Can Coal-fired Power Plants Compete with NG-fired GTCCs?

Authors: Keith Moore - President,
CastleLight Energy Corp.
Melbourne F. Giberson, Ph.D., P.E.,- President,
Turbo Research, Inc., d.b.a TRI Transmission & Bearing Corp.

1.0 Introduction:

In just the past few years, some 572 U.S. coal-fired power plants (and some nuclear plants) have been - or are scheduled to be - mothballed, shut down or abandoned, and along with their loss comes the loss of many thousands of jobs that support the electric generating industry. A major factor causing the plant closures has been the recent development of oil well fracking technologies that make available large quantities of low-cost natural gas. The new highly efficient (60%) Gas Turbine Combined Cycle (GTCC) plants coupled with cheap NG claim to deliver electricity to the grid at a lower cost than the older coal plants. Further, EPA has proposed to replace Obamas **Clean Power Plan** with a new plan that improves the efficiency of coal-fired plants (to reduce CO_2 emissions).

The owners of older coal-fired power plants want to know; "Should I mothball or just abandon this plant?" "What options, if any, do I have to make it competitive with a natural-gas fired GTCC?" "What plant modifications are needed and what will it cost?"

The principle in play is simple: "We are throwing away reliable "installed, permitted and paid-for-power-plants" in favor of new power plants that aren't. The result is higher-cost electricity. "

TRI and CastleLight Energy Corp have proposed Re-Engineering programs for existing coal-fired power plants; to bring them into the 21st century. TRI provides equipment and processes that significantly improve the plant's efficiency. CastleLights field demonstrated technology, the **Clean Combustion System** (CCS) meets EPAs stringent Air Quality sulfur-dioxide (SO_2) and nitrogen-oxides (NO_x) regulations with low capital and low operating cost.

2.0 Cost Assessment:

DOE-NETLs office asked TRI and CastleLight Energy to provide a "top-level" assessment of their technology when applied to a 1970s vintage, sub-critical (30.5% efficiency) 400 MW PC (pulverized coal) Tangential design boiler, firing a low-rank, low-sulfur Powder River Basin (PRB) coal.

For this assessment, the plant was assumed operational, has maintained its "Title V" operating permit, and is paid for and fully depreciated by the present owner. However, the plant's low efficiency results in a high (non-competitive) operating cost resulting in a low capacity factor (% of MW rating) of electricity dispatch to the grid. The plant has an ESP (electrostatic precipitator) for particulate control, but does not have the necessary FGD (flue gas scrubber for SO_2 control) and SCR (selective catalytic reduction of NO_x) to be compliant with the more stringent EPA Air Quality regulations required for future operation. The owner has determined this plant cannot recover the exorbitant cost to install the necessary FGD and SCR equipment. Therefore, this plant, and many more like it across the U.S., are to be mothballed and/or abandoned.

In numbers, these coal-fired plants represent the largest portion of the total fleet of coal-fired electric generating plants in the U.S.

2.1 Levelized Cost of Electricity (LCOE):

The LCOE is an estimate of the cost of electricity (in $/MW-hr.) supplied to the grid by a power plant. The LCOE is derived from a plant's annual estimates of capital cost, capacity factor, fixed and variable O&M (operation & maintenance) costs, and fuel and transmission costs. The LCOE provides a reference with which to compare the cost to generate electricity from many different resources.
The focus of this assessment is to derive the LCOE for the existing coal-fired power plant after:

a.) Installing the conventional "back-end" FGD and SCR pollution controls, or
b.) Re-Engineered for higher efficiencies with 21st century technologies.

Then someone asked; "What's the LCOE for a new natural-gas-fired GTCC plant? Could a Re-Engineered 1970s coal-fired power plant compete?"

3.0 Conventional Emissions Control Technology for Coal-Fired Power Plants

To meet EPAs pollution emission requirements, such as the **Cross-State Air Pollution Rule (CSAPR - SO_2)** and **The Regional Haze Rule (NO_x),** the existing coal-fired plant must clean the flue gas before exhausting it to the atmosphere.

