Materials & Components

in Fossil Energy Applications

A newsletter of the U. S. Department of Energy
Advanced Research and Technology Development
Materials Program, and EPRI

Number 157 **April 1, 2002**

Development of technically and economically viable processes for the conversion and utilization of fossil fuels is a major objective of both the DOE Fossil Energy program and EPRI. Many new and different processes are being investigated in areas of coal gasification and liquefaction, improved power generation and advanced combustion. As these processes evolve to the pilot plant stage and beyond, materials selection and component design become increasingly important for reliable and economical operation. The newsletter is intended to serve as a medium for exchange of information and experiences pertinent to the use of materials and components among the communities interested in the development of fossil energy systems.

Operating Experience and Issues with HRSGs

In recent years, the majority of new power plants installed have been based on natural gas-fired combined-cycle gas turbines (CCGTs) that were primarily designed for continuous operation. The change in electricity market conditions brought about by deregulation in the United Kingdom and in the United States has resulted in the increasing requirement for these gas-fired plants to be operated in a cyclic mode. This trend led the United Kingdom power company Innogy, plc to make a careful assessment of the challenges that cyclic operation would pose for the combined-cyclic turbine plants. Particular consideration was given to problems posed by subjecting the plants to modes of operation outside their original design envelope, especially startup and shutdown characteristics, risks involving plant water chemistry, and damage management issues.

In most heat recovery steam generator (HRSG) designs, little consideration is given to access for repair and maintenance. As a result, in a typical horizontal-duct HRSG, shown schematically in Fig. 1, plant damage and duct leaks can lead to prolonged forced outage times, and refurbishment also can require extended periods, both of which are commercially unacceptable for cyclic (two-shifting) operation. This makes it imperative to assess the risks, introduce modifications, and to develop effective condition monitoring and maintenance programs. Many of the challenges involved in the move from base-load operation of HRSGs to cyclic operation are centered on component fatigue, which requires consideration of the contributions from mechanical, thermal, and corrosion sources.

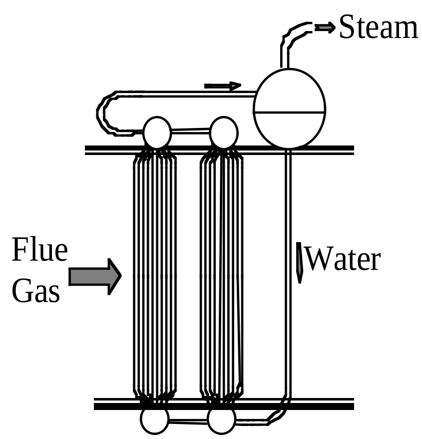

Figure 1. Schematic arrangement of evaporator tubes in a horizontal-duct HRSG

Thermal Fatigue

Thermal fatigue is a familiar problem in thermal power plants where it appears as cracking caused by the different rates of thermal expansion present during plant startup

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and shutdown.

In HRSGs the risk of thermal fatigue in the headers is comparatively small, since the operating temperatures are relatively low compared to large, fossil-fired boilers, so that the headers are therefore smaller and have thinner walls. Nevertheless, the conditions experienced by HRSGs coupled to gas turbines now under development will soon match those of a conventional plant.

A particular risk of thermal fatigue in HRSGs can arise when large volumes of condensate form in superheater elements while the plant is being gas purged or is shutdown. Depending on design, certain headers are more at risk than others, and this risk can be ranked by taking account of the location, wall thickness, component geometry, and operating temperatures. Particular attention must be given to examining the detailed tube layout and support arrangements to identify potential loading mechanisms from differential tube and header expansion. Once this is achieved, a targeted inspection program can be implemented to identify problems as they develop, and to allow preventive maintenance.

One cause of the formation of condensate is the loss of heat from the HRSG while it is shut down. This can be reduced by using a stack damper. A further source of cool down of the HRSG is from the passage of cold air from the normal purge operation of the gas turbine after tripping or a planned shut down. This particularly affects the leading superheater circuits of the HRSG, where large quantities of condensate can form. If this condensate is still present when the turbine bypass valves are open, it is likely to impact on the outlet headers and outlet pipework system, potentially causing both fatigue and distortion. These conditions also lead to the possibility of fatigue being caused to the header stubs. Further, the original drains frequently are designed to cope only with cold-start conditions, which are not the most onerous. Modeling by Innogy of condensate formation during plant startup or shutdown sequences has allowed the drains to be resized and located at the optimum points to facilitate the removal of condensate from the HRSG.

Preheaters and Economizers

For preheaters and economizers, the likelihood of external dew-point corrosion occurring, and of steaming when off-load is important. In some low-temperature circuits, it is often possible for temperatures to be higher off load than when the plant is on load, because heat is released from the high-pressure circuits off load. Additional risks for economizers are header stratification, and stub cracking resulting from the thermal shock that occurs when cold water is introduced at startup. This can be a particular problem in vertical tube economizers that are generally less flexible to contraction of the inlet tubes as cold water is introduced, compared with the other rows. The solution to this problem may involve recirculating the water to reduce the temperature differentials. Introduction of additional flexibility into the routing of tubing, or modification of the design or placing of the supports also can be effective. The tube elements in vertical-duct HRSGs are likely to be more mechanically flexible and less at risk of failure than in horizontal-duct designs. This is mainly because in the vertical-duct designs the tube modules are arranged in horizontal serpentines between inlet and outlet headers, so that they can readily accommodate differential expansion of the tubes within the tube supports. In contrast, in horizontal-duct designs with vertical tubes, the need to have intermediate headers at the ends of the tube passes results in more constraint on tube movement. Horizontal tubing also eliminates the possibility of steam locking that can occur in vertical-tube designs with inverted loops instead of mixing headers.

Superheaters and Reheaters

In superheaters and reheaters, the risk of fatigue from cyclic operation is focused mainly at the stub-to-header weld, and at other stress-concentrating features. The superimposition of creep on these components can exacerbate the damage caused by fatigue as the plant ages. The level of fatigue risk in headers is very dependent on the design of the tube stub-to-header weld: these are frequently of a partial-penetration design, similar to a socket weld detail. Since a large HRSG can involve up to 19,000 separate welds, this type of weld represents a significant risk, especially where thin section tubing is involved.

Other components such as ducts, seals, casings, and insulation also may suffer from fatigue. Tube plate movement, and wear of the tube fins also can be problems in vertical-duct designs. In many cases the issues that arise with these components can be readily overcome at the plant concept and design stage but, once installed, present considerable maintenance difficulties.

