# COMMERCIAL SUCCESSES OF GASIFICATION TECHNOLOGY

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***THROUGHOUT THE WORLD TODAY, GASIFICATION TECHNOLOGY IS BEING USED TO GENERATE POWER AND DESTROY WASTE.***

THERE IS A LARGE WORLDWIDE BASE OF COMMERCIALLY proven gasification-to-power. Although black liquor gasification is not yet commercially proven, there are tie-ins that need to be considered when developing a black liquor project. This article discusses gasification in general: the technology, some of the configuration options available, and some of the considerations for black liquor gasification.

Gasification technology is being applied to make power, for chemicals, and for waste destruction. In the Texaco power portfolio, 46% is Integrated Gasification Combined Cycle (IGCC) related. About 3900 megawatts of IGCC is being installed commercially. Some of it is in operation, and another large fraction is currently starting operation. There are 69 Texaco plants operating commercially worldwide. The bulk of these are actually for chemicals production. Hydrogen or hydrogen-to-ammonia is our biggest market, but syngas production is quickly shifting over to power production as our major use of the gasification process.

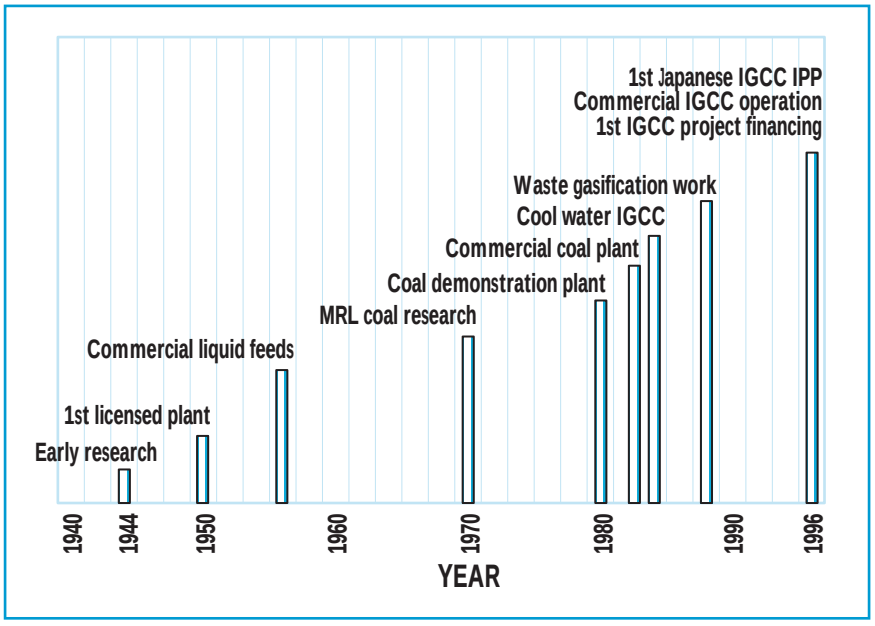
**Figure 1** illustrates some significant milestones in gasifier development. The first gasifier was licensed 48 years ago. In 1984 the Cool Water IGCC demonstration unit started up. It was the first time we sent syngas to a gas turbine on a commercial scale unit. The first commercially operating IGCC plant started up in 1996 at the Tampa Electric Company. About the same time, financial closure was achieved on three Italian IGCC projects. We view that as a milestone because those are non-recourse finance projects where the banks are depending on the gasifier to perform in order to be repaid their money. Those projects have to work, and they are currently starting operation.

**Figure 2** is a sketch of our gasifier. A variety of feedstocks, ranging from natural gas to coke, are offered commercially today. Coke is the heaviest feedstock next to pure carbon. Natural gas is used in chemicals production, not power production. We also gasify and destroy refinery waste.