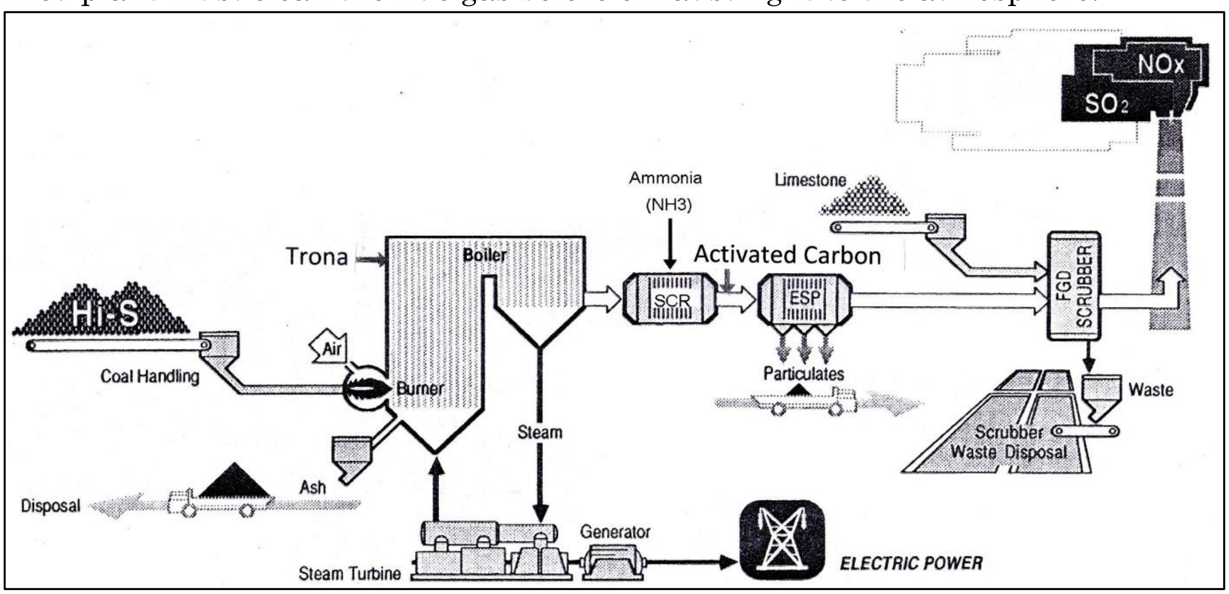

Fig 1. Flow Diagram – Tangential Boiler with FGD & SCR added

Figure 1 is a simple flow diagram illustrating the back-end equipment required to meet the EPA air quality regulations.

- **SCR + Ammonia Injection = NO_x control**
- **ESP (Up dated) = Fine Particulate control**

Can Coal-fired Power Plants Compete with NG-fired GTCCs?

- **FGD+ Limestone = SO_2 control**
- **Trona (Na_2CO_3) Injection = SO_3 control**
- **Activated Carbon = Hg (Mercury) control**
- **Land Fill Required for Scrubber Waste Products**
- **FGD Waste Water Management is Required**

This equipment adds large pump and fan parasitic loads that cost about 2% of the plants MW rating (reduced efficiency = increased CO2 emissions).

TABLE 1. 400 MW PRB Fired Tangential Boiler	Parameter	FGD + SCR Added	Base Line Unit
Levelized Cost of Electricity	\$/MW-h	46.2	Not Competitive
MW Rating Gross	MW	393	400
Plant MW Rating Net	MW	358	365
Plant Heat Rate Net	Btu/kWh	11,398	11,180
Plant Efficiency Net	%	29.9%	30.5%
Plant Auxiliary Loads	MW	42	35
MW Increase / Penality	MW	-6.9	
SO_2 Emission Rate	Lb./MMBtu	0.2 (105 ppm)	1.71 (900 ppm)
NO_x Emission Rate	Lb./MMBtu	0.15 (110 ppm)	0.4 (400 ppm)

Table 1 compares the performance of the conventional FGD & SCR modified power plant with the existing plant. Note the loss of efficiency and poorer heat rate due to the parasitic loads of the emission control technologies.