Water Chemistry

Since the wall thickness of tubing in many HRSGs is much less than in conventional boiler plants, it is less tolerant of loss of wall section through pitting attack or other corrosive loss. Horizontal HRSG designs are not self draining, so that careful consideration must be given to the control of water chemistry during off-load periods to prevent corrosion. Further, cyclic operation makes it increasingly difficult to regulate and control the boiler water chemistry. Problems such as phosphate ‘hideout’ can be difficult to manage, and this has led to the replacement of phosphate dosing in favor of all-volatile treatment in the high-pressure circuits of some of the HRSGs operated by Innogy. Another problem of cyclic operation is that control of dissolved oxygen in the boiler water is more problematic, since the original plant deaeration systems are frequently deficient under this mode of operation. These concerns lead to a requirement for increased emphasis on monitoring of boiler water chemistry, since batch sampling may be of only limited use. The choice of sampling locations and techniques that will be effective under cyclic operation requires careful consideration.

Pipework

For plants subjected to cyclic operation, particular attention is required to identify any interface problems between the design of the pipework and the requirements of particular items or plants such as the HRSGs. In particular, if two or more HRSGs are interconnected, there is a possibility of temperature differentials occurring in common pipework. Further, experience has shown that pipework-support systems may not be capable of the duties imposed by cyclic operation. Hence, it is recommended that a program of both hot and cold surveys be carried out to ensure that movement of pipework and the stress levels developed are within acceptable limits, and that support and pipework defects are identified in any plant subjected to prolonged cyclic operation.

Controls

In many CCGT plants, automated startup sequence controls can be a limitation during cyclic operation. Sequence logic can be upset by minor faults in the plant instrumentation and control system, causing considerable delays that can be difficult to understand and address because of the complexity of the system.

Abstracted from: D. Bogert, *Innogy, plc, Swindon, United Kingdom*, "Dealing with the Rigors of Cyclic CCGT Operation: An Operators Perspective," Modern Power Systems, pp.33-35, October 2001. Published by permission of Wilmington Publishing.

Operating Experience From Coal-Based IGCC Power Plants

The four major coal-based integrated gasification combined cycle (IGCC) plants, each of 250-300 MW, commissioned in the 1990's have now either entered or are about to enter full commercial service. These pioneer plants, two in the United States (Tampa and Wabash), two in Europe (Buggenum and Puertollano) experienced the usual spate of problems during their initial two or three years of operation. However, they are now running with much improved availabilities, similar to those of many other solid-fueled plants. Furthermore the lessons learned from these pioneer plants suggest several areas where materials development could further improve the availability of IGCC plants as currently commercially offered.

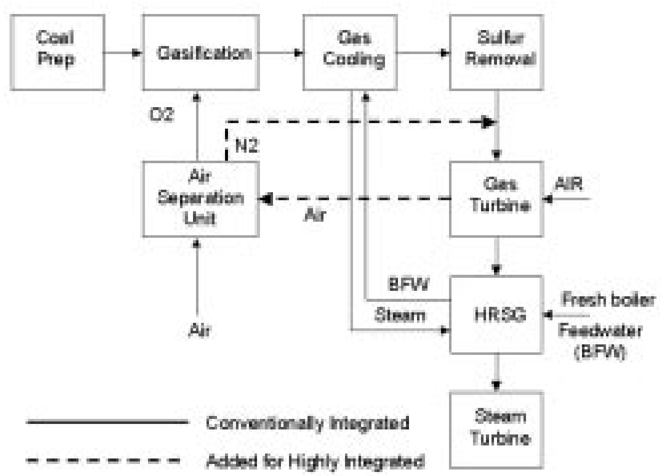

Figure 2. Schematic diagram of a generic IGCC plant

An overall block flow diagram of a coal-based IGCC plant is shown in Fig. 2. All of the successful operating plants are oxygen blown, and operate at a pressure of 25-30 bars. Extremely stringent emission standards can be achieved by removing the emission-forming constituents from the syngas under pressure, prior to combustion in the power block:

- Sulfur is removed (99.5-99.99%) from syngas by processes widely used in petroleum refining and natural gas processing, and is produced as sulfur or sulfuric acid for sale.
- NO_x emissions are controlled by modulation of the gas turbine firing temperature using nitrogen and/or moisturization.
- Particulates are removed from the syngas by filters or water wash prior to combustion, so that emissions are negligible.
- Chlorine is removed from syngas by water wash and subsequent wastewater treatment; salt or ammonium chloride can be produced as by-products if zero water discharge is required.
- Mercury and other hazardous air pollutants (HAPs) can

be removed from the syngas by absorption on an activated carbon bed, using proven technology from the chemical industry.

The coal ash is produced as a dense slag with several potential uses [no limestone scrubber sludge or large volume of solid waste as there would be with PC or circulating fluidized-bed combustion (CFBC)]. Furthermore if CO_2 removal is required from coal-based power plants, CO_2 removal from syngas under pressure is expected to be much less expensive than post-combustion removal from the flue gas of PC or natural gas-fired combined cycle (NGCC) plants.

The main issues with regard to the widespread adoption of this technology are considered to be: (i) demonstration of high availability that at least equals existing direct PC plants and (ii) capital cost reduction to compete with state-of-the-art pulverized coal (PC)-fired plants and natural gas-based combined cycles.

Experience With Coal-Based IGCC Plants

The key design features of the four plants of interest are summarized in Table I. The major components and overall design performance of these plants, compared with that achieved to date are shown in Table II. In the US units the gasification island has usually been the largest unplanned outage contributor, whereas in the European units the gas turbine combustor vibration problrms and hot spots have been the main concern.

Air Separation Units: Air separation units (ASUs) typically have annual equivalent availabilities of ~98%. However, in the last two or three years, the ASUs at Tampa and Wabash have experienced unusual outages. At Tampa the ASU availability was uncharacteristically low in Years 4 and 5. The major problem in Year 4 was a distillation column leak, and in Year 5 failure of the 4th stage impeller of the main air compressor required 28 days to weld repair cracked joints in the impeller and to return the machine to service. At Wabash the longest unplanned outage in 2000 was caused by a moisture-related ground fault that damaged the oxygen compressor motor terminal box in the ASU. A weld failure in the cold box also caused a significant outage for insulation removal and weld repair.

The ASU typically represents 10-15% of total plant cost or 120-170$/kW. There is, therefore, considerable incentive to develop new ASU processes. Air Products and Praxair each are leading teams to develop ionic transport membranes (ITMs) operating at 800-900°C. A preliminary estimate of the cost impact of the ITM ASU on IGCC is a reduction of 100 $/kW, and a heat rate reduction of 200 Btu/kWh. If realizable, this gain is impressive, but concerns remain over the durability of the high-temperature components and the integration of the high volume of high-temperature vitiated air into the IGCC design. Ideally, a separation process (membrane) would be preferred that operates at closer to ambient temperatures.

