NATURAL GAS COMBINED HEAT AND POWER (CHP) AS A BACKUP FOR WIND APPLICATIONS

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Track C2
Who is Recycled Energy Development (RED)?

• Private Equity backed energy project developer – we finance, own, operate energy projects at industrial sites (“Host”).

• We take full energy-project responsibility including CapEx and OpEx risk.

• Host executes a long-term Energy Services Agreement and enjoys lower energy costs, thus becoming more competitive.

• Our principals have collectively invested >$3 billion and commissioned > 250 projects during the last 35 years

• In early September, we acquired Kodak’s utility infrastructure at the Eastman Business Park (EPB), Rochester, NY.
  • Utility services (125 MW power, steam, chilled water, compressed air, sewer services, nitrogen, natural gas and potable water) to >40 businesses at the park.
  • Investments in gas fired assets to meet the EPA’s Boiler MACT criteria.

• We also own and operate CHP assets in CA, NJ and MA
Trends and headlines

MidAmerican Plans $1.9 Billion Windfarm Build-out in Iowa
MidAmerican Energy Company last month announced it wants to invest about $1.9 billion to build 1,050 megawatts of new wind power in Iowa by year-end 2015.

Top 10 Articles of 2012

1. A list of possible coal closures in the U.S.
   - Court rules against coal-fired power plant
     Ruling lets lower court ruling stand that required environmental review. Read More
   - AEP unit plans coal-to-natural gas conversion at power plant
     Two units to undergo conversion, one unit to be retired. Read More

Executive order calls for more cogeneration

Natural Gas up
Coal down
Wind up
Ethanol production is well positioned to profit from recent macro-economic trends
Energy flows: Ethanol plant boiler steam, utility coal power and wind-turbine power

An ethanol plant pays for heat

A coal power plant pays to get rid of heat

Wind? Green power!

So what’s the concern?

- Ethanol plant operations
  - Heat is used
  - * Plant Boiler $\eta = 80\%$

- Grid power
  - Steam Turbine Generator STG
  - Steam
  - Condenser & Cooling Tower
  - Heat is wasted
  - ** Utility Boiler $\eta = 75\%$

- Grid power
  - Wind-turbine Farm
  - Wind
  - No heat

* Usually a Thermal Oxidizer Boiler. **Often a stoker or pulverized coal
Can you run your plant with unpredictable power, however “green” it might be?

Concern with wind power:
Intermittent and unpredictable

50% supply swing in ~5 hours

24-hour actual wind power supply in the Midwest ISO (MISO)
Concern with coal fired power: Boiler MACT, low gas prices and more

Boiler Maximum Available Control Technology (MACT) are emissions control rules for Mercury (Hg), Filterable Particulate Matter (PM), Hydrochloric Acid (HCl) and Carbon Monoxide (CO)

Finalized by US EPA on Dec. 20, 2012 with short compliance window. Options include
- Spend on pollution control equipment
- Convert coal boiler to burn natural gas or Invest in natural gas boiler
- Invest in a gas Combined Heat and Power system with Spinning Reserve (CHP-SR)

Coal boiler operators have to comply with Boiler MACT.

Today, “burner-tip” price of coal and gas is essentially the same.
Concerns of each entity

<table>
<thead>
<tr>
<th>Entity</th>
<th>Concern</th>
<th>Traditional solutions</th>
</tr>
</thead>
</table>
| Ethanol Plant           | • Cost of steam and grid power  
                          • Drought or flood  
                          • Blend wall  
                          • “Agenda group” criticism | • Preheat feed-water, improve controls  
                          • Demand reduction measures  
                          • Point to oil-import reductions |
| Coal Utility            | • Cost of Boiler MACT regulations  
                          • Cost of coal  
                          • Cost of coal boiler O&M | • Spend on pollution control equipment  
                          • Switch to gas  
                          • Shut down coal plant |
| Wind Power Producer     | • Loss of value due to inability to deliver firm capacity  
                          • Blamed for grid instability  
                          • Blamed for being a “subsidy hog” | • Spend on simple cycle Gas Turbine (GT) to “firm” wind  
                          • Spend on fuel for GT  
                          • Spend on O&M for GT |

Combined Heat and Power with Spinning Reserve (CHP-SR) can profitably address concerns.

Traditional solutions mostly echo spend, spend and spend.
Observation: Plenty of natural gas, ethanol plants, wind turbines and coal power plants

Wind increasing
Coal decreasing
Gas: cheap & plentiful
Ethanol plant has:
Gas supply
Elec. Sub-station

Which States Rely Most on Coal?