5.0 Re-engineered Coal-Fired Power Plants w/ Efficiency Modifications + CCS

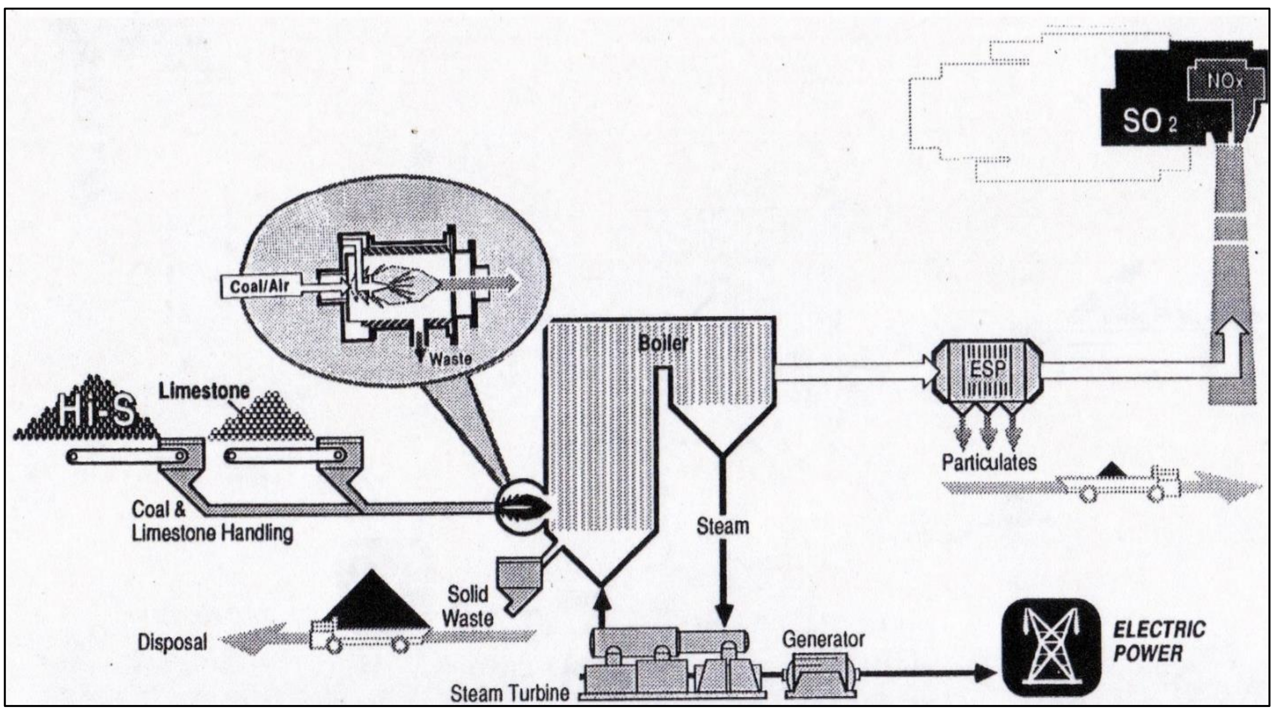

Fig.**2. Flow Diagram – Re-engineered Boiler with CCS Emission Control for SO_2 and NO_x**

Figure 2. is a flow diagram of the re-engineered plant with a CCS that replaces the original coal burners, providing "in-furnace SO_2 and NO_x control" to meet EPA air pollution regulations. Plant equipment modifications provide improved efficiency and performance. As before, an ESP (or bag house) provides control of fine particulates. Table 2 summarizes the re-engineered power plant compared to the existing plant.

