermentation processes for making alcohols.

THE ENVIRONMENTAL BENEFITS OF GASIFICATION

Besides fuel and product flexibility, gasification-based systems offer significant environmental advantages over competing technologies, particularly coal-to-electricity combustion systems. Gasification plants can readily capture carbon dioxide, the leading greenhouse gas, much more easily and efficiently than coal-fired power plants. In many instances, this carbon dioxide can be sold, creating additional value from the gasification process.

Carbon dioxide captured during the gasification process can be used to help recover oil from otherwise depleted oil fields. The Dakota Gasification plant in Beulah, North Dakota, captures its carbon dioxide while making substitute natural gas and sells it for enhanced oil recovery. Since 2000, this plant has captured and sent the carbon dioxide via pipeline to EnCana's Weyburn oil fields in Saskatchewan, Canada, where it is used for enhanced oil recovery. More than five million tons of carbon dioxide have been sequestered.

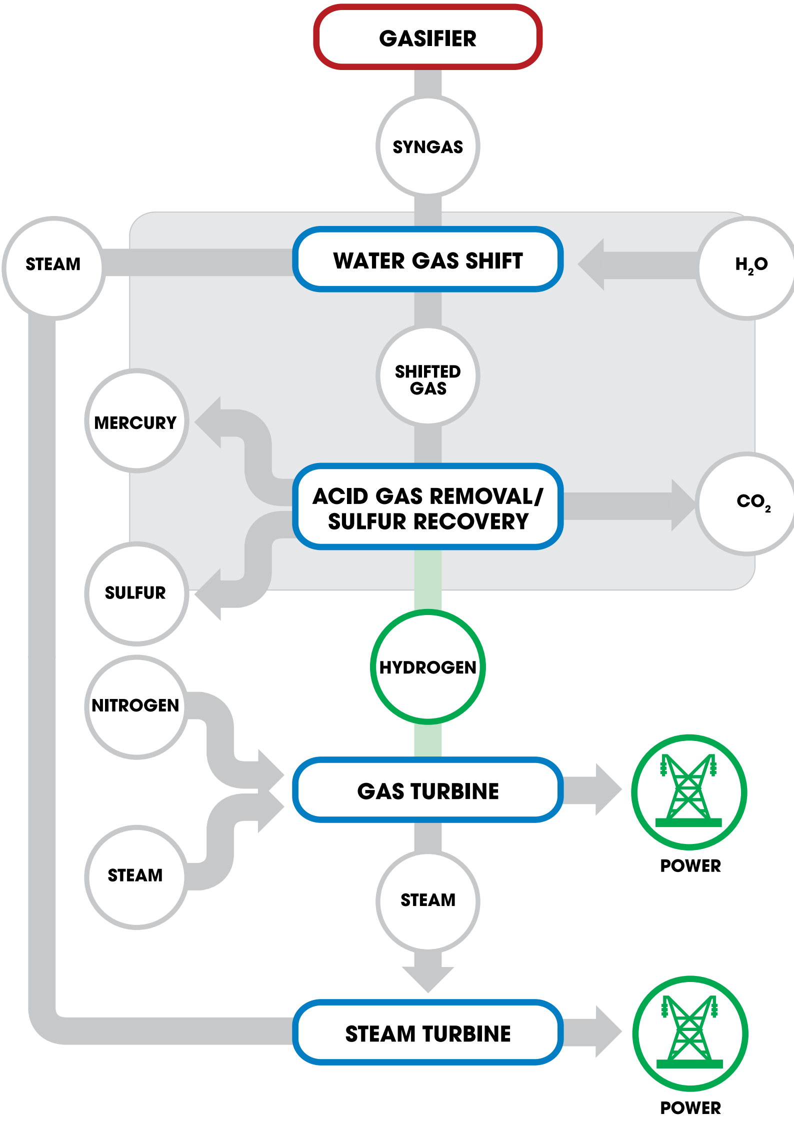
CARBON DIOXIDE

In a gasification system, carbon dioxide can be captured using commercially available technologies before it would otherwise be vented to the atmosphere. One process, called the water-gas shift reaction, is illustrated on the next page.