IMAGE SOURCES: Ethanol <ethanolrfa.org>, Wind <awea.org> Coal <ACEEE>, Gas (<cia.gov>)
The wind balancing value of Combined Heat and Power with Spinning Reserve (CHP-SR)

CHP-SR is a “common sense” solution

<table>
<thead>
<tr>
<th>Case</th>
<th>Wind power supply</th>
<th>Gas Turbine load</th>
<th>SR GT operating profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>High</td>
<td>Low</td>
<td>Stand-alone</td>
</tr>
<tr>
<td>B</td>
<td>Low</td>
<td>High</td>
<td>Stand-alone</td>
</tr>
<tr>
<td>C</td>
<td>High</td>
<td>Low</td>
<td>CHP-SR</td>
</tr>
<tr>
<td>D</td>
<td>Low</td>
<td>High</td>
<td>CHP-SR</td>
</tr>
</tbody>
</table>

**Spinning Reserve Gas Turbine (SR GT):**
A Gas Turbine that continually varies power output to balance variable wind power generation

**Combined Heat & Power with Spinning Reserve (CHP-SR):**
An "electrically oversized” thermally matched CHP system, normally operating at reduced power output

**Heat Rate (HR):**
Fuel MMBtu burned per MWh electricity generated

**Image Sources:** Solar turbines
Case A: High wind and low load SR GT. Stand-alone ethanol plant boiler steam

Burning fuel twice is wasteful and inefficient

Fuel to power & steam; System Efficiency 48.7%

<table>
<thead>
<tr>
<th>Steam Balance</th>
<th>MMBtu/Yr</th>
<th>Fuel Balance</th>
<th>MMBtu/Yr</th>
<th>Power Balance</th>
<th>MWh/yr</th>
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</thead>
<tbody>
<tr>
<td>HRSG</td>
<td>0</td>
<td>SR GT</td>
<td>3,276,000</td>
<td>Wind Power</td>
<td>504,000</td>
</tr>
<tr>
<td>Ethanol boiler</td>
<td>1,890,000</td>
<td>Ethanol boiler</td>
<td>2,368,800</td>
<td>SR GT power</td>
<td>252,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,890,000</td>
<td>TOTAL</td>
<td>5,644,800</td>
<td>TOTAL</td>
<td>756,000</td>
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</tbody>
</table>

Waste heat 288 MMBtu/Hr
GT exhaust 288 MMBtu/Hr

SR GT load 390 MMBtu/Hr 50% LHV 26%
Gas 390 MMBtu/Hr

Electric Grid TOTAL POWER 90 MW
Wind power 60 MW

Ethanol plant boiler LHV 80%
Gas 282 MMBtu/Hr

slide # 10
Case B: Low wind balanced by high load SR GT. Stand-alone ethanol plant boiler steam

Burning fuel twice is wasteful and inefficient

Fuel to power & steam; System Efficiency 48.7%

<table>
<thead>
<tr>
<th>Steam Balance</th>
<th>MMBtu/Yr</th>
<th>Fuel Balance</th>
<th>MMBtu/Yr</th>
<th>Power Balance</th>
<th>MWh/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRSG</td>
<td>0</td>
<td>SR GT</td>
<td>5,040,000</td>
<td>Wind Power</td>
<td>252,000</td>
</tr>
<tr>
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<td>1,890,000</td>
<td>Ethanol boiler</td>
<td>2,368,800</td>
<td>SR GT power</td>
<td>504,000</td>
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<tr>
<td>TOTAL</td>
<td>1,890,000</td>
<td>TOTAL 7,408,800</td>
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<td>TOTAL 756,000</td>
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</table>

Waste heat 396 MMBtu/Hr

GT exhaust 396 MMBtu/Hr

SR GT load 100%

Ethanol plant boiler LHV $\eta$ 80%

Electric Grid TOTAL POWER 90 MW

Wind power 30 MW

GT power 60 MW

Gas 600 MMBtu/Hr

steam 0 MMBtu/Hr

steam 225 MMBtu/Hr

Gas 282 MMBtu/Hr

Heat Recov. 0%
Case C: High wind and low load CHP-SR. Waste heat to ethanol plant.