TABLE 2. 400 MW PRB Fired Tangential Boiler	Parameter	Re-Engineered w/ Eff Mods + CCS	Base Line Unit
Levelized Cost of Electricity	$/MW-h	33.3	Not Competitive
MW Rating Gross	MW	447	400
Plant MW Rating Net	MW	412	365
Plant Heat Rate Net	Btu/kWh	9,293	11,180
Plant Efficiency Net	%	36.7%	30.5%
Plant Auxiliary Loads	MW	35	35
MW Increase / Penality	MW	47.00	
SO_2 Emission Rate	Lb./MMBtu	0.2 (105 ppm)	1.71 (900 ppm)
NO_x Emission Rate	Lb./MMBtu	0.07 (50 ppm)	0.4 (400 ppm)

5.1 Proposed Plant Modifications for Increased Efficiency and MW Production:

As noted earlier, EPAs revised **Clean Power Plan** expected to improve coal-fired plant efficiency (reduce CO_2 emissions by about 6%). Such efficiency modifications have not been applied, nor permitted for coal-fired plants due to the perverse interpretation of EPAs **New Source Review** regulations.

TRIs specialty is the design and modification of large rotating equipment, such as adding "variable-speed-fluid-drives" to large electric motors (6,000 HP) that drive the fans and pumps. TRI recommends the following modifications:

a. A first low-cost step to improve the plant efficiency is to recover the low-level waste heat from the boiler and equipment. The power plant and its associated operating equipment, coal mills, pumps and fans will be enclosed in a building (as an "indoor station"). All the residual heat from the equipment will then collect high in the roof area of the building. New ducting to the forced-draft fans will draw this pre-warmed air to the burners for combustion air.

b. Other recommended structural features are multiple elevators or man-lifts installed to optimize labor efficiency, and provisions for permanent overhead cranes with suitable rated lifting capacity.

c. For higher efficiency, a new Main Boiler Feed Pump will be re-located and driven via a variable-speed-fluid-drive from the Main Steam Turbine or Generator shaft.

d. The existing Start-up Boiler Feed Pump with the existing driver will be maintained.

e. The large horsepower ID and FD fans will be modified with variable-speed-fluid-drives to provide reliable mechanical speed control for improved efficiency. If helpful, these fans will be re-sized to fit the new air flow conditions.

f. The Condensate Pumps and Condenser Cooling Water Pumps will be modified with electronic VFD vertical Motors and Controls to better control possible over-cooling of condensate (reduces heat needed in boiler).

g. The feedwater heaters will be retrofitted to provide a more efficient feed-water heater system; for example, a total of 8 feed-water heaters, one being the De-Aerator.

h. The steam turbine rotors will be retrofitted for improved efficiency - assume 1 High Pressure, 1 IP, and 2 DFLP with the reheat and extraction points as needed. This may involve reworking the foundation.

i. If required, the plant Digital Control System (DCS) may be updated for improved operation, data monitoring and recording, including the new CCS burner management and combustion control system. A new DCS will permit these older sub-critical plants to operate on sliding pressure, and thereby enable flexible turn-down operation to low levels to follow the variation in electric demand, such as from night time and renewable wind and solar electric supply.

5.2 Clean Combustion System' (CCS) Review

The **'Clean Combustion System' (CCS)** comprises a "coal drying process" coupled with an 'add-on' hybrid coal gasification chamber that replaces the boiler's original coal burners and wind box.

Figure 2 is a typical tangential boiler modified with the CCS coal gasification / combustion chambers mounted to the boiler wall (on two sides) Staged combustion air is added using the existing corner ports to complete combustion.

