Cool Water: Demonstration of a Clean and Efficient New Coal Technology

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Cool Water, the world's first commercial-scale, integrated coal gasification combined cycle power plant, has been operating successfully since May 1984 near Barstow, California. The 100-megawatt plant, which was completed ahead of schedule and under budget, is probably the cleanest coal-fired power generating facility now in commercial operation. An ongoing demonstration program at Cool Water shows that future baseload power plants that use this technology can be built modularly in increments of a few hundred megawatts and compete economically with much larger, conventional coal-fired power plants equipped for flue gas desulfurization.

If electric utilities are to continue to rely heavily on coal for power generation, ways must be developed to utilize this fuel that are more environmentally acceptable. One particularly promising new technology involves first gasifying coal in an exothermic process and then removing sulfur to form a clean-burning gas capable of driving a combustion turbine generator. The energy penalty that would otherwise make such a process uncompetitive is overcome by recapturing the heat produced by both the gasifier and combustion turbine, using it to produce steam, and then creating more electricity in a steam turbine generator. Taken together, these stages form an integrated gasification combined cycle (IGCC) power plant—the first fundamentally new method of generating electric power from coal that has reached commercial operation in the power industry since the 1920's.

A demonstration plant based on this technology that generates about 100 megawatts (MWe) of usable electric power is the Cool Water facility at Southern California Edison Company's power station at Daggett, California, near Barstow. The facility features a proprietary, second-generation coal gasification process developed by Texaco, Inc., coupled to slightly modified, commercial combined cycle power generating equipment provided by the General Electric Company. This commercial-size, modular train consumes 1000 tons of coal a day to produce power in compliance with the nation's strictest emission standards for sulfur oxides, nitrogen oxides, and particulates.

Since load growth for electric utilities is now low and uncertain, raising the capital for major 750- to 1000-MWe coal and nuclear plants has become extremely difficult. In addition, as much as 40 percent of the capital expenditures on conventional coal-fired power plants must now be devoted to pollution abatement equipment, especially flue gas desulfurization "scrubbers" (*1*). As an alternative, IGCC plants would enable utilities to add generating capacity in more easily financed 300- to 400-MWe increments, which would not require scrubbers and could be designed and constructed in 3 to 4 years after licensing approval. The Cool Water facility is designed to provide the necessary demonstration plant data and hands-on operational experience for utilities to confidently order fully competitive IGCC baseload plants in the near future.

Project Background and Objectives

The Cool Water program was designed to find ways to reduce utility dependence on imported oil and to improve the environmental acceptability of coal-based power generation. Studies indicate that IGCC plants offered substantial environmental advantages as a baseload (continuous) power generating option, compared to conventional coal-fired facilities equipped with scrubbers (*2*), and that their projected power costs would be competitive (*3*). The cost of building a 100-MWe IGCC plant in the Mohave Desert was estimated as $294 million (*4*).

The primary goal of the Cool Water program has been to design and construct a 100-MWe IGCC plant and operate it for a test and demonstration period of at least 5 years. Operation started in May 1984. Specific objectives include demonstration of acceptable system and equipment performance at a full commercial module scale, and confirmation of environmental acceptability within existing and proposed California environmental regulations, the nation's most stringent. As part of this confirmation, plant emissions will be determined with a wide variety of foreign and domestic bituminous coals, ranging from low to high sulfur content.

In addition, the operational flexibility of IGCC technology will be tested throughout all operating modes (start-up, shutdown, load following, and emergency response). The reliability and availability of both the plant and its individual pieces of equipment will be assessed, and the knowledge gained will be used to develop operating, maintenance, safety, and training procedures for future plants. Finally, economic and operations data will be determined that can be used as a firm design basis for multiple-module IGCC commercial plants.

Design and Construction Features

The design of the Cool Water plant is shown as a block flow diagram (Fig. 1). Approximately 1000 tons per day of coal are crushed, formed into a slurry with water, and pumped at an elevated pressure (40 atmospheres) to the gasifier, a relatively small vessel near the top of the plant's main tower. Here the slurry is combined with oxygen in controlled proportions and injected into the top of

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Table 1. Initial cool water plant operations versus plan in 1984.

Goal	Planned date	Date achieved
First syngas production	1 June	7 May
Initial electrical production	25 June	20 May
First IGCC power generation		30 May
Full-load IGCC operation		15 June
Ten-day SFC acceptance test completion	1 August	23 June

the gasifier. Partial combustion of the coal at approximately 1370°C produces a medium-Btu gas consisting mainly of hydrogen and carbon monoxide. At this temperature, the coal ash melts to form a slag.