## HOW A GASIFIER WORKS

For an entrained flow gasifier, feedstock and oxygen are fed into the top and react in a high temperature, refractory-lined vessel to produce a syngas. The basic reaction is a hydrocarbon reacting with oxygen to produce hydrogen and CO. We are typically operating at 1200° to 1500°C. One of the big advantages of this process is that the sulfur is converted to $H_2S$ and can be removed from the gas to very low levels using standard refinery processes. **Figure 3** shows how the gasifier fits into the overall quench design.

Generally, there is a small fraction of carbon in the feed that is not converted and is recycled. For coal, there is usually 10-15% ash, and that is converted into a glassy slag that is removed through a lockhopper. There is a trace of methane, which is the heaviest hydrocarbon produced by the gasifier. There are no tars or other environmental problems with the gasification system. For solid feedstocks, we mix water and coal and wet grind them to form a slurry, which is pumped into the gasifier. Black liquor could be pumped directly into the gasifier, skipping the grinding mill. If a supplemental fuel is available, black liquor can be used to reduce the amount of water in the grinding step. This procedure might also reduce the amount of liquor concentration needed to obtain the desired high heating value for black liquor. Using black liquor, we would expect the solids (mainly sodium) to dissolve and be pumped out of the quench chamber rather than require a lockhopper. After the gas is cooled, it is scrubbed with water to remove all the particulate and leave only syngas coming out of the top of the water wash system. This approach makes the downstream processing of the syngas much easier.




*1. Significant milestones in gasification development*

## HEAT RECOVERY

**Figure 4** shows a full heat recovery configuration. $H_2S$ is removed from the gas in a standard refinery Acid Gas Removal (AGR) unit, typically amine or Selexol® based. The $H_2S$ is converted into a sulfur byproduct in the sulfur recovery unit (SRU). In a pulp and paper application, this sulfur recovery unit would probably be eliminated, and caustic would be used to recover the sulfur. Using caustic for the main scrubbing system is questionable because of the selectivity with $CO_2$. We get a high selectivity for sulfur removal and pass most of the $CO_2$ through the system with standard AGR systems, which provide obvious advantages even in the black liquor industry.

Hydrogen byproduct production is an option. Many plants are located near refineries where there is a need for hydrogen, and this has a higher value than fuel to the gas turbine. Hydrogen can be made with a relatively small investment, purified with a membrane, and polished with a Pressure Swing Adsorption (PSA) unit to help the project economics.

At this point, all the $H_2S$ has been removed, and the clean syngas is sent to the gas turbine.

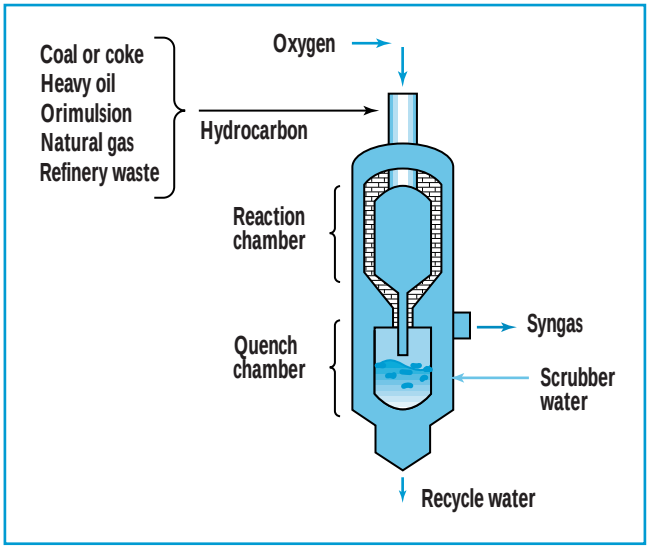
For two reasons, we also feed nitrogen into the gas turbine: to reduce NOx production in the gas turbine and to boost turbine output. The nitrogen dilutes the fuel to a very low Btu value, which lowers the flame temperature in the combustion turbine. As a result, NOx production is reduced to 25 ppm or lower, even on the advanced turbines.