Gasification Units: The main causes of outage in the slurry-fed, refractory-lined gasifiers at Tampa and Wabash have been injector tip failure and refractory wear. The injector tips are typically made of wear-resistant material (WC-based alloys have been used). The typical life of injector tips at Tampa is 50-60 days, while Wabash has claimed a slightly longer life of up to 3,000 hours. Injector life on the dry coal-fed Shell gasifier is longer, typically ~1 year. The cause of tip failure has usually been described as stress corrosion cracking involving dissolution of H_2S from the gasifier in liquid slurry present (however briefly) on the tip.

The refractory life in the Texaco gasifier at Tampa and the E-GAS gasifier at Wabash has been about two years. The replacement process, including cool down, refractory replacement and heat up, requires an outage of more than 30 days to accomplish. Wear is pronounced in the slag removal areas and needs regular repair (by patching). Unless refractory replacement can be scheduled to coincide with other necessary inspections (e.g. gas turbine hot gas path inspections) they significantly reduce plant availability. In larger (500 MW) commercial plants a spare gasifier may be required to meet availability goals. In the Shell gasifier the relatively modest refractory coating of the water wall is easy to patch/replace in a few days, so that a major outage is not required.

The slag tap at Wabash has also plugged on three occasions causing a 10-12 day outage. More regular attention to slag viscosity measurements apparently has solved the problem. However, it is recommended that all future plants should include a slag breaker in the slag removal path.

All the entrained gasifiers have experienced erosion/corrosion in the gray/black/slag water recycling piping. While there is a recognized need to keep the chloride content of the circulating water low to minimize corrosion, the presence of slag particles results in a very aggressive erosive/corrosive environment. In addition, Buggenum and Puertollano have experienced problems with overheating and corrosion of the slag shield at the slag outlet, and a new cooled design may be required to solve the problem.

Table I. Design Aspects of Major Coal-Based IGCC Projects

Project Name	Wabash River	Tampa	NUON (formerly Demkolec) Buggenum	ELCOGAS
Location	Indiana	Florida	The Netherlands	Spain
Gasification Technology				
Gasifier type	E-GAS™: 2-stage, up-flow, entrained	Texaco: single-stage, down-flow, entrained	Shell: single-stage, up-flow, entrained	Prenflo: single-stage, up-flow, entrained
Feed system	coal water slurry	coal water slurry	dry coal lock hoppers	dry coal lock hoppers
Slag removal	continuous	lock hoppers	lock hoppers	lock hoppers
Slag fines recycle	yes	yes	yes	yes
Recycle gas quench	some to second stage	none	large recycle quench to 900°C	large recycle quench to 900°C
Syngas Cooler	down-flow, fire tube	down-flow, radiant water tube and convective fire tube	down –flow, concentric coil, water tube	upflow/down-flow (two pass) radiant and convective water tube
Supplier	Boris (DB)	MAN - radiant Steinmuller-convective	Steinmuller	Krupp Uhde – radiant. Steinmuller – convective
Structure height, m (ft)	55 (180)	90(295)	75 (246)	80 (262)
Air Separation Unit				
Supplier	Liquid Air	Air Products	Air Products	Air Liquide
Pressure (bar)	conventional (5)	high (10)	high (10)	high (10)
-Air supply compressor	100% separate	100% separate	100% from gas turbine	100% from gas turbine
Nitrogen use	mostly vented	GT NO_x control	syngas saturator for GT NO_x control	syngas saturator for GT NO_x control
Gas Clean Up				
Particulate removal	candle filter at ≈ 350°C	water scrub, no filter	candle filter at 230°C	candle filter at 240°C
Chloride removal	water scrub	water scrub	water scrub	water scrub
COS hydrolysis	yes	added 1999	yes	yes
AGR process	MDEA	MDEA	sulfinol M	MDEA
Sulfur recovery	Claus plant with tail gas recycle to gasifier	sulfuric acid	Claus plant with tail gas treating unit (SCOT)	Claus plant with tail gas treatment and recycle to COS
Clean Gas Saturation	yes	no	yes	yes
Gas Turbine				
Type	GE 7 FA	GE 7 F	Siemens V 94.2	Siemens V 94.3
Combustors	multiple cans	multiple cans	twin vertical silos	twin horizontal silos
Firing T. °C (°F)	126 0 (2300)	1260 (2300)	1100 (2012)	1260 (2300)
NO_x control	saturation and steam injection	nitrogen to combustors	saturation and nitrogen dilution	saturation and nitrogen dilution

Syngas Heat Exchanger: All four IGCC plants feature saturated steam generation from the hot raw syngas in the syngas coolers (SGC). Fouling and associated corrosion of the SGCs has occurred to a varying extent at all the plants. Tampa has vertical radiant water tube and horizontal fire tube convective SGCs. Buggenum and Puertollano have water tube SGC designs. Wabash has a down-flow fire tube design supplied by Borsig. The SGC fire tube design is much less expensive than the water tube design, but may be more susceptible to fouling. Materials that would permit superheated steam production in the SGC would improve the steam cycle efficiency. Both Buggenum and Puertollano have conducted some materials tests in this regard. If materials were available that could enable

Table II. Design and Actual to Date Performance of Major IGCC Projects

Project	Wabash	Tampa	Buggenum	Puertollano
Gas turbine (MWe)				
Design (achieved)	192 (192)	192 (192)	155 (155)	182.3 (185 -200 at ISO)
Steam turbine (MWe)				
Design (achieved)	105 (98)	121 (125)	128 (128)	135.4 – 135 at ISO
Auxiliary power (MWe)				
Design (achieved)	35.4 (36)	63 (66)	31 (31)	35 at ISO
Net power (MWe)				
Design (achieved)	261.6 (252)	250 (250)	252 (252)	300 at ISO
Net heat rate (HHV)				
Design (achieved)				
- Btu/kWh	9030 (8600)*	8600 (9100)**	8240 (8240)	8230
- kJ/kWh	9530 (9071)*	9075 (9599)**	8695 (8695)	8681
Net plant efficiency (%)				
LHV basis: design (achieved)	39.2 (41.2)*	41.2 (38.9)**	43 (43)	42.2
HHV basis: design (achieved)	37.8 (39.7)*	39.7 (37.5)**	41.4(41.4)	41.5

*Adjusted for HRSG feed water heaters in service

**Adjusted for gas/gas exchangers in service.

heat exchange between hot raw syngas and clean syngas, the energy input into the Brayton cycle could be increased with a significant improvement in overall efficiency. Such high-temperature heat exchangers may also benefit other advanced power cycles under development.

