Re-Engineering Coal-Fired Power Plants
for Low Emissions and
Competitive Electricity Dispatch

By

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Are FGD Scrubbers and SCR Systems Obsolete?

When did you last:

- **Dial a Phone?**
- **Type a Letter?**
- **Fly in a Commercial Piston Engine Airplane?**

What Happened?

Technologies don't evolve, they LEAP FROG!

A. INTRODUCTION

Owners and operators of the some 1200 coal-fired electric generating plants (~336 GW) in the U.S. face daunting challenges to address the strict new environmental regulations being issued by the EPA. Abundant new sources of low cost natural gas, along with new wind and solar generation now also compete to supply the electric grid.

Are the existing coal-fired power plants obsolete? Can they still compete with low cost natural gas and renewable energy sources?

What will become of the older, smaller plants (25% or ~300 plants < 300 MW) that have not invested in the air quality control equipment being required by the EPA? They cannot afford the cost to install conventional air pollution control equipment. Many are being placed on "stand-by", moth-balled or sold for very little money. Some even are being abandoned and/or demolished.

We predict that U.S. electric demand will grow with the economy and that there will be opportunities to "re-engineer" existing coal-fired units with fresh technology to meet the EPA challenges and continue to provide competitive electricity dispatch. Further, new coal beneficiation processes are envisioned that may significantly improve a plant performance and operating cost by extracting the oil values from the coal before firing; to thereby derive a new strategic and secure domestic U.S. oil supply.

Here is a review of the environmental issues facing coal-fired plants and a fresh technical approach to address these issues.

B. New EPA Regulations for Air Quality and Global Warming Emissions

The EPA has issued a blizzard of new rules in the last four years that have made it far more difficult and expensive to obtain an air permit for emissions from a new or modified electric generation units (EGU). The list includes new National Ambient Air Quality Standards (NAAQS) for very fine particulates (PM 2.5; particles < 2.5 microns), new tighter controls for sulfur dioxide (SO_2) and nitrous oxides (NO_x) emissions; revisions to New Source Performance Standards (NSPS) and Prevention of Significant Deterioration (PSD) rules; new standards for emissions of hazardous air pollutants (HAP's – control of mercury and heavy metal emissions); a new program for controlling interstate transport of pollutants; and a new and more restrictive policy for addressing plant upset emissions during start-up, shutdown, and malfunction (SSM).

In addition, EPA has issued first-time rules governing emissions of greenhouse gases (GHG's – to control CO_2 emissions). It is expected that these proposed standards will discourage building any "new" coal-fired plants. However, the fleets of existing coal-fired power plants now expect to see new GHG requirements and must determine if there are any affordable options to enable continued competitive operation.

C. The Perverse EPA Interpretation of New Source Review (NSR)

An example of an older coal-fired power plant is like grand dad's 1960 Buick, sitting in the garage, still in good condition, well maintained and ready to run. It can fire up and take you for a ride in the country any time. With normal maintenance and repairs, it can be fully operational and continue to run as long as needed.

However, the EPA and environmentalist consider these older coal-fired power plants obsolete and to be shut down. They are using any and all methods to cause this to happen including the stringent new environmental regulations. One tool is a perverse interpretation of the 1990 Clean Air Act's New Source Review (NSR) rule.

As an example, one day we notice that the old Buick's radiator has a small leak, and after a visit with our mechanic, we learn that the radiator can't be repaired, but must be replaced.

Per the EPA rules, the radiator replacement will require a Permit to do the work. However, in completing the Permit, we learn that the EPA has determined that a new radiator will extend the life of the car, resulting in more (new) pollutant emissions. This rule interpretation triggers a New Source Review (NSR) claim. And we now learn that to meet NSR requirements, replacing the Buick's radiator will require that the car must also be up-dated to meet all of the emissions regulations required of a brand new car! Of course, the cost to do this probably exceeds the cars value, and so it may be moth-balled or scrapped.

Because of this NSR interpretation, power plant owners are careful to not do anything to their plants that may trigger an NSR claim. Further, the many opportunities to improve a plants efficiency, performance, and even reliability have

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been placed on hold. What's needed are fresh cost-effective options to keep the plants operating and emissions compliant.