Directly below the gasifier is a radiant cooler, in which the molten slag solidifies during a 36.6-m vertical fall. Radiant heat is recovered by a water wall encircling the interior of the cooler and used to generate steam at 1600 pounds per square inch gauge (psig). A lock hopper at the bottom of the radiant cooler collects about 90 percent of the coal ash as inert, glasslike grains of solidified slag, which is separated from water and screened before being collected for disposal. Recently the solidified slag has been certified as being nonhazardous so that it can be sent to a conventional land fill. The synthesis gas (syngas) next passes to a convection cooler, also about 36 m high, in which it passes over tubes filled with water to further remove heat and to raise additional steam.

After remaining particulates and condensates are removed, the syngas enters a Selexol desulfurization unit. In this proprietary process (*5*) a solvent is used to absorb most of the gaseous sulfur compounds, mainly hydrogen sulfide. The sulfur compounds then pass to a Claus unit, which converts them to elemental sulfur that is sold as a by-product. The remaining unconverted sulfur compounds are further cleaned in a SCOT (Shell-Claus Offgas Treatment) system and incinerated. Overall sulfur removal of 95 to 99 percent is achieved routinely.

After cleanup, the syngas is heated, and either it is saturated with water to control flame temperature, and thus minimize nitrogen oxide production, or steam is injected into the gas turbine combustors. The former method is less costly, but these alternatives are still being evaluated. The gas is then burned and expanded in a slightly modified 65-MWe General Electric Frame 7 (Model E) combustion turbine. An associated heat recovery steam generator (HRSG) provides superheated steam at 1350 psig and 510°C to a 55-MWe steam turbine. In addition to recovering the heat released during gas combustion, the HRSG also superheats the saturated steam produced in the syngas coolers.

Of the 117 MWe (gross) produced, approximately 20 MWe are used on site. This 20 MWe includes the electricity needed to power an "over-the-fence" Airco Inc. air separation plant (*6*) that supplies the gasifier with up to 1000 tons of 99.5 percent oxygen per day. The remaining approximately 100-MWe (net) output enters the SCE system on 230-kV lines, helping provide power to the utility's more than 3.3 million customers. The Cool Water facility is designed to operate initially at a heat rate of 11,300 Btu/kWh, although later modifications in the coal slurry and oxygen supply are expected to bring this down to 10,600 Btu/kWh.

One of the most important construction aspects of the Cool Water plant is that all major equipment was shop-fabricated for greater quality control, then shipped to the site and erected with minimal field operations. Probably the most dramatic element of this shop fabrication approach was the construction, shipment, and installation of the syngas coolers. Each cooler is 4.6 m in diameter and 36.6 m long with 10.2-cm-thick pressure vessel walls. The water wall in the radiant cooler was fabricated from approximately 100 sections (6.1 by 1.5 m) that had been "Alonized" (coated with aluminum oxides) to add corrosion protection against sulfidation. Each cooler weighed approximately 600 tons and the pair were the largest heat exchangers ever to be fabricated and shipped for installation. They were loaded onto a barge in Tennessee, which moved them through the Panama Canal to Long Beach, California. They were then brought individually to the Cool Water site by rail on a special Schnabel car, which is equipped with hydraulic supports that can shift a load laterally to negotiate tight curves. The transit from Chattanooga to Long Beach took a little less than 1 month, and within another month both vessels were placed in the predesigned tower. At that point, only four major field welds were required to complete the installation.

The successful demonstration of this modular shop fabrication and construction approach is an important contribution to planning generating unit additions with short lead times. Indeed, Cool Water has provided the experience for utilities to adopt such practices in the immediate future, starting a new era of shop-fabricated, field-installed power plants.