Hot Gas Filtration: As a first principle it is advantageous to remove the particulate matter from the syngas at as high a temperature as possible. However a temperature below 650°C is necessary to avoid alkali vapor condensation, and below 540°C is probably preferred to avoid the use of unreliable refractory-lined piping and to allow the selection of materials that will provide more reliable operation of the gas turbine fuel control valve. The operating temperatures of the hot gas filters in the current IGCC plants are ~350°C at Wabash (metallic elements) and 250°C at Buggenum (ceramic elements) and at Puertollano. Solids bridging, candle degradation and breakage, and fouling and corrosion of metallic components are continuing problems for which more development and exposure time [such as at the DOE/SCS/EPRI Power Systems Development Facility (PSDF) and elsewhere] is required to find workable solutions. Metallic (iron aluminide) filters appear promising but chloride-related down time corrosion remains a threat. It should also be noted that if hot gas separation membranes (e.g. for CO_2 and H_2 separation) are to succeed, hot gas filtration is the *key enabling technology* to avoid the inevitable fouling of membrane surfaces by particulate matter.

Hot Gas Desulfurization: Despite considerable R&D in both the US and Europe a low cost, attrition-resistant sorbent for syngas desulfurization is not available. All of the existing IGCC plants use COS hydrolysis at about 200°C and conventional acid gas removal (AGR) processes at ~40°C for desulfurization. Ammonia and chloride are typically removed in a water wash step prior to the COS hydrolysis unit. If a desulfurization process could be developed for removal of H_2S at 250°C, then moist syngas could be fed to the gas turbine without loss of energy and mass through condensation. However mercury and other trace metals also need to be removed before the gas turbine [unless they are to be removed from the high volume flow of flue gas downstream of the heat recovery steam generator (HRSG)] and it is considered rather unlikely that effective Hg removal could be effective at the higher temperatures.

Mercury and other Trace Element Removal: The US Environmental Protection Agency is planning regulations for Hg removal from coal plants.Eastman Chemical has reported 90-95% Hg removal from syngas using presulfided activated carbon beds at a system pressure and 30°C (18 years experience). This process also captures other trace elements and species that should also improve downstream operations. There should be less formation of heat-stable salt in the AGR, and less deposition in the gas turbine and HRSG. However there is a need for additional data on speciation, alternative sorbents, and the effect of different upstream processing on Hg capture.

Membrane Separation of Gas Species: Many organizations are conducting R&D on new membranes to effect the separation of syngas gas species; sometimes shift reaction capability is also planned to be incorporated. Such membranes will almost certainly require prior removal of the particulate matter. The effect of volatile trace metals and chlorine on the membranes must also be considered. Unfortunately, most of the candidate membranes under development (e.g. for CO_2/H_2 separation) rely on a large pressure differential, so that one product is delivered at high pressure and the other low pressure. However, it would be preferred to have both products at high pressure to avoid compression costs and associated energy losses. Some pressure differential is obviously required, but it would be preferable to minimize this for the reason just mentioned.

Advanced Turbine Systems RD&D Needs

Long blade life at high temperatures (coatings, cooling, etc.) is obviously needed in both natural gas-fired and IGCC applications. Advanced gas turbines such as the GE H-series, incorporating developments from the U.S. Department of Energy's Advanced Turbine Systems program, are designed for operation on natural gas and need further modifications to operate efficiently on the syngas produced in IGCC plants. Probably a new compressor with additional surge margin would be required to take full advantage of the extra mass flow and electrical output possible in IGCC.

Additional combustion and system testing for syngas and H_2 firing is also needed to achieve the ultra-low NO_x emission levels that are under consideration in some environmental jurisdictions. The possibility of requiring the installation of selective catalytic reduction (SCR) systems has been suggested. However before any regulations are imposed that might require SCR, additional work is needed to determine what sulfur level is required in syngas to avoid deposition in the HRSG and corrosion by ammonium bisulfate.

RD&D Issues For Advanced Power System Concepts

Humid Air Turbine-type cycles integrate well with lower-cost quench gasification, where low-level heat can be used to provide additional energy to the gas turbine (Brayton) cycle. The equipment uses standard components, but some development is needed.

Siemens-Westinghouse has proposed a solid oxide fuel cell (SOFC) with ITM-type processing on the anode gas to complete fuel oxidation and yield a flue gas consisting of $CO_2 + H_2O$. This would enable the use of clean syngas (or natural gas) to produce pure CO_2 without need for shift and prior CO_2 removal and attendant energy losses. The cost of SOFCs currently is too high, and considerable efforts are in progress with the aim of markedly reducing the cost per kWh for these units. If SOFCs are to penetrate beyond the distributed generation market into central stations, then the additional materials costs for manifolding of hot gas streams also need to be reduced.

The O_2-fired rocket engine moderated with recycle CO_2 proposed by Clean Energy Systems (see Materials and Components No. 139, pp. 10-11, April 1999) could also use clean syngas or natural gas to produce a stream of pure CO_2. The challenges inherent in this cycle are the rocket engine development and the materials needed for the high-temperature steam environment, as well as the high cost of the large ASU.

IGCC for CO_2 Removal, Hydrogen and Clean Transportation Fuels Production

If CO_2 removal is required either for environmental reasons or for the production of hydrogen or clean transportation fuels (by Fischer Tropsch synthesis) then shift reactors and associated heat exchange can be added in the syngas treatment train. For methanol or Fischer Tropsch synthesis the syngas should be shifted to a H_2/CO ratio > 2. The reactions are:

$$CO + 2H_2 \Leftrightarrow CH_3OH$$

and

$$nCO + 2nH_2 \Leftrightarrow nCH_2 + nH_2O$$

For hydrogen production or if CO_2 removal for use or sequestration is needed or required, then the shift reaction is taken all the way (or as far as possible) to hydrogen.

It is possible to design now for a clean IGCC by using a phased approach to IGCC construction in which designs and plant layout are used that will permit the addition of shift reactors and associated equipment when required for CO_2 emissions control, or if co-production of H_2 or liquid fuels or chemicals can be warranted. Given the uncertainty of future US regulations with regard to CO_2 removal, and whether permanent CO_2 sequestration can be accomplished, this pragmatic phased construction approach can be a valuable strategic hedge to ensure that coal-based plants can continue as part of a diverse power generation portfolio.

-From: Neville A.H. Holt, *EPRI*; based on a paper presented at the 3rd International Workshop on “Life Cycle Issues in Advanced Energy Systems, Woburn, England.

