Coal Gasification Technology for Coal-Fired Power Plants

McIlvaine Hot Topic Hour

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Objective:

Re-engineer coal-fired power plants to reduce operating cost, and generate very competitive electricity with very low emissions.

Approach:

Apply coal beneficiation and coal-gasification processes to existing coal-fired power plants.
Conventional Coal-Fired Power Plant with Back-End Emission Controls

SO$_2$ = FGD + Limestone; NO$_x$ = SCR + Ammonia;
SO$_3$ = Trona ?, Hg = Activated Carbon ?

<table>
<thead>
<tr>
<th>SO$_2$</th>
<th>NO$_x$</th>
<th>PLANT EFFICIENCY</th>
<th>POWER OUTPUT</th>
<th>PLANT LIFE</th>
<th>INCREMENTAL ELECTRICITY COST</th>
<th>CAPITAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>90%</td>
<td>2+ % Decrease</td>
<td>2+ % Decrease</td>
<td>No Change</td>
<td>11 - 15 Mils/kWh</td>
<td>$280 - 300</td>
</tr>
</tbody>
</table>

* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

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Coal-Fired Power Plant
Re-Engineered with Hybrid of Coal-Gasification
SO₂ & NOₓ Controls Right in the Combustion Step

**COMPIRED WITH CONVENTIONAL TECHNOLOGY**

<table>
<thead>
<tr>
<th>SO₂ EMISSION REDUCTION</th>
<th>NOₓ EMISSION REDUCTION</th>
<th>PLANT EFFICIENCY</th>
<th>POWER OUTPUT</th>
<th>PLANT LIFE</th>
<th>INCREMENTAL ELECTRICITY COST</th>
<th>CAPITAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 - 90+ HIGH</td>
<td>NO CHANGE</td>
<td>NO CHANGE</td>
<td>Slight Extension</td>
<td>2-4 MILS/KWH</td>
<td>$75-110 PER KW</td>
<td></td>
</tr>
</tbody>
</table>

*CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT*
Typical Pulverized Coal-Fired Power Plant
500 MW w/5 Mills – “Direct Fired” Pulverized Coal

- Raw Coal Bunker
- Mill Fan
- Coal Mill
- Hot Primary Air
- SweeAir w/ Pulverized Coal
- Coal Feeder
- BoiSteam Out
- Burners
- Hot Secondary Air
- Hot Combustion Air
- Air Heater
- Hot Inert Flue Gas
- FD Fan
- ID Fan
- Emissions Control
- Waste Products

Flue Gas
- To Stack

Ambient Combustion Air

EnergWaste Products

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Re-Engineered Power Plant
“Indirect Fired” with Coal-Beneficiation Modifications

Raw Coal Bunker

Coal Beneficiation Module (One for each Coal Mill)

Dry Pulverized Coal & Inert Sweep Gas

Oil Collection System

Sweep Gas & Coal Moisture to Bag House

Waste Gas Products

High Quality Coal Fuel

Coal Feeder

Powdered Limestone

Coal Mill

Rock / Pyrite Disposal

Boiler Steam Out

Boiler

Economizer

FD Fan

Ambient Combustion Air

Hot Inert Flue Gas

WND BOX & PC Burners

Boiler Feedwater

Flue Gas Exhaust & Particulate to Baghouse

Air Heater

Hot Combustion Air

Hot (Inert) Sweep Gas

BLACK - EXISTING PLANT
BLUE - NEW EQUIPMENT
Re-Engineered Power Plant
Coal-Beneficiation Modifications

- **Add Coal-Beneficiation Modules – One for each coal mill**
  1. Re-route coal mill sweep gas:
     - Use the hot inert (low O\(_2\)) boiler exhaust vs. hot air
     - Improve safety - eliminate mill fires & puffs
     - Dry the coal (from >20% to <10% moisture)
  2. Separate the powdered coal from sweep gas with bag house:
     - Direct wet sweep gas to boiler stack
     - Process powdered coal to extract volatile hydrocarbon oil
  3. Separate carbon particles from oil vapor with cyclone:
     - Meter coal carbon with limestone added to furnace
     - Condense and collect oil from each mill