D. WAIVERS OF NSPS, PSD AND NO NSR

The EPA regulations for a brand new power plant are quite strict, but not nearly so for existing plants (yet). Under the 1990 Clean Air Act Amendments and recent court rulings, "if" the plant owner can show the plant modification will reduce emissions, he may apply for a permit to construct and receive a Waiver of New Source Performance Standards (NSPS) and Prevention of Significant Deterioration (PSD) requirements (and no NSR). The plant must show it will reduce emissions of SO_2, NO_x, mercury, SO_3, particulates and now, even carbon dioxide (CO_2). With such a waiver, the owner may now also replace and/or modify the plant equipment to improve efficiency, reliability, operability and availability.

Recall that our old pristine Buick needed a new radiator. In developing our needed permit, we learned that we could replace the old carburetor and spark distributer with a new computer controlled fuel injection and electronic ignition system. This modification looks affordable and would give the car better gas mileage (reduced CO_2) and lower NO_x emissions. These emissions may be not as good as a new car, but would be sufficient to get the permit and waivers to install the radiator and keep the car running a while longer, without triggering NSR!

E. RE-ENGINEERING OF COAL-FIRED POWER PLANTS:

1. COAL CHARACTERISTICS

Even with the recent abundant supplies of natural gas, the major sources of low-cost electricity for the U.S. electrical grid are expected to be supplied from nuclear (~20%) and coal-fired power plants (~40%). Coal will continue to be the abundant low-cost source of fuel for U.S. electric generating power plants. Including rail car shipping, the cost of coal delivered to a power plant will remain fairly stable (estimated at $2.39/MMBtu).[1] Low rank coals like the sub-bituminous Powder River Basin (PRB) coals from Montana and Wyoming comprise a major source of coal (about 40%) and supply many power plants located across the U.S. Mid-west and Southern States.

PRB coal contains carbon (40%), some water (~ 20%), non-combustible ash (10%), and a volatile hydrocarbon fraction (~35%). The elements in coal that form the power plant emissions are carbon – reports as CO_2, sulfur (~0.5% - reports as SO_2), nitrogen (~1% - reports as NO_x), and ash (reports as fly-ash particulates). PRB also has traces of mercury (< 150 parts per billion).

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1 U.S. Energy Information Administration – 9/10/13

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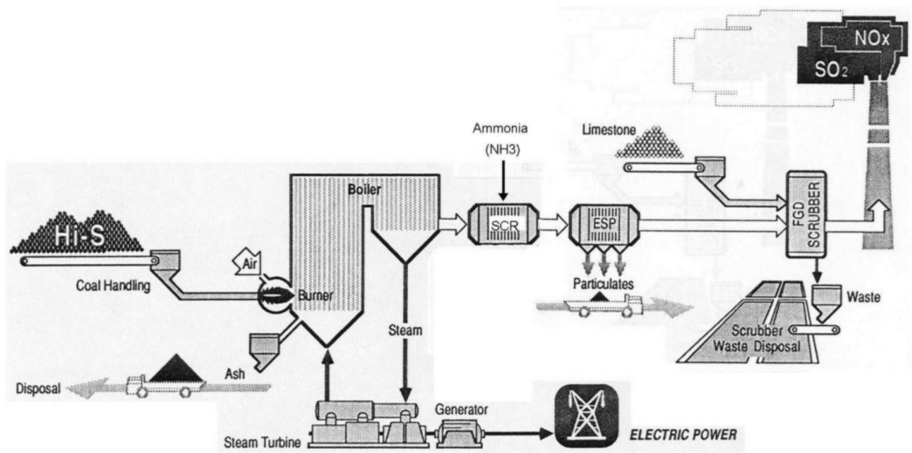

2. Conventional Backend Emission Control Technology:

Most of the newer, larger coal-fired plants (>400 MW) have added pollution control equipment to the backend of the power plant. As illustrated in the adjacent figure, this includes a selective catalytic reduction (SCR) system with ammonia injection to control nitrogen oxide (NO_x) emissions; an electrostatic precipitator or bag house to remove the fine fly ash particulate, and a flue gas desulfurization (FGD) wet limestone scrubber to control the sulfur dioxide (SO_2) emissions. To meet the new HAPS rules for mercury, activated carbon is metered into the flue gas before the particulate collector to capture the mercury emissions. Installation of this pollution control equipment requires a lot of real estate and may cost as much or more than the plants original cost. Only the large MW power plants can afford to pay for this expensive equipment and continue to dispatch competitively priced electricity.

3. Reducing CO_2 Emissions:

To reduce CO_2 emissions to meet EPA's new GHG rules, a power plant will work to improve its operating efficiencies (improve heat rate) and increase its capacity factor (% of operation). A coal fired power plant, running at or near its full-load MW design, operates with the highest MW of electricity generated per ton of CO_2 emissions (lowest BTU/ KwHr heat rate).