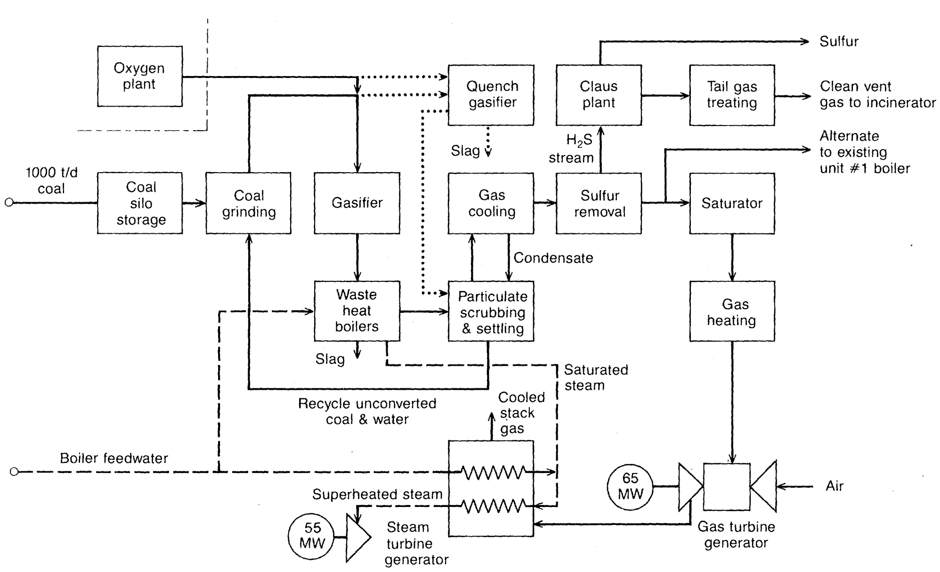

Fig. 1. Block flow diagram of Cool Water coal gasification program. The boiler feedwater heat exchange is not shown.

Schedule and Cost Performance

The Cool Water IGCC facility was constructed in approximately 28.5 months, with the plant being physically completed on 30 April 1984—1 month ahead of schedule (Table 1). The first syngas was produced on 7 May and the plant passed the critical 10-day performance test required by the U.S. Synthetic Fuels Corporation (SFC) by 23 June. The final cost to end of start-up was $263 million, more than $30 million under the original budget.

Plant Performance

During its first year of operation, the Cool Water plant has performed exceptionally well (Table 2). Although several minor start-up problems were encountered, no fundamental design limitations have been identified. Subsystem performance has exceeded design objectives with a few exceptions, which have tended to be mechanical in nature and thus readily fixed. Such problems have occurred less frequently than might have been feared in such a prototype plant, and none has indicated any inherent flaw in the IGCC process.

Coal handling has proceeded well and, once initial bottlenecks had been removed, the system has performed routinely at design levels. Soon after the plant start-up, worker unfamiliarity with coal handling led to a small dust fire in a day bin above the crushing equipment. Damage was minor and carbon dioxide is now added to reduce the potential hazard. Slurry preparation has worked satisfactorily, and the design slurry concentration of 60 percent coal has been achieved routinely.

Considerable wear and plugging have occurred in the mechanical slag handling equipment because of the abrasive nature of wet slag. Belt conveyors appear to be more satisfactory than drag conveyors for moving this material, and careful attention has been required to keep the lock hopper valves operating smoothly. Fine slag particles have also caused problems in the gas scrubbing system, which have been alleviated by the use of chemical additives.

The efficiency of carbon conversion and syngas production is better than the design basis, so that equipment installed to recycle unconverted carbon probably will not be used. Specific oxygen consumption has met design specifications and the AIRCO oxygen plant has been available more than 90 percent of the time. A liquid oxygen backup system is provided to cover periods when the oxygen plant is not operating. Both net power and overall heat rate have been superior to design specification. Plant capacity has varied considerably, as expected in a new plant, but has steadily improved and has been achieving about 60 percent in most months since a scheduled maintenance shutdown in March 1985.

An elaborate environmental monitoring program is being carried out at Cool Water and has already confirmed the plant's low emissions of sulfur, nitrogen oxides, and particulates. Table 3 shows emission test results compared to U.S. new source performance standards. The emissions measurements exceed the U.S. standards by factors of 10 or more. As a result, the Cool Water emissions are already at a level comparable or superior to those of a power plant burning natural gas. Comparable emission data are being collected for 3 percent sulfur bituminous coal from Illinois.

The combined cycle power train—including gas and steam turbines and the heat recovery steam generator—has performed reliably after the initial start-up period. No problems have been encountered with the use of syngas in the power train.

During a scheduled maintenance interruption during March 1985, several modifications were made to improve plant performance and reliability. The most important of these was connection of a spare quench gasifier that can be used when the main gasifier and its coolers are out of service. Instead of using the coolers to recover heat for making steam, this quench gasifier quenches the syngas with water to cool it and solidify the slag. Although the IGCC system will run at lower efficiency in the quench mode, the spare gasifier is a relatively inexpensive addition that will help increase overall plant availability. Other modifications made in March included changes in the gas saturator to reduce energy loss and further mechanical modifications.

Table 2. Overall performance of cool water plant. Abbreviations: GPM, gallons per minute; SCF, standard cubic feet (1 SCF = 280 Btu); and MWH, megawatt hour.