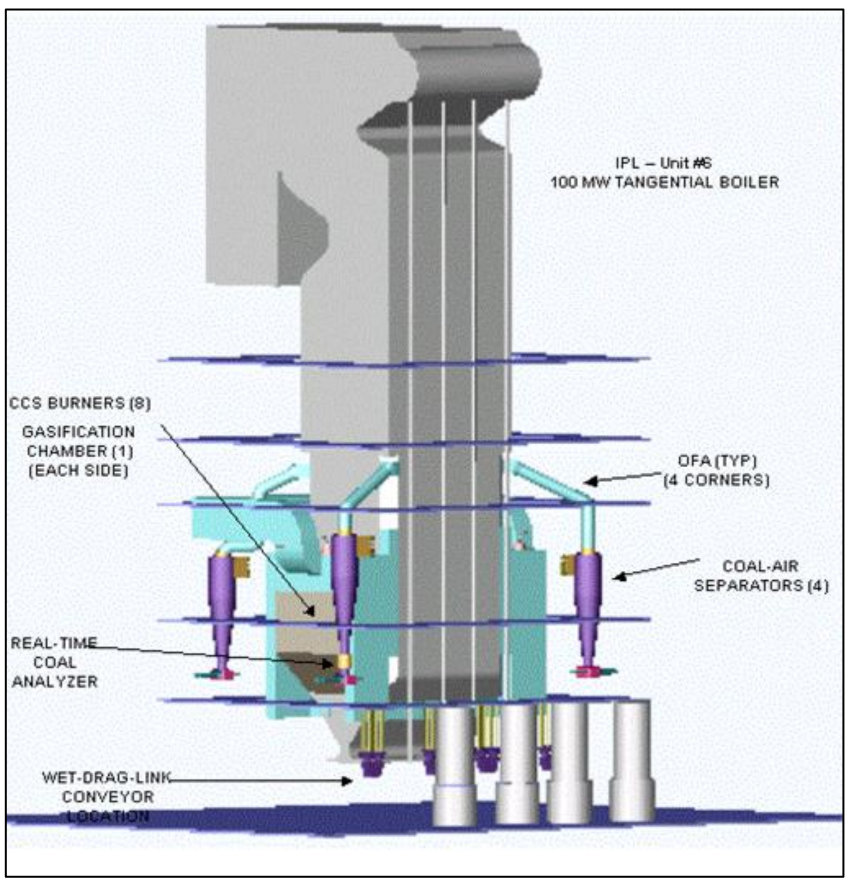

Fig 2. Tangential Boiler w/CCS Modification

Limestone is the only "chemical" required for control of SO_2 and NO_x pollutant emissions.

All the CCS equipment is familiar to plant operators. The operators can manage the plant the same as before, including start-up through to shut-down, and burners / mill out-of-service conditions. The major CCS operating difference is that it is a slagging gasifier, similar to the B&W Cyclone boiler, wherein the coal ash is a liquid that drains from the gasifier into a water quench tank for disposal.

5.1.1 CCS Coal Drying:

PRB coal contains from 25 to 30% water. Removing the water from the coal significantly improves the boiler's combustion efficiency (about 2% - by eliminating the energy losses due to the "latent-heat-of-water-vaporization").

The CCS uses the existing coal mills to pulverize the coal to a talcum-like powder (the same as before). Powdered limestone (calcium) is added to the coal to capture the sulfur in the coal.

Coal-fired plants typically use hot air (~600F air with ~20% O_2) as a sweep gas to convey the coal through the mill to the coal burners (a direct-fired design). The CCS modifies the coal preparation to an "in-direct -fired design. First, we use the plant's hot flue-gas exhaust (that is very low in oxygen ~3% O_2 @ ~600F) for the mill sweep gas. A safer process that protects the equipment from fire and puffs. As the coal is pulverized, the hot sweep gas evaporates water from the coal. From the mill, the sweep gas carries the dry powdered coal to a small bag house to separate the coal from the sweep gas. The coal is then metered from a small hopper and conveyed with fresh sweep gas to the CCS burners and gasifier on the boiler. The wet sweep gas from the baghouse is directed around the boiler and dumped to the power plant stack. This simple, safe, fast (about one-second) and inexpensive "coal-drying step" dries the coal to ~9% (its inherent moisture value) and improves the PRB coal's HHV values ~27% (from ~8520 to ~10,770 Btu/Lb.).