Inhibition of Vanadium-Induced Hot Corrosion in Gas Turbines

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Abstracted from: E. Rocca, P. Steinmetz, *University Henri Poincare*, *and Moliere, GT Energy Products, Europe*, "Revisiting the Inhibition of Vanadium-Induced Hot Corrosion in Gas Turbines," Paper 2001-GT-0005, presented at the ASME Turbo-Expo 2001, June 4-7, 2001, New Orleans, LA.

Underground Coal Gasification in Australia

Underground coal gasification (UGC) to convert coal in situ to a combustible gas that can be used as a fuel or as a chemical feedstock has been used in commercial-sized projects in the former Soviet Union for more than 40 years. Although significant research programs have been undertaken in the United States and Western Europe, these activities have not resulted in any commercial development so far. There now appears to be a combination of factors that gives a new emphasis to the commercialization of this technology in Australia. These include the new competitiveness of the power industry, a desire to switch to gas-fired gas turbines, and revived interest in synthetic fuels as a result of high oil prices. The project described in this article is located near the town of Chinchilla, west of Brisbane in Queensland, Australia. The project design includes an underground coal gasification production facility, a gas processing plant, and a power generation block. As of October 2001, gas had been produced for 21 months, and final process design, plant selection, and financing were in progress with an anticipated commissioning date at the end of 2002.

In its simplest form, the UGC process is initiated by drilling two adjacent bore holes into a coal seam to a depth typically greater than 100 m, then injecting pressurized oxidants such as air or oxygen/steam into one of the bore holes, and subsequent down-hole ignition of the coal seam and removal of the product gas from the second bore hole. Typically, the gas recovered using air injection has a calorific value in the range 3.5-5.0 MJ/m^3 (117-167 Btu/ft^3) with approximately twice these values being achieved with oxygen injection.

There are obviously a number of site-specific technical factors that are important in UGC, including the geology of the coal seam, overburden thickness and properties, and the hydrogeology of the coal seam and surrounding strata. Process parameters such as operating pressure, outlet temperature, and gas flow are governed by the coal and rock properties, and these vary with time and location. As a result, information on the processes conditions must be constantly monitored and updated as the gasifier develops. The underground gasifier can be made up of a number of underground reactors with largely independent outputs. This allows the gas streams from different reactors to be mixed as required to ensure consistent overall gas quality, and to vary gas output as desired. No ash or slag removal or handling is necessary with this process, since they stay behind in the underground cavities. Furthermore, ground water influx into the gasifier creates an effective steam jacket around the reactor making the heat loss in situ tolerably small. Optimal pressure in the underground gasifier promotes ground water flow into the cavity, thus confining the chemical process to the limits of the gasifier and preventing contamination in the area.

The Chinchilla gasifier involves a 10 m-thick coal seam and depths up to 140 m. It is designed to produce up to 155,000 nm^3/h of gas, but will normally be operated at 63% capacity. The product gas at the wellhead has a pressure of 10.5 barg and a temperature of 300°C. The gas contains as little as 4 ppmw of particles, and has an average water content of about 17% by volume. The water stream contains commercially-recoverable quantities of phenols and ammonia, and the liquid hydrocarbons condensed from the gas have a calorific value of 40 MJ/kg and have similar physical properties of those of a light crude oil. Because of the nature of the process, 100% availability of the gasifier can be achieved and the low cost of the gas results in an ability to sell into a power market where the current price can be as low as U.S. 1.5¢ per kWh.

Gas Turbines

The basic technical and functional requirements of gas turbines intended to be fired with syngas are different from those of gas turbines operating on natural gas. Because of the low heating value of syngas compared to natural gas, significantly more fuel is required in an integrated gasification combined cycle turbine, so that modifications are required to allow a greater mass flow in these systems. The syngas-specific features relate primarily to the combustion and fuel systems, but also include some special fire protection, packaging, and control modifications. The Chinchilla project is based on a General Electric Frame 6B gas turbine, which has an estimated combined cycle output of 67 MW(e). The gas turbine used employs a multiple can-angular combustor design that provides excellent flame stability, and has mixing properties that produce very low emissions. Natural gas or distillate is required as a startup fuel, so that syngas turbines must be capable of handling dual fuels.

Gas Processing Plant

The processing plant is used to condition the gas to satisfy strict requirements of the gas turbine. The raw gas produced at the wellhead is cooled to separate condensables and is then cleaned using sintered metal candle filters. Since candle filters require dry gas for normal functioning, the gas is reheated to a temperature above the dew point before entering the filters. Following filtration, the gas is compressed up to the level required by the gas turbine. Water separated from the gas flow is used to cool the raw gas in a heat exchanger, and to cool the air in the air compressor intercoolers. This water also will be used in the operation of the steam cycle once the steam turbine is installed.

Abstracted from: L. K. Walker, *Linc Energy, Limited,* M. S. Blinderman, *Ergo Exergy, Inc.*, and K. Brun, *G. E. Power Systems*, "An IGCC Project at Chinchilla, Australia, Based on Underground Coal Gasification," Paper presented at the 2001 Gasification Technologies Conference, San Francisco, October 8-10, 2001.

New Projects to Explore Ideas for Capturing and Storing Carbon Gases

A "breakthrough" development that could dramatically reduce the threat of global climate change is carbon sequestration – the capture and storage of greenhouse gases that otherwise would be expelled from energy facilities. As part of the U.S. Department of Energy's carbon sequestration effort, three new projects have been chosen for funding:

University of Texas at Austin, Austin, TX will develop an alternative solvent that captures more CO_2 while using 25 to 50 percent less energy than conventional,state-of-the-art MEA (monoethanol amine) scrubbing, a more conventional CO_2-removal method. By building on bench-scale system modeling studies and pilot-scale experiments, the university will develop and validate a process model to optimize parameters such as solvent rate, and stripper pressure. Because gas/liquid contact and CO_2 mass transfer would be enhanced, capital costs may be reduced.
Total project cost: $728,007; DOE share: $461,849; project duration: 3 years.

University of Massachusetts, Lowell, MA will perform a laboratory study of a deep-ocean CO_2-sequestration method that blends liquid CO_2, water and finely-ground limestone into an emulsion that could be pumped into the ocean for long-term storage. Because this emulsion has a higher density than seawater, it would sink to the deep ocean. This would make it possible to sequester CO_2 at shallower depths than current directed-injection techniques. Soluble calcium bicarbonate, food for aquatic organisms, would be formed and stored in the ocean indefinitely. The emulsion will be analyzed in-situ through windows to study its structure, droplet size and stability as a function of time (for one year). In the second year, the flow characteristics of an emulsion of liquid CO_2, water and a possibly a surfactant will be investigated. The optimal mix of reagents to produce a stable emulsion will be determined.
Total project cost: $267,840; DOE share: $206,290; project duration: 2 years.