Power plant equipment modifications that reduce CO_2 "GHG emissions" include processes to improve coal combustion efficiency (2 to 10%), increase the combustion air temperature (2 to 4%), reduce the exhaust gas temperature (2 to 4%), re-work and update the steam turbine (10 to 25%), and add variable speed drives to reduce fan and pump motor loads (2 to 10%).

4. A Hybrid of Coal-Gasification for Emissions Control:

The control of sulfur (SO_2) emissions from coal combustion, typically with the conventional Wet FGD / limestone scrubber, is the more difficult and expensive emission control process. Engineers know that sulfur can also be efficiently

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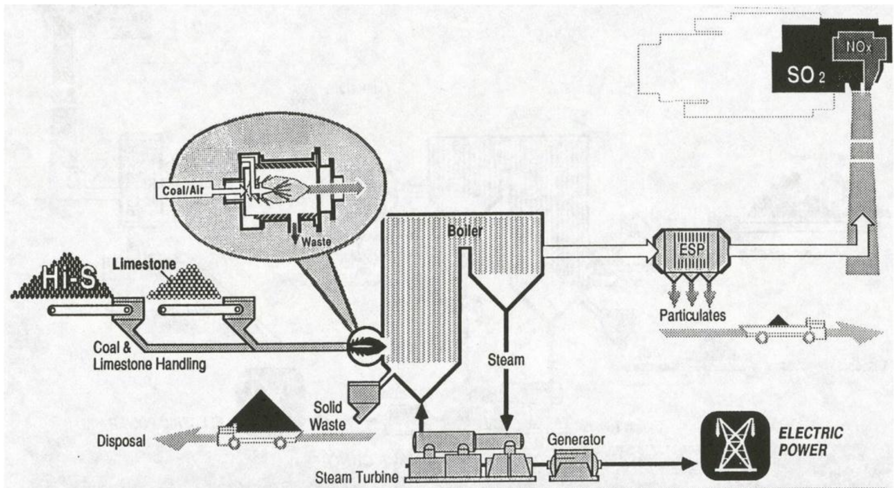
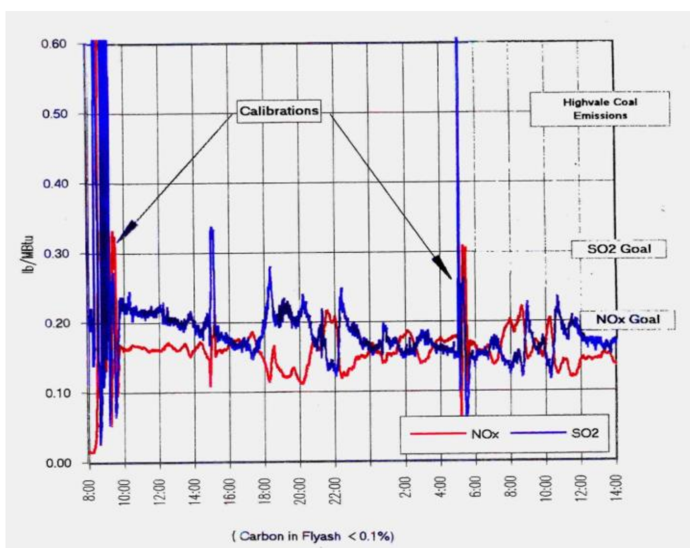
captured during the initial coal combustion step. The fluidized bed combustor (FBC) is a proven commercial process that burns coal at rather low temperatures (~1600F) in a bed of sand and limestone, fluidized with hot combustion air. As the carbon is burned and generates heat, the calcium in the limestone captures the sulfur (as a solid calcium-sulfate compound; $CaSO_4$). However, the FBC combustion process is rather slow, requiring seconds of residence time to burn the coal, and requires large high pressure blowers for fluidized combustion, features that limit the boiler size (<200 MW) and result in lower overall efficiencies.



Developments in coal-gasification (firing coal & limestone with very little air) also show efficient sulfur capture with NO_x control. By replacing the existing coal burners with a coal gasification module mounted on the furnace wall (shown in the adjacent figure), this "hybrid of coal-gasification" quickly captures the sulfur right in the initial combustion step. Along with the sulfur capture, a synergistic reaction destroys any NO_x formed from the fuel bound nitrogen (the major source of NO_x from burning coal) to elemental nitrogen. The captured sulfur is bound with the coal ash and drains from the gasification stage as bottom ash. The clean hot gases enter the boiler furnace to make steam. Additional over-fire air is staged in the furnace to complete the combustion of the gasified coal, and minimize formation of any thermal NO_x. An ESP or bag house provides the particulate control.



