Re-Engineering Coal-Fired Electric Generating Plants with Coal Gasification

By
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CastleLight Energy Corp.

- Technology evolved from coal combustion research at Rockwell International with further development by TransAlta Utilities.
- Hybrid of Coal Gasification with strong SO$_2$ and NO$_x$ emissions control ............
- Coupled with a fast Coal Beneficiation process ........
- Some $60$ million in Utility peer reviewed development and field demonstrations & commercial programs
- Patented Technology

CastleLight Energy Corp. provides:
- Overall Technology Management
- System Engineering, Design, CFD & PEPSE Analysis
- All Hardware, Equipment, Instrumentation, and Controls including supervision of installation by customer
- Commercial Warrantee & Technology License
TECHNOLOGY LEAP FROGS!

When was the last time you:
Dialed a Phone?
Typed a Letter?
Flew in a Piston Engine Airplane?

Observe...... these technologies are obsolete!

Technology LEAP FROGS! .... It does not evolve.

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Existing U.S. Coal-fired Plants
Must meet stringent EPA emission regulations

Some 600 older, smaller (100 to 400MW) coal-fired plants are subject to being mothballed, abandoned or demolished because of the following EPA regulations. They can not afford the cost for modifications!

- **Cross-State Air Pollution Rule:** $\text{SO}_2$ & $\text{NO}_x$
- **MACT Rule:** Mercury, $\text{HCl}$, & CO
- **Clean Power Plan:** $\text{CO}_2$ reduction
- **Coal Combustion Waste:**
- **Wastewater Discharge:**
Re-Engineered Plant Performance Targets
Estimated: firing PRB coals * (1.2 lb. SO₂/mm Btu Coal)

- **SO₂**: < 0.2 lb./mmBtu (~ 105 ppm) ~80% SO₂ reduction
- **NOₓ**: < 0.10 lb./mmBtu (~ 80 ppm)
- **CO**: < 320 ppm
- **SO₃**: Near Zero (condensable acid particulate)
- **HCl**: < 0.022 lb./mmBtu
- **Hg**: < 5.7 lb./Tbtu, (~ 40 ppb)
- **Particulates**: < 0.03 lb./mmBtu (bag house)
- **Bottom Ash & Fly Ash**: sailable product
- **Waste Water**: Reduce or eliminate
- **Plant Efficiency**: > 6% increase (= 6% CO₂ reduction)
  - Remove water from coal
  - High Temperature, high efficiency combustion (LOI < 1%)
  - Provide clean furnace wall & back pass surfaces
  - Reduce flue gas exit temperatures
  - Address / reduce parasitic loads (add variable speed drives)
  - Possible Steam Turbine Upgrade

* Preliminary estimates of performance, measured after bag house – no guarantees
Typical Coal-Fired Power Plant with Back-End Emission Controls

$\text{SO}_2 = \text{FGD} + \text{Limestone}; \text{NO}_x = \text{SCR} + \text{Ammonia};\text{SO}_3 = \text{Trona} \ ?; \text{Hg} = \text{Activated Carbon} \ ?$

<table>
<thead>
<tr>
<th>SO$_2$ EMISION REDUCTION</th>
<th>NO$_x$ EMISION 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>90% AND HIGHER</td>
<td>90% AND HIGHER</td>
<td>2+% Decrease</td>
<td>2+% Decrease</td>
<td>No Change</td>
<td>11 - 15 MILS/KWH</td>
<td>$280 - 300 PER KW</td>
</tr>
</tbody>
</table>

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

FIG. 1    TYPICAL PULVERIZED COAL-FIRED POWER PLANT
Re-Engineered Coal-Fired Power Plant
with Coal Beneficitation & Hybrid of Coal-Gasification

(\(\text{SO}_2\) & \(\text{NO}_x\) Control Right in the Combustion Step)

<table>
<thead>
<tr>
<th>(\text{SO}_2) EMISSION REDUCTION</th>
<th>(\text{NO}_x) 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+</td>
<td>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>
</tr>
</tbody>
</table>

* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

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Re-Engineered Power Plant
“Indirect Fired” - Coal-Beneficiation & Coal-Gasification / Combustion