<<<< Sell the oil and pay for the coal! >>>>
Coal Beneficiation Process
Powder River Basin (PRB) Low Rank Coals

- **Coal Characteristics - PRB:**
  - Low in Btu ~ 8300 Btu/Lb.
  - High in Moisture 20 – 30%
  - High in Ash 10 – 15%
  - High in Mercury 130 to 150 ppb

- **Coal Beneficiation Target - PRB Coals:**
  - Increase Btu ~ 10,000 Btu/Lb. (+20%)
  - Reduce Moisture 10 – 12% (- 50%)
  - Reduce Ash 7 – 10%(-) (- 50%)
  - Compliance Mercury ~36 ppb (- 75%)

- **EPA CAMR – Compliance Mercury (Hg):**
  - Existing Plants = 4.0 lb./Trillion Btu or ~ 36 Parts / Billion

- **Oil Production Example:**
  - **500 MW Electric Generation:** Fires 12,000 T/day PRB; cost = $360,000/day;
  - **Oil Product:** ~ 5000 barrel/day crude oil @ $72/BBL = $360,000/day income
  - **Coal By Product:** 10,000 T/day high quality coal-fuel for power plant
  - May show as a Carbon-Neutral Process (No CO₂ increase!)

"An Oil Well in the Coal Pile"

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The Clean Combustion System (CCS) Hybrid of Coal-Gasification & Combustion Schematic

CCS Gasification Chamber replaces coal burners & wind box

Existing Boiler Furnace
CCS Process Steps
SO₂ & NOₓ emissions control right in the combustion step

- An entrained-flow gasification of powdered coal; Creates a hot, fuel-rich gas, and frees the sulfur from the coal,
- Limestone - provides calcium, captures the sulfur in the coal,
- Forms calcium sulfide (CaS) - a solid particle,
- High temperatures melt the coal ash (alumina & silica) and encapsulate the CaS; forms liquid slag – drains as bottom ash,
- At these conditions, nitrogen is molecular N₂ (NOₓ < 50 ppm),
- Clean hot gases – CO, H₂ and N₂ enter boiler & cool,
- Staged over-fire air completes combustion to CO₂ & H₂O in boiler (<2300°F, where NOₓ formation is frozen).
Re-Engineered Power Plant
Indirect Fired with Coal-Beneficiation & Coal-Gasification Modifications

- Raw Coal Bunker
- Mill ID Fan
- Skin Cancer
- Surge Bin
- Pulverized Coal Feeder
- Water / Ash / Mercury / Oil Extraction Module
- Coal Feeder
- CCS Coal Gasification Chamber
  (SO2 & NOx Control)
- Over-Fire Combustion Air
- Boiler Steam Out
- Boiler
- Economizer
- Hot Inert Flue Gas
- Air Heater
- Flue Gas Exhaust & Particulate to Baghouse
- FD Fan
- Ambient Combustion Air
- Over-Fire Combustion Air
- CLEAN HOT FUEL-RICH GASES
- Over-Fire Combustion Air
- Pulverized Coal & Sweep Gas from Power Plant Coal Mill
- Sweep Gas w / Pulverized Coal
- Sweep Gases To Bag House
- Hot Combustion Air
- Hot (Inert) Primary Air
- Boiler Feedwater
- Bottom Ash Disposal
- Hot Inert Primary Air
Opposed-Wall Fired Boiler
500 MW – 24 Wall-Fired PC Burners

WITH CCS, NO SCR REQUIRED
CCS Re-Engineered Wall-Fired Boiler
Replace Burners with 24 new CCS Burners & 6 GC’s
CCS-Tangential™ Boiler Retrofit
100 to 300 MW
CCS-Cyclone® Industrial Steam Supply