University of Kentucky Research Foundation, Lexington, KY proposes to displace natural gas from black Devonian shales and use these organic-rich rocks to store CO_2. Studies have shown that CO_2 is preferentially adsorbed by gaseous coals in deep, un-minable coal seams in very much the same manner that gas is naturally stored in these coals. In fact, CO_2 displaces methane molecules in the ratio of two to one. The study will determine whether a similar phenomenon takes place in Devonian black shales, which serve as both a source and a trap for natural gas. This project will measure CO_2 adsorption along with natural gas production, and determine which shales offer the best sequestration potential. At the end of the project, data will be available through publications and Web-based systems.
Total project cost: $532,966; DOE share: $364,453; project duration: 2 years.

For more information, contact: Charles E. Schmidt, DOE National Energy Technology Laboratory, 412-386-6090, e-mail: schmidt@netl.doe.gov.

An Efficient Separation System for Hydrogen Recovery

When coal is gasified, a large fraction of the very hot gas produced is hydrogen. Hydrogen itself is a high-value-added fuel. One way to help make an integrated gasification combined cycle system economical is to have a unit that can separate and collect a significant portion of the hydrogen for use in more valuable ways, such as fuel for fuel cells or for use in petroleum refinery catalytic crackers. This approach is often termed 'fuel decarbonization,' and simply refers to the process of converting a hydrocarbon fuel into a carbon-free fuel, i.e., hydrogen. For such a process to be viable, it must include provisions for separating and capturing CO_2 and other oxides of carbon that are produced.

Researchers at the Inorganic Membrane Technology Laboratory (IMTL) in Oak Ridge, Tennessee, have developed a process to manufacture a highly-efficient, defect-free separation system that can effectively separate and isolate hydrogen from other gases in coal-derived synthesis gas. The Oak Ridge-developed gas separation system consists of a porous membrane made of a ceramic material. The difference in size between molecules of hydrogen and molecules of CO, CO_2, and hydrocarbon gases allows the smaller molecules of hydrogen to pass through the porous material and away from the remaining gases. The high-purity coal-derived hydrogen may then be collected and used as a feedstock for other advanced energy producing technologies or for chemical and petroleum processing such as hydrotreating.

Development of an inorganic porous membrane for separating hydrogen from very hot gases posed a serious technological challenge, since a separation device must be able to tolerate both high temperatures and harsh environments associated with coal gasification processes. Laboratory tests have shown that the Oak Ridge-developed process can provide sufficiently high separation factors, and additional tests at the National Energy Technology Laboratory (NETL) as well as at the Oak Ridge National Laboratory (ORNL) will to determine the stability of the membranes under simulated operating conditions.

In a related development, IMTL researchers are developing an economical means of producing a membrane separation system consisting of a carbon membrane on a porous metal support. While being developed primarily for use in petroleum-refining operations to economically recover unused hydrogen from the refinery purge gases, variants of this system may also be used in existing fossil fuel facilities to remove greenhouse gases.

Prototype testing of these new products will be conducted at the NETL and ORNL later this year. Funding for this research was provided through the DOE's Office of Fossil Energy through the Advanced Research Materials Program and the Petroleum Technology Program, both of which are administered by NETL. The IMTL is located at the DOE's East Tennessee Technology Park, which is operated by Bechtel Jacobs Company LLC.

For more information, contact: Steven Wyatt, (865) 576-0885 in Oak Ridge, Tennessee, or David Anna, (412) 386-4646 in Pittsburgh, Pennsylvania.

Update on Baglan Bay CCGT Power Plant

Baglan Energy Park is being developed on the site of BP Amoco's old Port Talbot works through a partnership between BP's Chemicals and Gas & Power businesses, the Neath Port Talbot County Borough Council, and the Welsh Development Agency, and is intended to attract energy users through the ready supply of electricity. A major feature of this development is a new combined-cycle gas turbine (CCGT) power plant, which will consist of a General Electric (GE) Frame 9H gas turbine, a heat recovery steam generator and steam turbine, and an electrical generator, as well as a GE LM2500 aero-derivative power generation system capable of black starting (i.e. starting with no electrical input). This is the first installation of a GE Frame 9H machine, and is expected to become a showcase for General Electric gas turbine technology.

The GE 9H is 12m long, 5m in diameter, weighs 370t, and is rated to produce 480MW of electricity in combined cycle operation. The engine incorporates technologies developed as part of the U.S. Department of Energy's Advanced Turbine Systems program, and is expected set a new standard for efficiency, close to 60% (based on the lower heating value of the natural gas fuel). The efficiency of the power plant will be further enhanced through the use of district heating to the surrounding area.

The first application to build a power plant at the site was made in 1996. This was made by BP Amoco, and was originally intended for a 1,100MW CCGT power plant. The new facility was approved by the UK's central government in early 1999. The H System was constructed in the General Electric facility at Greenville, South Carolina, and shipped to Baglan Bay in December 2000. After start up, it will undergo characterization testing through the summer of 2002 and a period of operation to validate its long-term performance and capabilities. However, it will still be expected to be fully commercial in 2002.

Operation of the new IGCC system will allow the closure of Baglan Bay's old power plant, which will substantially reduce the emissions of CO_2, NO_x, SO_x, and particulates from the site. Excess power will be exported to the local Welsh electricity grid.

Information extracted from the http://www.power-technology.com website.

The European COST Program

COST is an intergovernmental framework for European **Co**-operation in the field of **S**cientific and **T**echnical Research that was founded in 1971 to allow the co-ordination of nationally-funded research on a European level. The overall goal of COST is to ensure that Europe holds a strong position in the field of scientific and technical research for peaceful purposes, by increasing European co-operation and interaction in this field. The projects that are run within COST are called 'COST Actions,' and cover basic and pre-competitive research as well as activities of public utility.

COST has developed into one of the largest frameworks for research co-operation in Europe and is a valuable mechanism co-ordinating national research activities in Europe. The member countries participate on an 'à la carte' principle and activities are launched on a 'bottom-up' approach. Today it has almost 200 Actions and involves nearly 30,000 scientists from 32 European member countries and more than 46 participating institutions from 11 non-member countries and Non Governmental Organizations.