When the nitrogen flows into the expander side of the gas turbine and skips the compression side, there is a 15%-20% boost in power output that is maintained over a wide range of ambient temperatures. It avoids the ambient temperature output capacity effect found with a natural gas fired turbine.

Exhaust from the gas turbine is then sent to a heat recovery steam generator (HRSG) to make steam. These are fairly large gas turbines that lower costs and improve efficiency. At Tampa Electric, they make 250 net megawatts of power. About 200 megawatts is made from the gas turbine and another 100 megawatts from the steam turbine cycle. About 50 megawatts is consumed by the plant itself, including the air separation unit.

The Tampa configuration has heat recovery instead of a quench immediately downstream of the gasifier. They make high pressure steam from that unit to improve cycle efficiency. Two configurations are available: the quench, which has the lowest cost, and the full heat recovery, which has the highest efficiency.

The efficiencies shown in **Table I** are net power efficiencies, not boiler efficiencies as with a black liquor boiler.




*2. Gasifier in use at Texaco*

## STEAM EXPORT

Adding steam export improves the cycle efficiency, which is what would occur in a pulp and paper mill with exporting steam. Even in a quench cycle, steam export can boost those efficiencies significantly.

A potential benefit to the pulp and paper industry is the opportunity for greater power production with co-

generation of steam exported. A conventional steam cycle produces about 120-180 kWh/ton of steam exported, but adding the combustion turbine into the cycle shifts the power per unit of steam ratio to 600 to 1000 kWh/ton, a factor of 5 or 6.

## COST ISSUES

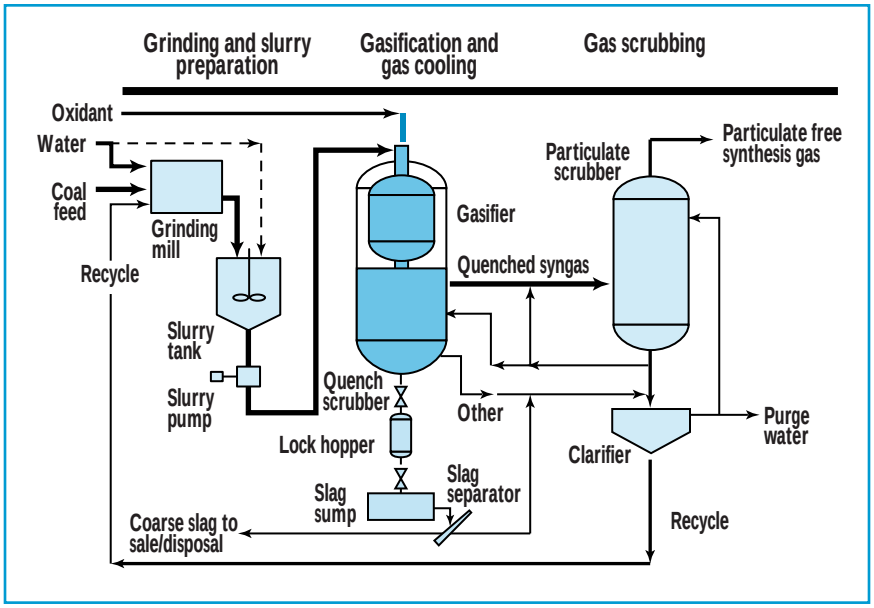
Comparing relative capital costs based on 400 megawatts, we see that a fairly large size plant is competitive in the power industry at $900/kWh because of the low cost of fuel without significant emissions.

The gasification block is a relatively small part of the overall cost, as indicated in **Table II.** When applied to black liquor, all parts are proven technology, except for the gasifier itself and the smelt recovery. Thus, in a commercial black liquor gasification unit, there would be 95% proven technology in the design and 5% invested in a technical demonstration of black liquor gasification. I would suggest that the technical demonstration be done in parallel with a commercial gasification unit, rather than as a stand alone demonstration, as there is a large investment required that has nothing to do with demonstrating the technology.