The adjacent chart illustrates the field demonstrated emissions performance of this Hybrid Gasification scheme firing Western low-sulfur PRB type coals:

- SO_2 < 0.2 lb./MMBtu (<105 ppm),
- NO_x < 0.15 lb./MMBtu (<110 ppm)
- High combustion efficiency (LOI < 0.1 %) and

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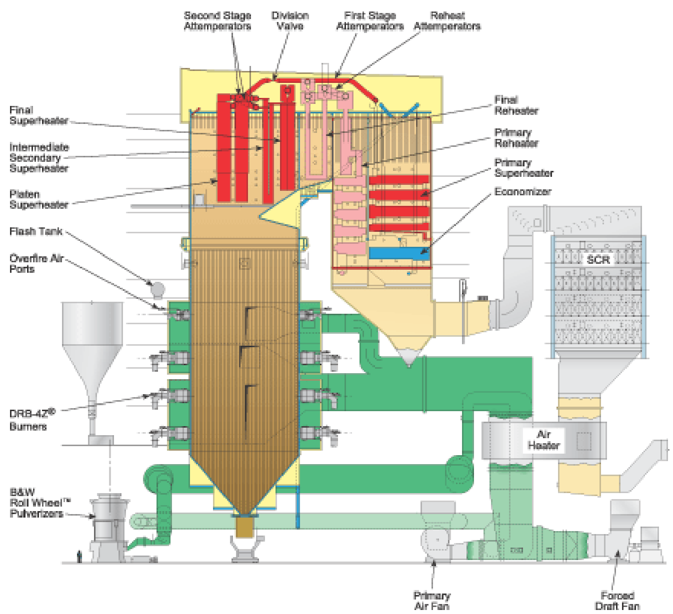
- Near-zero sulfur trioxide (SO_3) emissions.

This emission performance would meet EPA's SO_2 and NO_x requirements for most power plants.

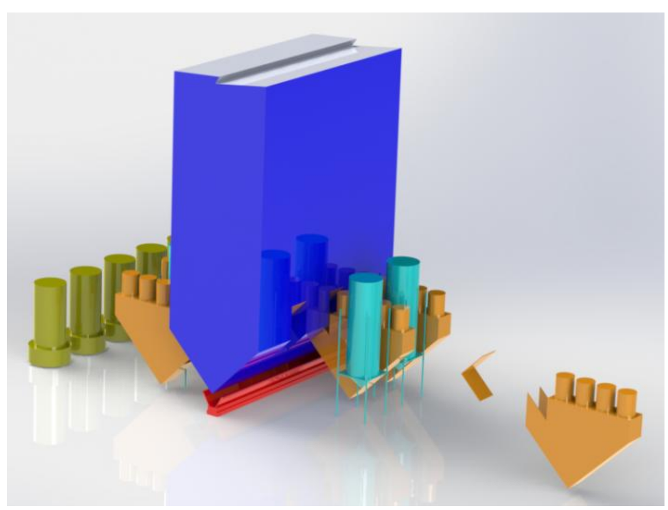
Notice that the Hybrid Gasification process nearly completes the coal combustion and removes most of the coal sulfur and ash pollutants before the fuel-rich gases enter the boiler's furnace. This feature protects the furnace walls from corrosion, slagging and fouling issues and provides the plant more flexibility to fire different coals. The only waste for disposal is the gasification chamber bottom ash and fine "near-zero-carbon" fly ash (have sale values). There is no waste water product.

5. Technology Maturity (Ready to Commercialize)

For a re-engineering example, we show a *typical 500 MW B&W opposed-wall-fired* electric generating power plant with 24 coal-burners, wind box and ducting (green). These items will be removed, leaving the boiler water walls. The burner ports will be bricked over or reconfigured as over-fire air ports. (The SCR unit is no longer required), Six new Hybrid Gasification Chambers with 24 new Burners will be pre-fabricated at a boiler shop and delivered to the site ready for installation.



Openings for the Hybrid Gasification Chamber(s) will be saw-cut through the furnace hopper water-wall section. The Hybrid Gasification Chamber assembly will be inserted into the openings as shown in the adjacent sketch. The furnace water-wall cooling flow will be maintained as before with new connections across the openings. Much of the combustion air ducting will be rerouted as over-fire air through new ports added to the upper furnace walls.