COST has a geographical scope beyond the European Union and most of the Central and Eastern European countries are members. COST also welcomes the participation of interested institutions from non-COST member states without any geographical restriction. As of 2001, institutions from

43 countries were participating in COST under different forms: 33 member states (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, Federal Republic of Yugoslavia); 1 Co-operating State (Israel); and 9 States with participating Institutions. Institutions from non-COST countries may join COST Actions and, at present, there are institutions from the following states: Armenia (2), Australia (2), Canada (4), India (1), Japan (3), China (Macao) (1), Russia (11), Ukraine (3), USA (6). There are also 3 participating Non-Governmental Organizations (NGO).

COST is based on Actions, which are networks of co-ordinated national research projects in fields that are of interest to a minimum number of participants (at least 5) from different member states. The Actions are defined by a Memorandum of Understanding (MoU) signed by the Governments of the COST states wishing to participate in the Action. The duration of an Action is generally 4 years.

Technical Domains
COST covers a wide range of scientific and technological domains. The present 17 domains and their share of running actions in 2001 are shown in Table IV.

Funding
COST represents an estimated volume of national funding of more than 1.5 billion Euros per year. An average of 60 000 Euros per Action is available for co-ordination depending on size and activity of the Action. This expenditure represents on average 0.5% of the overall national funding. This funding is basically used to cover co-ordination costs such as contributions to workshops/conferences, travel costs for meetings, contributions to publications and short term scientific missions of researchers to visit other laboratories. Funding for the actual research is provided by the companies and institutions themselves, which may receive funding from their national funding agencies.

Action may be created or joined by contacting the relevant national COST Co-coordinator. The main bodies of COST are:
• Committee of Senior Officials (CSO), which is the decision making and highest body in COST. It is composed of COST member states representatives, one of whom in each case acts as COST National Co-coordinator.
• Technical Committees (TC) are responsible for a particular sector under the authority of the CSO. Responsible for technical preparation work, they also oversee the implementation of the Actions and aid in the co-ordination, evaluation in an advisory capacity.
• Management Committees (MC) are in charge of implementation, supervising and co-ordinating the COST Actions. An MC is formed by not more than two representatives of each Signatory Country.

Table IV. Listing of COST Actions in Materials

Action No.*	Topic Areas of Programs in COST Domain: Materials
50	*Materials for gas turbines*
501	*Advanced materials for power engineering components, High Efficiency, Low Emission Systems*
51	*Materials for gas turbines*
502	*Corrosion in the construction industry*
52	*Materials for gas turbines53Materials for desalination plants*
503	*Powder Metallurgy, Powder Based Materials*
504	*Advanced casting and solidification technology*
505	*Materials for steam turbines*
506	*Industrial applications of light alloys, Generation and Evaluation of Property Data for Engineering Design with Light Metal Alloys*
56	*Materials for superconducting electrical machines*
507	*Measurement and Evaluation of thermochemical and thermophysical properties to provide a database for the development of new light alloys*
508	*Wood mechanics*
509	*Corrosion and Protection of Metals in Contact with Concrete*
510	*Advanced materials for temperatures above 1500°C - Development of testing methods*
511	*Interaction of microbial systems with industrial materials*
512	*Modelling in materials science and processing (MMSP)*
513	*Improvements in availability and quality of intermetallic-based materials*
514	*Ferroelectric ceramic thin films*
515	*Plasma and ion based surface engineering (PISE) techniques for materials*
516	*Tribology*
517	Production and assessment of cleaner metals for industrial exploitation
518	*Molecular materials and functional polymers for advanced devices*
520	Impact of Biofilm and Biofouling on materials and processes
521	Corrosion of steel in reinforced concrete structures
522	Power generation in the 21st century : ultra-efficient, low-emission plant
523	Nano-structured materials
524	Neutron imaging techniques for the detection of defects in materials
525	Advanced Electroceramics: Grain Boundary Engineering
526	Automatic Process Optimization in Materials Technology
527	Plasma polymers and related materials
528	Chemical solution deposition of thin films
529	Efficient Lightning for the 21st Century
530	Life Cycle Inventories for Environmentally Conscious Manufacturing Processes

* Actions in italics have been completed

One member of the CSO from each member state acts as national coordinator (CNC) for COST Actions. The CNC provides the liaison between the scientists and institutions in his country and the Council COST secretariat. The CNC has specifically to:
• ensure that the national funding is available
• appoint and officially forward the names of the national delegates to the technical committees (TC) and management committees (MC);
• forward proposals from other countries to experts in his own country; and
• assess at national level all projects undertaken within the COST framework.

The COST Secretariat is provided by the European Commission (scientific and administrative matters) and the Secretariat General to the Council of the European Union (secretariat of the CSO).

Further information may be obtained directly from the COST website: http://cost.cordis.lu

Calls for Papers

March 2-6, 2003: A symposium on "Materials Processing Under the Influence of Electrical and Magnetic Fields" will be held in conjunction with the 132nd Annual Meeting & Exhibition of TMS, in San Diego, California, USA. The symposium will cover physical phenomena, analytical and numerical models, numerical algorithms, experimental studies, physical modeling, and the development of new processes related to materials processing under the influence of electric and magnetic fields. Numerical topics may include the comparison of different software packages on the basis of their applicability, reliability, user-friendliness, accuracy, and cost. The symposium will include both presented papers and discussions in a workshop format. Summary and recommendations for future research topics of direct relevance to analytical model developers and numerical simulation software developers will be finalized during a round table discussion in the concluding sessions of the workshop. Abstracts should not exceed 150 words and should be submitted electronically via the TMS Conference Management System at http://cms.tms.org/ by July 15, 2002.

March 10-13, 2003: The 28th International Technical Conference on Coal Utilization & Fuel Systems, Theme: Coal: Energy Security for the Future, will be held at the Sheraton Sand Key Hotel, Clearwater, Florida. The Conference Committee is seeking papers that will deal with technical solutions to problems; specific strategies; projects; innovations; industry trends; and/or regulatory compliance. The goal is to present an extensive overview of emerging, evolving, and innovative technologies, fuels and/or equipment in the power generation industry, through the presentation of accomplishments, opportunities and challenges in the following areas: environmental & health aspects; advanced power systems & green coal technologies; utility perspective on coal-based fuels; opportunity fuels; domestic & worldwide coal resources quality issues; transportation issues; international programs – technical developments/policy issues. A one-page abstract should be sent via email, by October 31, 2002, to: Coal Technology Association, 601 Suffield Drive, Gaithersburg, Maryland, USA 20878; attention: Barbara A. Sakkestad (CTA), 'phone: 301/294-6080; fax: 301/294-7480; e-mail: BarbaraSak@aol.com; or Web site: www.coaltechnologies.com.