Coal	
Source [low sulfur (0.5%)]	Utah
Feed rate (ton/day)	1,000
Coal delivery (100-ton cars)	84
Oxygen	
Feed rate (ton/day)	920
Purity (%)	99.5
Water	
Operations makeup (GPM)	1,300
Wastewater (GPM)	250
Syngas production (10^6 SCF/hour)	3
Overall performance to 31 July 1985	
Total gasifier hours (No.)	5,465
Coal-fed [tons (dry)]	231,000
Gross power produced (MWH)	484,000

Future Directions

The initial experience with the Cool Water demonstration project supports the conviction that IGCC technology will be brought to full commercial realization. For this to come about, however, several near-term objectives must be met at the plant and some critical economic questions concerning the technology's competitive viability must be answered satisfactorily.

Among near-term objectives, the most important is to confirm the plant's heat rate so that commercial plants can be designed on a firm basis. Designs carried out indicate that the overall heat rate for commercial plants can eventually be brought to 9000 Btu/kWh.

Table 3. Cool water program heat recovery steam generator stack emissions.

	PPMv* (calculated)	Kg/hour	Kg/10^6 Btu (calculated)
SO_2			
Permit requirement	10	15.9†	0.016
Actual best result	9	15	0.015
U.S. new source			
Performance standard			0.136†
NO_x			
Permit requirement	50	63.5†	0.064
Actual test result	23	27.7	0.027
U.S. new source			
Performance standard			0.272
Particulates			
Actual test results		0.45	0.0005
U.S. new source			
Performance standards			0.014
Trace elements			
Fluoride		2.3	
Mercury‡		<2.9	
Beryllium‡		<0.73	

*Parts per million by volume. †EPA permit requirement for Utah (SUFCO) design coal, corresponding to 95% sulfur removal. Permit requirement for Illinois coal is 79.3 kg/hour, corresponding to 97% sulfur removal. ‡Removal (70%) of sulfur oxide for low sulfur coal. ‡None detected; detection limits shown.

This heat rate compares favorably with typical heat rates of about 10,000 Btu/kWh for pulverized coal plants with flue gas desulfurization. In addition, preparations are being made to operate tests on eastern high-sulfur bituminous coal. To obtain the data needed for utilities to make decisions regarding plants of this nature, efforts are being made to obtain more heat and material balance information routinely from automated data-retrieval systems. Continued improvement in plant reliability and on-line performance will also be sought.

The primary economic question that must be answered concerns the potential of IGCC plants to compete with other power generating options—specifically, direct coal firing with scrubbers and light water nuclear reactors. Detailed commercial plant design studies performed for EPRI based on the Cool Water plant configuration indicate that Texaco-based IGCC plants in the 400- to 600-MWe capacity range, using the next generation combustion turbine being developed by General Electric (an air-cooled unit with a 1204°C turbine inlet temperature), would result in an overall plant heat rate of only 9000 Btu/kWh for high-sulfur bituminous coal. The total plant investment is estimated to be approximately $1530/kWe (1984 dollars), with a cost of electricity of 4.8 cents/kWh at a 65 percent plant capacity factor. Such figures are quite competitive with those of both coal and nuclear plants built under today's standards.

Because IGCC plants can be added in capacity increments only one-third to one-half as large as other baseload plants, they offer an additional benefit to utilities faced with low and uncertain load growth. Rather than having to strive for economies of scale similar to those of competing options, IGCC plants can be built in modular trains that produce 150 MWe each from 1300 to 1500 tons of coal per day. Based on the Cool Water experience, an IGCC plant containing two or three such modular trains could enter service in less than half the time now required for much larger coal and nuclear plants.

A more flexible approach currently under consideration is "phased construction." In this approach, a combustion turbine is installed first and can quickly begin to generate electricity using natural gas or distillate fuel. Later a second combustion turbine is added, followed eventually by the gasification plant, heat recovery steam generator, and a steam turbine. This plan would allow a new plant to begin earning revenues by providing power using liquid or gaseous fuels, then shift to baseload operation using coal. The flexibility provided by this phased construction approach would offer utilities additional financial and capacity management benefits.

Although it still would be premature to estimate the ultimate success of the Cool Water plant or its impact on the electric utility industry, this demonstration program is clearly providing a firm basis on which individual utilities can appraise the IGCC technology. One indication of the seriousness with which the industry is considering this promising new method for utilizing coal is the recent formation of the Utility Coal Gasification Association, whose 35 utility members represent approximately half of all U.S. generating capacity. We expect that by mid-1986 such utilities could proceed with confidence to build a fully commercial IGCC plant, using the database established at Cool Water. The Potomac Electric Power Company has announced plans to install a 360-MWe integrated combined cycle gasification power plant on its system located in the Washington, D.C., area for operation in the 1990's.

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