Burning fuel once and recycling waste heat is efficient and profitable (see next)

<table>
<thead>
<tr>
<th>Steam Balance</th>
<th>MMBtu/Yr</th>
<th>Fuel Balance</th>
<th>MMBtu/Yr</th>
<th>Power Balance</th>
<th>MWh/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRSG</td>
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<td>SR GT</td>
<td>3,276,000</td>
<td>Wind Power</td>
<td>504,000</td>
</tr>
<tr>
<td>Ethanol boiler</td>
<td>0</td>
<td>Ethanol boiler</td>
<td>0</td>
<td>SR GT power</td>
<td>252,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,890,000</td>
<td>TOTAL</td>
<td>3,276,000</td>
<td>TOTAL</td>
<td>756,000</td>
</tr>
</tbody>
</table>

- Waste heat
  - 63 MMBtu/Hr

- GT exhaust
  - 288 MMBtu/Hr

- SR GT load
  - 390 MMBtu/Hr
  - LHV η 26%

- Electric Grid
  - TOTAL POWER 90 MW
  - GT power 30 MW
  - Wind power 60 MW

- Ethanol plant boiler
  - LHV η 80%

- Steam balance
  - 225 MMBtu/Hr

- HRSG
  - Heat Recov. 78%
  - Gas 0 MMBtu/Hr
Case D: Low wind balanced by high load CHP-SR. Waste heat to ethanol plant.

Burning fuel once and recycling waste heat is efficient and profitable (see next)

Fuel to power & steam; System Efficiency 71.6%

<table>
<thead>
<tr>
<th>Steam Balance</th>
<th>MMBtu/Yr</th>
<th>Fuel Balance</th>
<th>MMBtu/Yr</th>
<th>Power Balance</th>
<th>MWh/yr</th>
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</thead>
<tbody>
<tr>
<td>HRSG</td>
<td>1,890,000</td>
<td>SR GT</td>
<td>5,040,000</td>
<td>Wind Power</td>
<td>252,000</td>
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<tr>
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<td>0</td>
<td>Ethanol boiler</td>
<td>0</td>
<td>SR GT power</td>
<td>504,000</td>
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<tr>
<td>TOTAL</td>
<td>1,890,000</td>
<td>TOTAL</td>
<td>5,040,000</td>
<td>TOTAL</td>
<td>756,000</td>
</tr>
</tbody>
</table>

HRSG Heat Recov. 57%

Ethanol plant boiler LHV η 80%

Electric Grid
- TOTAL POWER
  - Wind power 30 MW
  - GT power 60 MW

SR GT load 100%

GT exhaust 396 MMBtu/hr

Waste heat 171 MMBtu/hr

Gas 0 MMBtu/hr

Fuel 600 MMBtu/hr

GT power 225 MMBtu/hr

Steam 0 MMBtu/hr
## Economic snapshot: operating assumptions

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>VALUE</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>hours/year</td>
<td>8,400</td>
<td>Ethanol plant, wind-turbine farm, SRGT, coal power plant and CHP-SR</td>
</tr>
<tr>
<td>Of which</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High wind</td>
<td>hours/year</td>
<td>4,200</td>
<td>Wind trailed by SRGT or CHP-SR</td>
</tr>
<tr>
<td>Low wind</td>
<td>hours/year</td>
<td>4,200</td>
<td>Wind balanced by SRGT or CHP-SR</td>
</tr>
<tr>
<td>Delivered fuel costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>$/MMBtu, HHV</td>
<td>$5.0</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>$/MMBtu, HHV</td>
<td>$4.0</td>
<td>$100 per ton</td>
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<tr>
<td>System non-fuel O&amp;M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR GT</td>
<td>$/MWh</td>
<td>$5.0</td>
<td>Typical, sited at wind-turbine farm</td>
</tr>
<tr>
<td>CHP-SR</td>
<td>$/MWh</td>
<td>$10.0</td>
<td>Typical, sited at Ethanol plant</td>
</tr>
<tr>
<td>Coal power plant</td>
<td>$/MWh</td>
<td>$15.0</td>
<td>Typical</td>
</tr>
<tr>
<td>Ethanol plant boiler</td>
<td>$/MMBtu steam</td>
<td>$1.0</td>
<td>Assumed for Thermal Oxidizer Boiler</td>
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<tr>
<td>Utility Coal boiler</td>
<td>MMBtu/MWh</td>
<td>12</td>
<td>Typical for older, sub-critical Rankine cycle coal power plants</td>
</tr>
<tr>
<td>Heat Rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol plant boiler efficiency</td>
<td>% LHV</td>
<td>80%</td>
<td>Assumed</td>
</tr>
</tbody>
</table>
## Economics: CHP-SR slashes operating costs