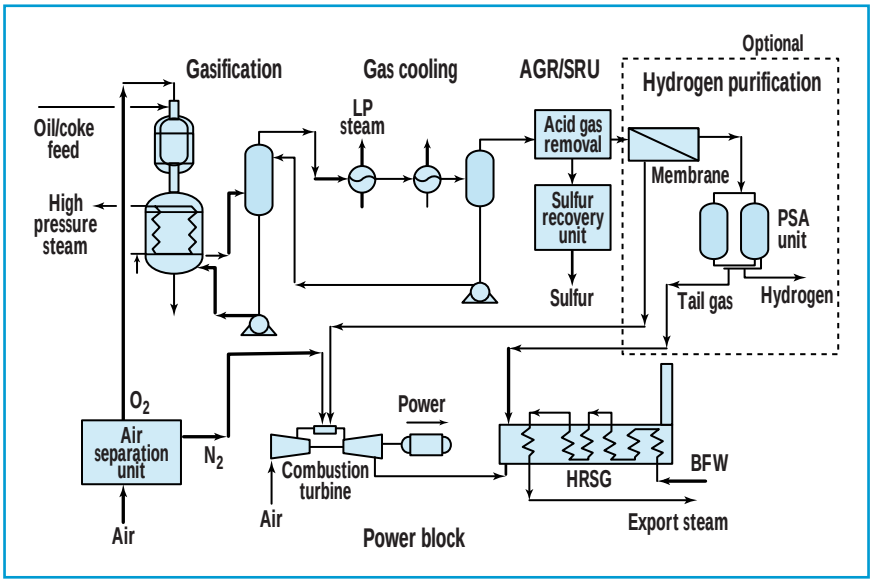
## COMPARISON OF BLACK LIQUOR TO OTHER FUELS

In comparing the physical properties of natural gas, oil, and coke—where there is commercial experience—to black liquor, as shown in **Table III**, black liquor is on the low end of the Btu range, chiefly due to the large amount of oxygen in it. The liquor is what I would call precombusted, with significant oxygen in the feed.

Compare this to the product syngas in **Table IV.** Even though black liquor provides a much lower total percentage of hydrogen and CO in the gas, the water will drop out as the gas cools down. The $CO_2$ is not that different, and in fact nitrogen is being added to lower the syngas heating value. If less nitrogen is put in, the nitrogen plus $CO_2$ comes out the same. This would actually reduce the nitrogen compression costs (relative to other syngas compositions) because of the higher $CO_2$ fraction.




*3. Quench design*




*4. Full heat recovery configuration*

| | Quench | Full heat recovery | Partial cogeneration* |
|---|---|---|---|
| **Coal** | 42.5% | 46.0% | 51% |
| **Oil** | 43.5% | 46.9% | 52% |

*Assumes 150,000 kg/h steam export from a nominal 400 MW quench combined cycle unit
*Efficiency based on net power*

***I. IGCC net power efficiencies, lower heating value (LVH)***

Thus, syngas from black liquor would also be excellent gas turbine fuel.

| | MM(US$) |
|---|---|
| Air separation unit | 37 |
| Gasification block (including $H_2$ purification) | 40 |
| Acid gas removal | 26 |
| Power generation block | 82 |
| Transmission and distribution | 22 |
| Offsites | 28 |
| **Subtotal field costs** | **235** |
| Field management costs | 6 |
| Contractor engineering | 30 |
| Owner's cost | excluded |
| **Total cost** | **271** |

**Basis for the cost:**

| | | |
|---|---|---|
| Coke | 2000 | metric tons/day |
| Net power | 250 | MW |
| Steam | 41,000 | kg/h |
| $H_2$ | 28 | $NM^3/hr$ |