Raw Coal Bunker

Mill ID Fan

PC Coal / Gas Separator

Surge Bin

Pulverized Coal Feeder

CWS Coal Feeder

Water / Ash / Mercury / Oil Extraction Module

Coal Feeder

Coal Mill

Hot (Inert) Primary Air

Boiler

Feedwater

Raw Coal

Bunker

Coal Mill

Ambient
Combustion Air

Boiler Steam Out

Furnace

Economizer

Hot Inert
Flue Gas

Over-Fire
Combustion
Air

Air Heater

Flue Gas Exhaust & Particulate to Baghouse

FD Fan

Sweep Gas w/ Pulverized Coal

Clean Hot Fuel-Rich Gases

Over-Fire Combustion Air

Hot Combustion Air

Bottom Ash Disposal

Oil

Ash
Re-Engineered Power Plant
Coal-Beneficiation Process

- **Add Coal-Beneficiation Modules – One for each coal mill**
  1. Replace the hot primary air to the coal mill:
     - With hot inert boiler flue gas ((low O$_2$ and near zero SO$_3$))
     - Improves operation safety - eliminate mill fires & puffs
     - Dries the pulverized coal (to <10% moisture)
  2. Re-direct the powdered coal and wet sweep gas from the mill to a small bag house:
     - Separate the wet sweep gas from the dry coal.
     - Dispose the wet sweep gas around the boiler to plant stack. (removed water improves boiler efficiency)
     - Collect the dry powdered coal in the bag house hopper
  3. Meter the dry powdered coal to new Gasification Burners

  **Must process the coal as fast as it is pulverized ……. (~one cubic foot coal / second)**
Coal Beneficiation Target
Powder River Basin (PRB) Low Rank Coals

- **Coal Characteristics - PRB:**
  - Low in Btu: ~ 8300 Btu/Lb.
  - High in Moisture: 25 – 35%
  - 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%)
  - Mercury Compliance: ~40 ppb (-75%)

- **EPA MACT – Mercury (Hg) Compliance:**
  - Existing Plants = 5.7 lb./Trillion Btu or ~ 40 Parts / Billion

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New Burners & Gasification Chamber replaces coal burners & wind box

Existing Boiler Furnace
Coal-Gasification & Combustion Process

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).
Demonstrated Emissions

SO₂ - 0.2 lb./mmBtu & NOₓ - 0.15 lb./mmBtu

ESSO LNS-CAP Facility, Cold Lake, Alberta, Canada
Example: Opposed-Wall Fired Boiler
500 MW – 5 Mills & 24 PC Burners (Remove Burners & Wind box)

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Re-Engineered Wall-Fired Boiler
Install 6 Gasification Chambers & OFA, 24 Burners, 6 Bag houses
Re-Engineered Tangential™ Boiler

Example: 100 MW
New Steam Generator Design
With $SO_2$ & $NO_x$ Emissions Control

Features:

- Affordable Boiler Design
- Smallest Boiler Footprint per $MW_T$
- Largest Steam Output per Ton of Steel
- 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 for Fly Ash Removal
- Wet bottom slagging operation
- Clean Furnace Walls
- Bottom Ash / Fly Ash is saleable
- No waste water disposal
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

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LNS-CAP
Top of LNS Burner

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LNS-CAP
Gasification Chamber Inspection
LNS-CAP
Slag to Water Trough

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Boiler Radiant Section
View Forward to Burner
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

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.
Coal - Sweep Gas Separator

- Separates powdered coal from mill sweep gas
- Inert gas used for bag cleaning (No O₂)
- Hopper w/ level switches maintains ~15 min. coal supply
- Gate & spouts to rotary feeders - meters PC to Gasification Burners
Stoker Boiler Furnace Deposits
Typical Examples
Operation Observations
CCS-Stoker® Furnace Ash Deposits
CCS-Stoker® Operation @ MCR
Steam Overboard

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# 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 SO₃:
  - 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 O₂)
- Improved Boiler Efficiency (2 to +10%) 
  - Reduce CO₂ emissions
  - High combustion efficiency (LOI < 1%)
- Limestone is only “chemical” required
- No waste water for disposal
- Construction permit with waiver of NSPS & PSD
  - No New Source Review (NSR) Trigger!

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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;
  - Provides SO$_2$ & 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;
  - “paid for” fuel = low cost electricity
- Meet EPA “CSPR & MACT goals
CastleLight Energy Corp.
Re Engineering Program

For Technical Presentations and Plant Surveys:
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See Web Site: www.Castle-Light.com

• “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”