### Ethanol Plant Boiler cost

<table>
<thead>
<tr>
<th>Description</th>
<th>$MM/yr</th>
<th>$/MMBtu steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel: Natural gas</td>
<td>$13.0</td>
<td>$6.9</td>
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<tr>
<td>non-fuel O&amp;M</td>
<td>$1.9</td>
<td>$1.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$14.9</strong></td>
<td><strong>$7.9</strong></td>
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</tbody>
</table>

### CHP-SR cost

<table>
<thead>
<tr>
<th>Description</th>
<th>$MM/yr</th>
<th>$/MWh</th>
<th>*steam credit</th>
<th>Net cost $/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel: Natural gas</td>
<td>$22.8</td>
<td>$60.4</td>
<td>($34.3)</td>
<td>$26.1</td>
</tr>
<tr>
<td>non-fuel O&amp;M</td>
<td>$3.8</td>
<td>$10.0</td>
<td>($5.0)</td>
<td>$5.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$26.6</strong></td>
<td><strong>$70.4</strong></td>
<td></td>
<td><strong>$31.1</strong></td>
</tr>
</tbody>
</table>

### SR GT cost

<table>
<thead>
<tr>
<th>Description</th>
<th>$MM/yr</th>
<th>$/MWh</th>
<th>*steam credit</th>
<th>Net cost $/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel: Natural gas</td>
<td>$22.8</td>
<td>$60.4</td>
<td></td>
<td>$60.4</td>
</tr>
<tr>
<td>non-fuel O&amp;M</td>
<td>$1.9</td>
<td>$5.0</td>
<td></td>
<td>$5.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$24.7</strong></td>
<td><strong>$65.4</strong></td>
<td></td>
<td><strong>$65.4</strong></td>
</tr>
</tbody>
</table>

### Utility: power plant cost

<table>
<thead>
<tr>
<th>Description</th>
<th>$MM/yr</th>
<th>$/MWh</th>
<th>*steam credit</th>
<th>Net cost $/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel: coal</td>
<td>$18.5</td>
<td>$49.0</td>
<td></td>
<td>$49.0</td>
</tr>
<tr>
<td>non-fuel O&amp;M</td>
<td>$5.7</td>
<td>$15.0</td>
<td></td>
<td>$15.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$24.2</strong></td>
<td><strong>$64.0</strong></td>
<td></td>
<td><strong>$64.0</strong></td>
</tr>
</tbody>
</table>

* Steam credit reflects value of displaced Ethanol boiler steam

** Value of avoided CapEx impact savings and depends on scope, weighted average cost of capital and Investment term for all entities – utility, SRGT, CHP-SR and ethanol plant.

CHP-SR power is cheaper than

- Utility self-generated coal power
- Wind power producer with a balancing SR GT
CHP-SR can profitably reduce greenhouse gas emissions by recycling waste heat.

**Benefit to the thermal host (Ethanol plant)**
- Reduced cost of steam and increased steam supply reliability
- More reliable power supply

**Benefit to Grid (Utility owned Coal Power Plant)**
- Profitably address Boiler MACT - avoid compliance CapEx and future increased OpEx
- Balance intermittent renewable power and increase its share of generation fleet
- Enjoy local grid stability including power factor support and reduced line loss.
- Retain thermal host (ethanol plant) as all-requirements power customer
Value creation process

Query: What is a Utility (coal boiler power plant) executive contemplating?
View: Probably need to shutter coal power plant due to pressure from
• Boiler MACT
• Disappearing gas-coal price differential
• Renewable energy mandates

Query: What can be done to maintain reliable electric service?
View:
• Execute a Purchase Agreement (PPA) with a CHP-SR developer who can, on grid operator command balance intermittent wind power

Query: What can an Ethanol plant manager / owner do to profit from these trends?
View:
• Execute a Steam Sale Agreement (SSA) with CHP-SR developer
• Assist CHP-SR developer engage with local utility to implement a CHP-SR project
• Share the profits generated from the project!
Questions?