Budgetary cost estimate
1997 US$; Location: U.S. Gulf Coast

*II. Typical costs of a gasification unit*

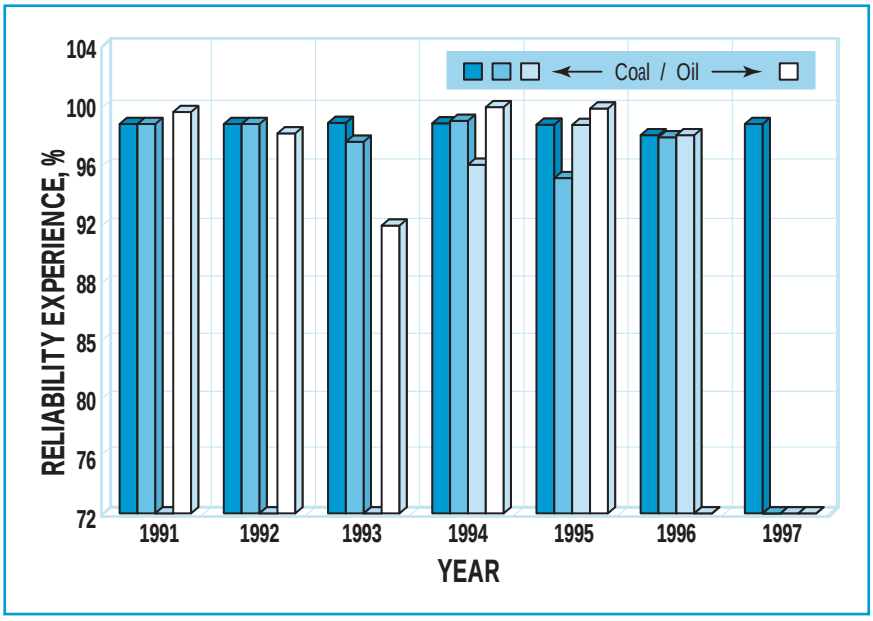
| | Natural gas | Oil | Coke | Black liquor |
|---|---|---|---|---|
| C, wt.% | 72.5 | 84.1 | 88.0 | 39.0 |
| H | 23.0 | 9.4 | 1.9 | 3.8 |
| O | 0.9 | 0.0 | 1.9 | 33.8 |
| N | 3.6 | 1.4 | 1.7 | 0.0 |
| S | 0.0 | 5.1 | 6.0 | 3.5 |
| Ash | - | - | 0.5 | 19.9 |
| Btu/lb | 22,500 | 17,400 | 14,200 | 6,583 |

*III. Feedstock compositions*

| | Natural gas | Oil | Coke | Black liquor |
|---|---|---|---|---|
| $H_2$, mole % | 55.6 | 38.5 | 25.8 | 30.0 |
| CO | 31.7 | 42.4 | 47.8 | 27.5 |
| $CO_2$ | 2.1 | 5.5 | 13.0 | 18.6 |
| $H_2O$ | 8.7 | 11.7 | 11.1 | 21.9 |
| $CH_4$ | 1.1 | 0.5 | 0.1 | 0.1 |
| $H_2S$ | 0.0 | 1.1 | 1.6 | 1.5 |
| $N_2$+Ar | 0.9 | 0.4 | 0.7 | 0.3 |

*IV. Similar syngas compositions*

For the pulp and paper industry, I would look at steam usage to see how much is needed. I would probably pick a gas turbine to match that steam usage, because when doing a cogeneration instead of a combined cycle, there is much higher efficiency. It will also give the lowest cost. Then I would match the fuel supply to the gas turbine. If the fuel can be supplied with black liquor gasification alone, fine. If supplemental fuel is needed, options to consider would include natural gas direct to the gas turbine or coal or coke in a parallel gasifier.




*5. Commercial reliability experience*

## REFINERY EXPERIENCE

At Texaco's El Dorado refinery, we actually do have a small cogeneration unit making 35 megawatts of power. This unit is unique in that it actually burns natural gas plus syngas. At the plant, they are gasifying the incremental petroleum coke that is not under long-term contract, as well as waste. The 35 megawatts balances what is needed at the refinery. There is no steam turbine because steam is exported to the refinery, and there is no air separator unit (ASU) air compressor because air is taken from the gas turbine. This size plant is running commercially, and it is a real option for the pulp and paper industry.