We notice that the evaporated moisture in the sweep gas may be condensed as a source of high quality boiler feedwater; ~100,000 gal/day (~75 GPM). [Note that Figure 1 shows cyclone coal-air separators in lieu of a baghouse].

5.1.2 CCS Hybrid-Coal Gasifier – SO_2 and NO_x Control: The CCS hybrid-gasifier is an "air-staged combustion process" that fires the coal-limestone mix with a "limited amount" of hot combustion air. The coal ignites and quickly consumes all of the oxygen, creating a hot fuel-rich gas. Under these gasification-like conditions, the sulfur is freed from the coal and captured by the calcium from the limestone to form calcium-sulfide (CaS) – a solid particle. Simultaneously, any NO_x formed from the fuel-bound nitrogen in the coal is destroyed to elemental nitrogen (N_2), even at these high temperature combustion conditions. The gasification chamber provides the residence time and temperatures to complete the reactions and melt the coal ash [silica (SiO_2) and alumina (Al_2O_3)] with the CaS to form a liquid glass (slag) that drains from the gasifier to a water filled quench tank below (as bottom ash). Thus, the coal sulfur is permanently locked in the ash and removed from the flue gases. The bottom ash is sluiced to a collection pond.

The hot fuel-rich gases exit the gasification chamber into the boiler furnace. There is no flame, just a bright orange, rather clear, fuel-rich gas of nitrogen (N_2), hydrogen (H_2) and carbon monoxide (CO). The hot gas radiates its energy to the boiler water walls to make steam and cools. Any molten fly ash droplets also cool quickly to form fine fly ash particles, to be collected down-stream in the ESP. We note that the furnace walls stay clean with very little ash deposition. Stages of additional air are then added to the furnace section to complete the combustion of hydrogen to water (H_2O), and carbon-monoxide to carbon dioxide (CO_2). As the staged combustion air is added, care is taken to avoid hot fire balls that may cause formation of any new "thermal NO_x". The gasses then exit the boiler furnace to the back-pass sections - the same as before the CCS retrofit.

5.2 Re-engineered Plant Performance Assessment:

Operating at full-load, the re-engineered sub-critical plant can now generate an additional 47 MW of electricity (412 MW, with a net plant heat rate of 9293 Btu/kW-hr, near that of a new super-critical coal-fired plant. Even though the same quantity of coal is fired as in the base line plant, the new 36.7% efficiency results in a ~ 6.2% reduction of CO_2 emissions on a per MW generated basis, addressing the EPAs proposed new **Clean Power Plan** objectives.

An important feature of this sub-critical plant design is its ability to operate over a wide turn-down, such as low load operation at night and load follow to meet the grid electricity demand as needed.

The plants new LCOE is estimated at 33.31 $/MW-hr. This price is expected to make the plant very competitive, and with a much-improved capacity factor, the plant will dispatch low-cost electricity for another twenty or more years.

5.2.1 CCS NO_x Emissions:

As mentioned earlier, the CCS features an inherent process to destroy nearly all NO_x to elemental nitrogen right in the initial combustion step. The CCS NO_x emission levels are very low; ~ 0.07 Lb. NO_x / MMBtu or ~50 parts per million (ppm), from start-up to full load operation.

This CCS NO_x performance is expected to meet the very stringent EPA Regional Haze Rule for NO_x (haze - a reaction of NO_x with volatile organic compounds (VOC) in sunlight that forms ozone (smog that limits visibility). CSAPR requires NOx emissions be controlled to less than 0.15 Lb. NO_x / MMBtu (110 ppm).