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## Appendices

### Boiler MACT limits - Federal Questions, vol 78 #21, Jan 31, 2013

<table>
<thead>
<tr>
<th>Subcategory</th>
<th>Flammable PM (or total selected metals) (lb per MMBtu of heat input)</th>
<th>HCl (lb per MMBtu of heat input)</th>
<th>Mercury (lb per MMBtu of heat input)</th>
<th>CO (ppm @3% oxygen)</th>
<th>Alternate CO CEMS limit (ppm @3% oxygen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing—Coal Stoker</td>
<td>0.040 (5.3E-05)</td>
<td>0.022</td>
<td>5.7E-06</td>
<td>150</td>
<td>340</td>
</tr>
<tr>
<td>Existing—Coal Fluidized Bed</td>
<td>0.040 (5.3E-05)</td>
<td>0.022</td>
<td>5.7E-06</td>
<td>130</td>
<td>230</td>
</tr>
<tr>
<td>Existing—Coal Fluidized Bed with FB heat exchanger</td>
<td>0.040 (5.3E-05)</td>
<td>0.022</td>
<td>5.7E-06</td>
<td>140</td>
<td>150</td>
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<tr>
<td>Existing—Cool Burning Pulverized Coal</td>
<td>0.040 (5.3E-05)</td>
<td>0.022</td>
<td>5.7E-06</td>
<td>190</td>
<td>320</td>
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<tr>
<td>Existing—Biomass Wet Stoker/Slanted Grate/Other</td>
<td>0.037 (2.4E-04)</td>
<td>0.022</td>
<td>5.7E-06</td>
<td>1,500</td>
<td>720</td>
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<td>Existing—Biomass Kin-Dried Stoker/Slanted Grate/Other</td>
<td>0.32 (4.0E-03)</td>
<td>0.022</td>
<td>5.7E-06</td>
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<td>ND</td>
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<td>Existing—Biomass Fluidized Bed</td>
<td>0.11 (1.2E-03)</td>
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<td>5.7E-06</td>
<td>470</td>
<td>310</td>
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<td>0.051 (0.5E-03)</td>
<td>0.022</td>
<td>5.7E-06</td>
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<td>2,000</td>
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<td>0.022</td>
<td>5.7E-06</td>
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<td>520</td>
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<td>Existing—Biomass Hybrid Suspension Grate</td>
<td>0.44 (4.5E-04)</td>
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<td>5.7E-06</td>
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<td>900</td>
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<td>Existing—Heavy Liquid</td>
<td>0.062 (2.0E-04)</td>
<td>0.0011</td>
<td>2.0E-06</td>
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<td>Existing—Light Liquid</td>
<td>0.0079 (6.2E-05)</td>
<td>0.0011</td>
<td>2.0E-06</td>
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<td>Existing—non-Continental Liquid</td>
<td>0.27 (8.6E-04)</td>
<td>0.0011</td>
<td>2.0E-06</td>
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<td>Existing—Gas 2 (Other Process Gases)</td>
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<td>0.0017</td>
<td>7.2E-06</td>
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<td>New—Coal Sticker</td>
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<td>0.022</td>
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<td>340</td>
</tr>
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<td>0.022</td>
<td>8.0E-07</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>New—Cool Burning Pulverized Coal</td>
<td>0.0011 (2.3E-05)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>New—Biomass Wet Stoker/Slanted Grate/Other</td>
<td>0.030 (2.6E-05)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>620</td>
<td>390</td>
</tr>
<tr>
<td>New—Biomass Kin-Dried Stoker/Slanted Grate/Other</td>
<td>0.030 (4.0E-03)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>460</td>
<td>ND</td>
</tr>
<tr>
<td>New—Biomass Fluidized Bed</td>
<td>0.0009 (3.5E-05)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>230</td>
<td>ND</td>
</tr>
<tr>
<td>New—Biomass Suspension Burner</td>
<td>0.030 (6.5E-03)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>2,400</td>
<td>2,000</td>
</tr>
<tr>
<td>New—Biomass Dutch Ovens/Pile Burners</td>
<td>0.0032 (3.9E-05)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>330</td>
<td>620</td>
</tr>
<tr>
<td>New—Biomass Fuel Cells</td>
<td>0.020 (2.9E-05)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>910</td>
<td>ND</td>
</tr>
<tr>
<td>New—Biomass Hybrid Suspension Grate</td>
<td>0.026 (4.4E-04)</td>
<td>0.022</td>
<td>8.0E-07</td>
<td>1,100</td>
<td>900</td>
</tr>
<tr>
<td>New—Heavy Liquid</td>
<td>0.013 (7.5E-05)</td>
<td>4.4E-04</td>
<td>4.8E-07</td>
<td>130</td>
<td>ND</td>
</tr>
<tr>
<td>New—Light Liquid</td>
<td>0.0011 (2.5E-05)</td>
<td>4.4E-04</td>
<td>4.8E-07</td>
<td>130</td>
<td>ND</td>
</tr>
<tr>
<td>New—Non-Continental Liquid</td>
<td>0.023 (6.6E-04)</td>
<td>4.4E-04</td>
<td>4.8E-07</td>
<td>130</td>
<td>ND</td>
</tr>
<tr>
<td>New—Gas 2 (Other Process Gases)</td>
<td>0.0067 (2.1E-04)</td>
<td>0.0017</td>
<td>7.9E-08</td>
<td>130</td>
<td>ND</td>
</tr>
</tbody>
</table>