Design Capacity (MCR): 165,300 lb./h Steam (74 T\(_M\)/h)

Features:
- Smallest Boiler Footprint per MW\(_T\)
- Largest Steam Output per Ton of Steel
- Internal SO\(_2\) & NO\(_x\) Emissions Control
- Near Zero SO\(_3\) emissions
- High Combustion Efficiency (Reduced CO\(_2\)—Near Zero LOI)
- Fires most all coal types
- PC Coal-fired w/Limestone added
- Slag Screen Fly Ash Removal
- Wet bottom slagging operation
- Clean Furnace Walls
- Bottom Ash / Fly Ash is saleable
- No waste water disposal
- Affordable & Rapid Delivery
Re-Engineered Power Plant with CCS & Coal Beneficiation Processes
Stack Emissions Estimate* firing PRB coals (1.2 lb. SO$_2$/mm Btu Coal)

- SO$_2$ = $< 0.2$ lb./mmBtu (< 105 ppm)
  ~80% SO$_2$ reduction
- NO$_x$ = $< 0.10$ lb./mmBtu (< 75 ppm)
- CO = $< 300$ ppm
- LOI = $< 1\%$ (high efficiency combustion)
- SO$_3$ = $< 0.1$ ppm (condensable particulate)
- Mercury = $< 40$ ppb
- Particulate = $< 0.03$ lb./mmBtu (bag house)
- Boiler Efficiency = 2 – 10% increase

* Preliminary estimates of performance, measured after bag house – no guarantees
Rockwell International
25 x 10^6 Btu/hr (1 ton/hr) Test Facility (1990)
LNS-CAP Facility
ESSO Site, Cold Lake, Alberta Canada
50 mmBtu/hr – 3T/hr PRB Coal
LNS-CAP
Top of LNS Burner
LNS-CAP
Slag to Water Trough

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Boiler Radiant Section
View Forward to Burner
Demonstrated Emissions

SO$_2$ - 0.2 lb./mmBtu & NO$_x$ - 0.15 lb./mmBtu

ESSO LNS-CAP Facility, Cold Lake, Alberta, Canada
CCS-Stoker® Project

- **Objective:**
  - Reduce operating cost by half
  - Construction Permit w/ waiver NSPS, PSD; no NSR
  - Emissions Warrantee: <0.9 lb. SO₂/mmBtu, <0.25 lb. NOₓ /mmBtu

- **Project Initiated:** Oct 2005,
  - **Commissioning:** Jan 2007

- **CEC Scope:** Process Design & Engineering;
  - Supply all equipment, hardware, electrical, instrumentation / controls
  - Provide Commercial Warrantee & License

- **Client Scope:** Site Construction Management;
  - Equipment Installation, as directed by CLPRC
  - Commissioning & Start-up

- **Project Support:** In part, by the Illinois Department of Commerce and Economic Opportunity through the Illinois Clean Coal Institute and the Office of Coal Development.
Coal-Fired Stoker Boiler
(typical)

CCS Retrofit Modifications

Remove:
- Stoker Feeders,
- Ash Hopper,
- Brick over stoker grate
- Control Panel

New Equipment:
- CCS Burner,
- Gasification Chamber,
- Combustion Air Heater
- Boiler Instruments,
- Coal Mill, Bag house, FD fan, BM & Combustion Sys,
- HMI & PLC Controls
- New MCC

Operators (one/shift):
- Was all manual operation;
- Now with HMI - from cold start to automatic full load operation in 5 hrs.
CCS-Stoker® Retrofit
30 MW (Thermal) - 125 mmBtu/hr – 5 T/hr Coal
CCS-Stoker® Gasification Chamber
CCS-Stoker® Gasification Chamber Installation

- McBurney Corp designed and supplied the GC
- Connected to the boiler drums for natural circulation water cooling
- Shop fabricated membrane wall studded and refractory lined.