5.2.2 CCS Sulfur (SO_2) Emissions:

Montana PRB coal contains ~ 0.73% sulfur, which when burned emits ~1.71 Lb. SO_2 /MMBtu or ~900 ppm SO_2. When firing PRB coals, the CCS has demonstrated SO_2

emissions of ~0.2 Lb. SO_2 / MMBtu (105 ppm) which meets the CSAPR requirements of less than 0.6 Lb. SO_2 / MMBtu (315 ppm).

The CCS technology essentially obsoletes FGD/SCR systems with significant capital and operating cost savings for air quality emissions control.

5.2.3 Other CCS Features:

The CCS process demonstrates a significant boiler heat rate improvement from coal drying and excellent LOI (loss-on-ignition < 0.1%) with near-zero carbon in the ash. Since the CCS removed the sulfur in the combustion step, there will be near-zero sulfur trioxide (SO_3) in the exhaust gases. Now the boiler gas exit temperature can be reduced for further efficiency gains. The CCS bottom ash (slag) and high calcium fly ash products have a ~$3/Ton sale value, making possible reduced or no landfill cost. As important, the CCS recycles all process water to meet a zero-water discharge requirement.

6. LCOE for a New Natural-Gas fired GTCC

The LCOE was estimated for a 400 MW Gas Turbine Combined Cycle plant. Using recent cost data from a 170 MW GT design, we estimate a new GTCC at 1,525 $/kW. When compared to the relative stability of coal prices, the price of natural gas is quite variable. Using recent Henry Hub data, the natural gas price was assumed as $3.60/MMBtu. The estimated LCOE for a new GTCC is $37.76 $/MW-hr. (at 80% capacity factor.

6.1 To answer the question; *"Can a Re-Engineered 1970s coal-fired plant compete with new natural-gas-fired GTCC plant?",* Table 3 compares the three technologies from this assessment; including the CAPx capital cost, the operating fuel cost, the fixed and variable O&M cost and the estimated LCOE for each case.

We notice that the cost and delays to get any new power plant permitted in many communities can be difficult and unknown. ***Clearly, a lower risk, lower-cost program is to maintain our fleet of permitted, commissioned and operable coal-fired electric generating plants with off-the-shelf proven technology***.

TABLE 3. 400MW Power Plant; Estimated Cost & LCOE - 80% CF

Technology (Modification)	Retrofit CAPx ($/kW)	Fuel ($MW-hr)	Fixed + Variable O&M ($/MW-hr)	LCOE ($/MW-hr.)
Re-Engineered w/Efficiency Mods + CCS (412 MW Net)	620	19.71	2.47	33.31
New NG Fired GTCC Plant @ 60% eff. (400 MW Net)	1525	16.61	0.68	37.75
Add FGD + SCR to plant + ESP Update (358 MW Net)	1252	21.41	4.63	46.24

The LCOE comparisons show that when efficiency modifications are coupled* with 21st century technology *PERHAPS IT'S POSSIBLE for 1970s coal-fired plant to compete with a new gas-fired GTCC!

Can Coal-fired Power Plants Compete with NG-fired GTCCs?

AUTHOR RESUMES

Melbourne F. Giberson, Ph.D., P.E.
President / Owner – Turbo Research, Inc.
d/b/a TRI Transmission & Bearing Corp.

TRI Bearings support over 50,000 MW of Electrical Generation.

Contact: TRI Transmission & Bearing Corp.
Engineering Services and Products:
P.O. Box 454, Lionville, PA Tel: 610-363-8570
E-mail: mel.giberson@turboresearch.com
www.turboresearch.com

Keith Moore

President – Castle Light Energy Corp.

Business Development &Technology Management

Mr. Moore focuses on strategies to mitigate / control pollution emissions from coal-fired electric generating plants to meet stringent EPA air quality regulations.

CONTACT:
Castle Light Energy Corp.
3401 W 5th Street, #200,
Oxnard, CA 93030
E-Mail: keith@castle-light.com
Phone: 805-551-0983
Visit: www.Castle-Light.com