Converting the carbon monoxide to carbon dioxide and capturing it prior to combustion is more economical than removing carbon dioxide after combustion, effectively "de-carbonizing" or, at least, reducing the carbon in the syngas.

Gasification plants manufacturing ammonia, hydrogen, fuels, or chemical products routinely capture carbon dioxide as part of the manufacturing process.

CO_2 REMOVAL FLOW



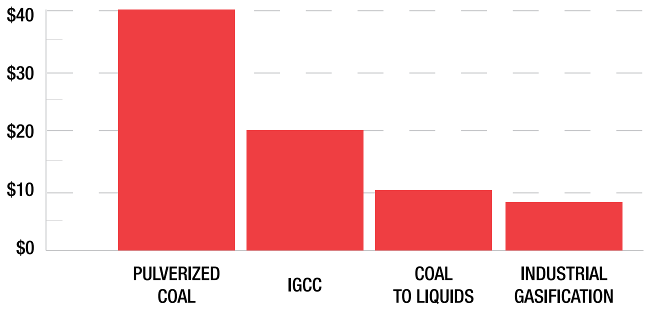
According to the Environmental Protection Agency, the higher thermodynamic efficiency of the IGCC cycle minimizes carbon dioxide emissions relative to other technologies. IGCC plants offer today's least-cost alternative for capturing carbon dioxide from a coal-based power plant. In addition, IGCC will experience a lower energy penalty than other technologies if carbon dioxide capture is required. While carbon dioxide capture and sequestration will increase the cost of all forms of power generation, an IGCC plant can capture and compress carbon dioxide at one-half the cost of a traditional pulverized coal plant. Other gasification-based options, including the production of motor fuels, chemicals, fertilizers or hydrogen, have even lower carbon dioxide capture and compression costs. This will provide a significant economic and environmental benefit in a carbon-constrained world.

AIR EMISSIONS

Gasification can achieve greater air emission reductions at lower cost than other coal-based power generation, such as supercritical pulverized coal. Coal-based IGCC offers the lowest emissions of sulfur dioxide nitrogen oxides and particulate matter (PM) of any coal-based power production technology. In fact, a coal IGCC plant is able to achieve low air-emissions rates that approach those of a natural gas combined cycle (NGCC) power plant. In addition, mercury emissions can be removed from an IGCC plant at one-tenth the cost of removal from a coal combustion plant. Technology exists today to remove more than 90% of the volatile mercury from the syngas in a coal-based gasification-based plant.

CO_2 CAPTURE AND COMPRESSION COSTS

($/METRIC TON)



Source: MIT and Eastman Gasification Services

SOLIDS GENERATION

During gasification, virtually all of the carbon in the feedstock is converted to syngas. The mineral material in the feedstock separates from the gaseous products, and the ash and other inert materials melt and fall to the bottom of the gasifier as a non-leachable, glass-like solid or other marketable material. This material can be used for many construction and building applications. In addition, more than 99% of the sulfur can be removed using commercially proven technologies and converted into marketable elemental sulfur or sulfuric acid.

WATER USE

Gasification uses approximately 14–24% less water to produce electric power from coal compared to other coal-based technologies, and water losses during operation are about 32–36% less than other coal-based technologies. This is a major issue in many countries — including the United States — where water supplies have already reached critical levels in certain regions.

THE ECONOMIC BENEFITS OF GASIFICATION

While a gasification plant is capital intensive (like any manufacturing unit), its operating costs can be lower than many other manufacturing processes or coal combustion plants. Because a gasification plant can use low-cost feedstocks, such as petcoke or high-sulfur coal, converting them into high-value products, it increases the use of available energy in the feedstocks while reducing disposal costs. Ongoing research, development, and demonstration investment efforts show potential to substantially decrease current gasification costs even further, driving the economic attractiveness of gasification.