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Stoker Boiler Furnace Deposits
Typical Examples
Operation Observations
CCS-Stoker® Furnace Ash Deposits
## CCS-Stoker® Retrofit Performance
### Preliminary Results – Full Load Operation

<table>
<thead>
<tr>
<th>Item</th>
<th>Stoker Base Line Test</th>
<th>Preliminary CCS Performance</th>
<th>% Change from Base Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂ Stack Emissions (lb/MMBtu)</td>
<td>1.80</td>
<td>0.72</td>
<td>- 67.0 %</td>
</tr>
<tr>
<td>NOₓ Stack Emissions (lb/MMBtu)</td>
<td>0.50</td>
<td>0.14 (88 ppm)</td>
<td>- 72.0 %</td>
</tr>
<tr>
<td>Boiler Efficiency</td>
<td>77.0</td>
<td>86.9</td>
<td>+ 12.8 %</td>
</tr>
<tr>
<td>CO₂ Emissions - Ton/yr GW credits (% Reduction)</td>
<td>94,019</td>
<td>73,720</td>
<td>20,300T/y (- 21.6 %)</td>
</tr>
<tr>
<td>Project Cost Recovery (from firing lower cost coal)</td>
<td></td>
<td>~ 3 years</td>
<td></td>
</tr>
</tbody>
</table>
CCS Features
Improved Operability, Availability & Reliability

- All equipment off-the-shelf & familiar to the operators
  - Safe, stable burner operation,
  - Same startup, shutdown and turndown as the PC plant
- Bottom Ash (slag) removed before furnace
  - low particulate/ash load; clean furnace, less soot blowing
- Sulfur removed from furnace gases - near-zero SO$_3$:
  - Allows for lower furnace exit temperatures
  - Minimize water-wall wastage & corrosion,
  - Can use hot boiler exhaust for pulverizer sweep air:
    - Dry the coal – reject moisture
    - Improves coal pulverizer safety from fire & puffs (low O$_2$)
- Improved Boiler Efficiency (2 to +10%)
  - Reduce CO$_2$ emissions
  - High combustion efficiency (LOI < 1%)
- Limestone is only “chemical” required
- No waste water for disposal
CCS Summary
(Key Strategic Issues)

- From Fundamental Combustion Theory to Commercial Operation
- Fire lower cost coals - reduce plant operating cost
- Meets EPA’s new stringent regulations for SO\(_2\) & NO\(_x\)
- Allow power plant upgrade with waiver of NSPS & PSD - No NSR
- Low Retrofit Cost; maintains older, smaller plants competitive
- Improve plants capacity factor & dispatch
- Fits within plant & boiler site footprint
- Ash products have value (sell bottom ash & fly ash)
- No hazardous or toxic chemicals required

It’s ADVANCED COAL GASIFICATION TECHNOLOGY!
Strategic Business Opportunity?

Acquire Abandoned Coal-fired Power Plants

- Re engineer and Update PC Electric Generation Plant with CCS;
  - Provides \( \text{SO}_2 \) & \( \text{NO}_x \) emissions control,
  - Waiver of NSPS, PSD, & no NSR
- Integrate a CBM on each coal Mill
- Improved power plant performance
  - improves boiler heat rate/efficiency - less fuel fired
- Very competitive dispatch;
  - “\text{paid for}” fuel = low cost electricity
- Meet EPA “CAMR” goals (+90% mercury reduction)
- Can show carbon neutral process = No \( \text{CO}_2 \) increase!
CastleLight Energy Corp.
Re Engineering Programs

Please Contact CastleLight Energy Corp.
Keith Moore - President
Phone: 805-551-0983   E-mail: keith@castle-light.com
See Web Site: www.Castle-Light.com

For Technical Presentations / Plant Surveys and Reports:

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

• “Operating Experience of a Coal-Fired Boiler Retrofit with an Advanced Hybrid of Coal Gasification For SO₂ & NOₓ Emissions Control and Reduced Operating Cost”

• Proposal: - “Re-Engineering Coal-Fired Power Plants with the Clean Combustion System”