NA-Not applicable; ND-No data available.  
*3-run average, unless otherwise noted.  
*30-day rolling average, unless otherwise noted.  
*10-day rolling average.
## APPENDIX

### Power-Gen 2013 CHP WHP

<table>
<thead>
<tr>
<th>NOx</th>
<th>Sox, HCl and Acid Gasses Control Technologies</th>
<th>Hg Control Technologies</th>
<th>Metals (PM) Control Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low NOx Burners</td>
<td>Fuel Switching</td>
<td>Fuel Switching</td>
<td>Fuel Switching</td>
</tr>
<tr>
<td>LNB with OFA</td>
<td>Furnace / Duct Sorbent Injection</td>
<td>Boiler Additives</td>
<td>Humidification and Agglomeration (Flue Gas Conditioning)</td>
</tr>
<tr>
<td>SNCR</td>
<td>Dry Scrubbers – SDA – CDS-EAD</td>
<td>Direct or Indirect Flue Gas Cooling</td>
<td>Combustion Modifications</td>
</tr>
<tr>
<td>SCR</td>
<td>Wet Scrubbers</td>
<td>Sorbent Injection With Existing Particulate Control Systems</td>
<td>Retrofitting Existing ESPs</td>
</tr>
<tr>
<td></td>
<td>Repowering</td>
<td>Scrubber Additives</td>
<td>Dry and Wet Electrostatic Precipitator (ESP)</td>
</tr>
</tbody>
</table>

**Blue Box: Front-End Control Technology**

**Green Box: In-situ Control Technology**

**Red Box: Back-End Control Technology**

*Note: The table includes various control technologies for NOx, Sox, HCl, and Acid Gasses, along with Hg and Metals (PM) control. The table is color-coded to distinguish between front-end, in-situ, and back-end control technologies.*
Shale gas fracketing has unlocked huge domestic gas supply

APPENDIX: Is there a fuel switch risk? gas availability

Lower 48 states shale plays
US gas production has increased dramatically.

Several LNG export projects in the planning stage
Currently, “burner-tip” price of coal and gas are essentially the same.

You can buy a 3-year gas strip for just over $4/MMBtu today.

APPENDIX: Is there a fuel switch risk? Gas versus coal price

This is also reflected in power generation statistics from the US Energy Information Administration (EIA),

1950 to 2012

2010 to 2012
Emissions control rules for “major source” coal, oil, biomass and process gas boilers

- Impacts > 500 coal units, >800 oil units and > 400 biomass units
- 3-to-4 year compliance window from publication of final rule

Stringent limits for
- Mercury (Hg)
- Filterable Particulate Matter (PM)
- Hydrochloric Acid (HCl)
- Carbon Monoxide (CO)

Compliance likely uneconomic for older coal and oil boilers. Options include
- Spend on pollution control equipment
- Convert coal boiler to burn natural gas
- Invest in natural gas boiler
- Invest in a gas Combined Heat and Power system with Spinning Reserve (CHP-SR)
APPENDIX: An example site affected by Boiler MACT

A “classic” CHP system.
Economical when coal was inexpensive and pollution control was “not my problem”

Does this look like your coal boiler operations?

Stoker system, 30-to-70 years old; $\eta \sim 75\%$ and FSF~1.6 MMBtu/Klb

Burns costly compliance coal, steam load (3,000 Kpph) and 95% (8,322 hrs/yr) operations

High non-fuel O&M costs ($25$-to-$30$ million/year)

Minimal pollution control - ESP or BH only. Monitor SOx, NOx, PM, Hg, HCl and CO

But, you have a VALUABLE air permit

STG = Steam turbine Generator; ESP = Electro-Static Precipitator, FSF = Fuel-to-Steam Factor
APPENDIX: Selected Boiler MACT pollution control equipment

Your system today controls **PM. Less effective for Hg. Ineffective for HCl, NOx, SOx**

Option #1: Control PM, HCl. **Less effective for Hg.** Controls NOx, SOx

Option #2: Control PM, HCl, Hg. Controls NOx. **Less effective for SOx**

**CO control via combustion system improvements; i.e. more CapEx**