3D View of Hybrid Gasification Retrofit of a 500MW Power Boiler

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Re-Engineering Coal-Fired Power Plants

The Hybrid Gasification technology can be applied to all boiler types, tangential, wall-fired and cyclone boiler designs, and perhaps even the conversion of some oil and natural gas type boilers to coal firing. Each plant will have site specific details that require a custom engineered retrofit. The work is scheduled to fit the plants annual maintenance outage, and can be completed in about one year from receiving a construction permit. As important, the cost for the gasification equipment and furnace modifications are about one-third that of conventional FGD and SCR equipment. The older, smaller coal-fired power plants that are now in limbo due to the strict new EPA regulation are candidates for this "re-engineering" program.

6. Reduce Plant Operating Cost with Coal Beneficiation:

The coal fuel is largest operating cost for coal-fired power plants. Recent natural gas prices have been competitive with the cost of coal, leading plant owners to consider the possibility of switching fuels or perhaps co-firing gas with coal. This is not a simple decision. A natural gas flame has significantly different radiation (emissivity) characteristics compared to a coal flame, which affects the boiler's performance. Once a coal-fired boiler is converted to fire NG, EPA's NSR regulations make it very difficult to go back to firing coal. Further, the quantities of NG consumed are huge, requiring a large NG piping system to supply a sufficient quantity of gas.

Coal-fired power plants prepare the coal for firing by first pulverizing the coal to a talcum-like powder (~50 micron particles) in a pulverizer using hot sweep air. Recall that PRB coal contains a lot of water (~20%). The pulverizing step evaporates about half of this water from the coal. In the existing power plants, the sweep air (and moisture) conveys the powdered coal directly to the furnace where it is burned with additional hot combustion air.

However, the Hybrid-Gasification conversion process requires use of an "in-direct coal firing scheme". The powdered coal from each coal mill is rerouted to individual bag-house coal-air separators where the sweep air (with water) and powdered coal are separated. This simple step of removing the water vapor will improve the boiler heat rate ~ 2% (which will also reduce CO_2 emissions). The coal is collected briefly in the separator hoppers, and then metered to the new Burners by individual rotary feeders to provide the required fuel-rich gasification combustion.

We observe that with the powdered coal collected in the bag-house hopper, there are perhaps other new coal beneficiation opportunities that may be developed to improve the coal quality before the coal is fired in the furnace:

1. The coal pulverizing step separates the carbon particles from the ash particles (alumina and silica or sand). It is feasible to create a higher quality, low-ash carbon fuel by separating the carbon particles from the ash particles.

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2. This separation step also removes some of the mercury from the coal – to reduce mercury emissions.
3. Further, some of the coal's volatile fraction (~35%) may be extracted from the fine coal particles with a flash-pyrolysis process; to produce a crude oil product. This pyrolysis oil may be used directly as fuel or processed further by hydrogenation into synthetic gasoline and diesel fuels with conventional refinery distillation and separation methods. Sales of the oil by-products would help offset the power plants coal cost, and thereby significantly reduce the plants operating cost.

It is important that these processes be conducted as fast as the coal is pulverized, so that the high-quality carbon fuel can then be metered directly back to the power plant to maintain the plants electric generation. Even with the addition of the oil extraction step, we expect to be able to report a carbon-neutral power plant (no CO_2 increase) and meet the EPA's new GHG requirements for existing power plants.

For example, assume a 500 MW power plant consumes ~10,000 Tons/day of PRB coal. This coal costs about $30/ton or $300,000/day. We estimate the potential crude oil production from this amount of coal at ~5000 bpd. If the oil values are assumed to be > $60.00/Barrel (~$300,000/day), the oil sales can offset the power plants cost for the coal. (EIA estimates oil cost at ~$100.00/Barrel) [2]

There are ~400 power plants firing PRB coals across the U.S. If 60% of this fleet were re-engineered with coal beneficiation and hybrid-gasification pollution emissions control, the fleet would process some 4 million Tons/day of PRB coal to produce ~1.25 million bpd of competitively priced crude oil (and ~100,000 bpd of JP-8 jet fuel, ~275,000 bpd of diesel fuel, and ~600,000 bpd of gasoline).

This proposed power plant re-engineering program could provide the U.S. a new secure (and distributed) domestic oil supply to offset most of U.S. foreign oil imports and continue to generate very competitive low-cost, low-emissions electricity ……. for as long as the plants operate.

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