## EMISSIONS

We get very low emissions from our unit because we can remove the sulfur to low levels, and we add nitrogen to reduce the NOx. **Table V** indicates typical emissions. The "typical" emissions levels are what we run in the United States. The "minimized" levels are what we are marketing in Japan, and they include a COS hydrolysis unit. COS is very hard to remove from

| Pollutant | Typical | Minimized |
|---|---|---|
| SOx | 0.30 | 0.05 (3 vppm) |
| NOx | 0.25 | 0.03 (3 vppm) |
| Particulates | 0.02 | 0.01 |
| kg/MWh | | |

*V. Emissions from IGCC unit*

the syngas, so we convert it to $H_2S$ to obtain very, very low sulfur levels. In Japan, even at 25 ppm, they will put in a Selective Catalytic Reduction (SCR) unit in the HRSG in order to minimize the NOx emissions.

## RELIABILITY

Reliability is a concern. Commercial reliability demonstrated on coal and oil is in the 98-100% range, illustrated in **Fig. 5.** These sites include spare gasifiers, as these units are for chemicals production.

| Company | Products | Feedstock | Startup |
|---|---|---|---|
| Lunan (China) | Ammonia ($H_2$) | Coal | 1993 |
| Sinopec (China) | Town gas | Coal | 1995 |
| Tampa Electric (U.S.) | Power | Coal | 1996 |
| El Dorado (U.S.) | Power/Steam | Coke | 1996 |
| Weihe (China) | Ammonia ($H_2$) | Coal | 1996 |
| Nanjing (China) | Chemicals | Coal | 1997 |
| Farmland (U.S.) | Ammonia ($H_2$) | Coke | 1999 |
| API (Italy) | Power/Steam | Visbreaker tar | 1999 |
| ISAB (Italy) | Power/Steam/$H_2$ | Asphalt | 2000 |
| Delaware City (U.S.) | Power | Fluid coke | 2000 |
| BOC (Australia) | Hydrogen | Refinery offgas | 2000 |
| Singapore Syngas | $H_2$/CO | Heavy oil | 2000 |
| U.S. refiner | Power/Syngas | Coke/Heavy oil | 2000 |
| SARLUX (Italy) | Power/Steam/$H_2$ | Visbreaker tar | 2001 |
| NPRC (Japan) | Power | Heavy oil | 2003 |
| Total/EDF (France) | Power | Heavy oil | 2003 |
| Repsol/ Iberdrola (Spain) | Power/$H_2$ | Heavy oil | 2004 |

*VI. Gasification units currently in operation or planned for startup*

As far as the commercial success of gasification technology is concerned, Tampa and El Dorado are running, and next year two Italian projects are scheduled to start up. We also have two units in Japan. These are all commercial and greater than 250 megawatts, with the exception of El Dorado. For conventional gasifier feeds of coal, coke, and heavy oil, there is commercially proven, highly reliable, and very low emissions technology. The fact that all those feedstocks are successfully gasified demonstrates the feedstock flexibility. We also have converted coal gasification units to heavy oil and coal units to coke. Gasification technology is selling, proving it to be cost effective. **Table VI** lists recent gasification units and others planned for startup.

Black liquor needs to be demonstrated. The first need is a site. The demonstration will probably need power export capability (i.e., a local power market with a reasonable price for power), as a large gas turbine will be needed to take advantage of the efficiencies available with cogeneration exporting steam to the plant. An alternate fuel to run the unit will be needed so that the investment is not dependent upon the black liquor gasifier operation. Particularly in the first year, the black liquor boiler can be run in parallel while gasification is demonstrated. TJ

*Jahnke is project director for marketing of IGCC technology in Japan with Texaco's Power and Gasification Division.*

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