December 1-4, 2003: The World Conference on Corrosion and Corrosion Maintenance Expo and Celebration of the Ninth Corrosion Awareness Day will be held in Mumbai, India. Abstracts of papers are requested by August 31, 2002, in the areas of corrosion problems in the chemical, petrochemical, fertilizers, textile and paper industries; corrosion in infrastructures; corrosion in oil and gas and off shore structures; underground pipelines and storage tanks; corrosion problems in power plants; corrosion problems in aircraft and aerospace; corrosion problems in ships and naval installations; cathodic protection; coatings and linings; microbiological induced corrosion; corrosion inhibitors and water treatment chemicals in process industries; NDT and failure analysis; high-temperature corrosion; thermal spray and high-temperature coatings; corrosion monitoring; corrosion audit; localized and stress corrosion cracking; and corrosion education. These topics will be covered in four parallel sessions at the conference. For details contact Mr. Mukul Gupta, Chairman, Corcon 2003, NACE Training Center, 305-A, Galleria, Hiranandani Gardens, Powai, Mumbai 76, India; Phone: 011-91-22-579-7354; Fax: 011-91-22-692-1572; Email: nace@bol.net.in; or Website: www.naceindia.org.

Meetings Calendar

August 4-8, 2002: The 2002 ASME Pressure Vessels and Piping Division Conference (PVP-2002) will be held at the Hyatt Regency Vancouver, Vancouver, British Columbia, Canada. Technical sessions will discuss: codes and standards; computer technology; design and analysis; fluid-structure interaction; high-pressure technology; materials and fabrication; operations, applications, and components, seismic engineering; non-destructive examination; and student paper competition. For details, contact: Conference General Chair, Howard H. Chung, MITEC International, Inc., 1022 Revere Court, Suite 100, Naperville, Illinois 60540; 'phone: 630.961.1321; fax: 630.961.2066; e-mail: hchung@corecomm.met, or technical Program Chair, William J. Bees, BWX Technologies, Inc., 91 Sterling Avenue, P.O. Box 271, Barberton, Ohio 44203-0271; 'phone: 330.860.2436; fax: 330.860.2087;
e-mail: wjbees@mcdermott.com.

August 26-28, 2002: The 5th International Conference on Microscopy of Oxidation, University of Limerick, Republic of Ireland. For details, see Materials and Components, No. 154, Oct. 2001 (Calls for papers).

September 22-27, 2002: The 15th International Corrosion Congress: Frontiers in Corrosion Science and Technology, will be held in the Granada Congress and Exhibition Center, Granada, Spain. The congress will cover the major topics of corrosion and corrosion protection of current interest, from the fundamental to the practical point of view. For details, contact: 15th ICC Secretariat, Viajes Iberia Congresos, San bernardo, 20, 28015 Madrid, Spain; 'phone: 011.34.91.531.9449; fax: 011.34.91.532.4543; or e-mail: congresos.Madrid@viajesiberia.com

A Word From Our Sponsors...

Mark your calendars for the 19th Annual International Pittsburgh Coal Conference, which will be held at the Radison Hotel Greentree, Pittsburgh, Pennsylvanis on September 23-27, 2002. The Conference will focus on Coal: Energy and the Environment and is intended to present an in-depth update on new and emerging technologies, as well as an examination of the recent environmental issues and their effects on the utilization of coal from a global perspective. Papers are sought in the following topic areas: pre-utilization; direct utilization; indirect utilization (including hot gas cleaning, syngas conversion and fuel cells); utilization materials, simulation, control and nonfuel use (including materials, instrumentation, and controls for coal utilization); and post utilization and environmental issues (including flue gas cleanup, greenhouse gas control, and CO_2 sequestration, and animal biomass utilization). For further information, contact the program secretary, the Pittsburgh Coal Conference, University of Pittsburgh, 1249 Benedum Hall, Pittsburgh, Pennsylvania 15261; 'phone: 412-624-7440; fax: 412-624-1480; e-mail: pcc@engrng.pitt.edu.

In addition, the 7th Liege Conference will take place at the Palais de Congres in Liege, Belgium, from 30 September to 2 October 2002. As in previous Liege conferences, the purpose is to report on the achievements of the materials research and development activities in Europe, especially within the COST 522 Concerted Action on 'Ultra-Efficient, Low-Emission Power Plants.' Related national and international research on materials for advanced power generation plant will be incorporated into the program. The official language of the Conference will be English. The Conference program will consist of invited lectures given by internationally recognized speakers and including selected COST 522 participants, and poster contributions, a format that has been very successful in the previous Liege conferences. The following topics will be covered:

- Materials for advanced steam cycle plant
- Materials and coating systems for gas turbines
- Materials for advanced components
- Materials related issues for fossil, biomass and waste fuels.

Papers dealing with materials research and development for advanced power engineering also will be presented as posters during the conference. The material classes of interest are low- and medium-alloy steels, high-chromium martensitic steels, austenitic steels, high-temperature nickel-base alloys, superalloys, iron-base oxide dispersion-strengthened alloys, intermetallics, ceramics and composites. Aspects such as fabrication, processing, coatings, testing, and service performance and lifetime assessment will be addressed.

The papers and poster contributions presented will be published in the Conference Proceedings, which will be available at the Conference. For further information, contact: The 7th Liege Conference, Forschungszentrum Julich GmbH, Conference Service, 52425 Julich, Germany; 'phone: 011 49 24 61 61 38 33; fax: 011 9 24 61 61 53 33; e-mail: e.wittig@fz-juelich.de

Materials & Components **No. 157, April 1, 2002**

Prepared for the U.S. Depatrtment of Energy, Fossil Energy AR&TD Materials Program, and the Electric Power Research Institute. Edited by Dr. R. R. Judkins, Manager, Fossil Energy Program, Oak Ridge National Laboratory, Bldg. 4508, P.O. Box 2008, Oak Ridge, TN 37831-6084, telephone (865)574-4572, Dr. Ian G. Wright, telephone (865)574-4451, and Dr. J. Stringer, Executive Technical Fellow, Strategic Science and Technology, EPRI, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303, telephone (650)855-2472.

Materials & Components Newsletter is available free of charge to qualified individuals worldwide who are involved in present or potential materials/components activities related to the development of fossil energy systems. Requests to be placed on the distribution list should be addressed to: Ian G. Wright, Oak Ridge National Laboratory, Bldg. 4500-S, P.O. Box 2008, Oak Ridge, TN 37831-6156, telephone (865)574-4451, fax: (865)241-0215, e-mail: wrightig@ornl.gov.

U.S. Dept. of Energy/EPRI Newsletter
Oak Ridge National Laboratory
Bg. 4500-S, Rm. Z-60
P.O. Box 2008
Oak Ridge, TN 37831-6156

Postage & Fees Paid
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