In addition, gasification has a number of other significant economic benefits.

- The principal gasification byproducts (sulfur, sulfuric acid, and slag) are marketable.
- Gasification can produce a number of high-value products at the same time (polygeneration), helping a facility offset its capital and operating costs and diversify its risks.
- Gasification offers wide feedstock flexibility. A gasification plant can be designed to vary the mix of the solid feedstocks or run on natural gas or liquid feedstocks when desirable.
- Gasification units require less emission control equipment because they generate fewer emissions, further reducing the plant's operating costs.
- Investment in gasification injects capital into the economy (by building large-scale plants using domestic labor and suppliers), and creates domestic jobs (construction to build, well-paid jobs to run) that cannot be outsourced to overseas workers.

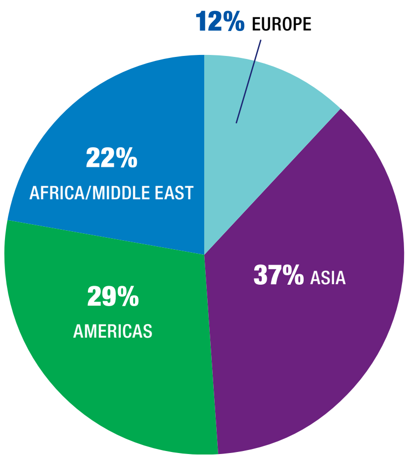
THE GASIFICATION MARKET OUTLOOK

The forecast for growth of gasification capacity focuses on two areas: large-scale industrial and power generation plants and the smaller scale biomass and waste to energy area.

INDUSTRIAL AND POWER GENERATION GASIFICATION

Worldwide industrial and power generation gasification capacity is projected to grow 70% by 2015, with 81% of the growth occurring in Asia. The prime movers behind this expected growth are the chemical, fertilizer, and coal-to-liquids industries in China, oil sands in Canada, polygeneration (hydrogen and power or chemicals) in the United States, and refining in Europe. China is expected to achieve the most rapid growth in gasification worldwide: the Chinese have focused on gasification as part of their overall energy strategy. Since 2004, 35 new large-scale gasification plants have been licensed or built in China.

GLOBAL SYNGAS CAPACITY BY REGION



By contrast, no new large-scale gasification plants have started in the United States since 2002. The industrial and power gasification industry in the United States faces a number of challenges, including rising construction costs and uncertainty about policy incentives and regulations. Despite these challenges, U.S. industrial and power gasification capacity is expected to grow.

A number of factors will contribute to this expansion:

- Volatile oil and natural gas prices will make low-cost and abundant domestic resources with stable prices increasingly attractive as feedstocks.
- Gasification processes will be able to comply with more stringent environmental regulations because their emission profiles are already substantially less than more conventional technologies.
- There is a growing consensus that carbon dioxide management will be required in power generation and energy production. Since the gasification process allows carbon dioxide to be captured in a cost-effective and efficient manner, it will be an increasingly attractive choice for the continued use of fossil fuels.

BIOMASS AND WASTE-TO-ENERGY GASIFICATION

The greatest area of growth in terms of the **number** of plants in the U.S. is likely to be in the biomass and waste-to-energy gasification areas. Because they are smaller in scale, these plants are easier to finance, easier to permit and take less time to construct. In addition, municipal and state restrictions on land-fills and incineration and a growing recognition that these materials contain valuable sources of energy are driving the demand for these plants.

A number of factors will contribute to the growing interest in biomass and waste gasification:

- Restrictions on landfill space
- Efforts to reduce costs associated with waste management
- Growing recognition that biomass and waste contain unused energy that can be captured and converted into energy and valuable products
- Ability to use non-food biomass materials and convert them into valuable energy products

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