Potential Coal Plant Retirements
Under Emerging Environmental Regulations

Metin Celebi, Frank Graves, Gunjan Bathla, and Lucas Bressan

The Brattle Group

December 8, 2010
Outline

Introduction and key conclusions

EPA regulations and coal plants

Economic retirement model

Results

Appendix
Emerging EPA regulations on air quality, water use and ash disposal will likely require existing coal units to choose between installing expensive control equipment and retirement.

Continuation of current low electricity prices in the next five years will also increase the pressure to retire.
Analysis of coal plant retirement exposure

Developed a tool to analyze economics of retrofit vs. retirement for every coal unit in the U.S. under various scenarios of environmental regulation.

- Estimate future capacity factor for each unit by dispatching against projected hourly power prices.

- Decide each year whether to retire based on comparing 15-year projected avoidable costs of retrofit against:
  - revenues from energy and capacity markets for merchant units (on an after-tax basis),
  - cost of replacement power from gas CCs or CTs for regulated units.
Brattle coal plant retirement screening tool

Economic Drivers (by region)
- Hourly projected energy prices
- Unit-specific VOM cost, heat rate, and projected coal prices
- FOM cost by age
- Projected capacity prices
- Projected cost of replacement power from gas CC/CTs

Environmental Drivers (by region)
- Regulation scenarios
- Existing control equipment
- CapEx for retrofit
- Additional FOM for each retrofit
- Compliance year

Retirement Analysis

Results
- Retired coal capacity
- Compliance costs
- CO₂ emissions
- Regional reserve margins
- Gas and coal demand

Note: The version of the tool presented here does not consider potential feedback effects of retirements on wholesale electricity or fuel prices.
Uncertainties and contingencies

These results present a retirement exposure analysis, identifying which units become uneconomic under current market projections.

♦ Where the local effects of potential retirements are severe, it is likely that market responses, regulatory allowances, or perhaps even environmental policy adjustments would occur that would mitigate some of the impacts, especially where reliability is at risk.

♦ On the other hand, there are also frictional effects of making numerous, industry-wide retrofits and capacity replacements, which would tend to increase the difficulties of meeting the new environmental regulations. These have also not been modeled.

This analysis describes just one particular set of region-specific market conditions.

♦ This is only one possible view of the future – There are major uncertainties surrounding long run market circumstances and regulatory policy that would affect these projections.

The modeling capability behind this presentation would allow us to explore unit-specific impacts of other potential future market conditions, investment decision criteria, and more detailed circumstances faced by individual companies or generating units.
Key conclusions – coal plant retirements

A requirement to install **scrubbers and SCRs** on coal units by 2015 would result in **40-55 GW** of economic retirements

- Another 11-12 GW of coal units would retire if **cooling towers** (@ $200/kW) are also mandated
- Higher-end of range based on doubling the retrofit costs due to potentially increasing demand for labor and control equipment or due to site-specific constraints

**$70-130 billion investment** on scrubbers and SCRs (for 187 GW coal capacity) would be needed to comply with the EPA mandates

- An additional **$30-50 billion** compliance investment would be needed if **cooling towers** are also mandated.

Most of the economic retirements are with **merchant units** (which rely on market revenues), in contrast to **regulated units** whose retirement decisions are based on the cost of replacement power.

- We analyzed merchant units against wholesale spot conditions, not considering any LT PPAs

### U.S. COAL PLANT CAPACITY VULNERABLE TO RETIREMENT BY 2020

<table>
<thead>
<tr>
<th></th>
<th>Retirements with Scrubber &amp; SCR Mandate GW</th>
<th>Additional Retirements with Cooling Tower Mandate GW</th>
<th>Total Retirements GW</th>
<th>Percentage of Total Capacity</th>
<th>Retrofit Capital Costs for Compliance $ Billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nationwide Total</td>
<td>40-55</td>
<td>11-12</td>
<td>50-66</td>
<td>16-21%</td>
<td>5-7%</td>
</tr>
<tr>
<td>Merchant</td>
<td>37-48</td>
<td>8-10</td>
<td>47-56</td>
<td>64-76%</td>
<td>11-14%</td>
</tr>
<tr>
<td>Regulated</td>
<td>3-6</td>
<td>1-4</td>
<td>3-10</td>
<td>1-4%</td>
<td>1-2%</td>
</tr>
</tbody>
</table>
Key conclusions – coal plant retirements (cont’d)

Most of the retirements would be in NERC regions RFC, SERC and ERCOT.

[Map showing retirements in different NERC regions with various capacity ranges indicated in GW.]
Key conclusions – coal plant retirements (cont’d)

Market areas with the largest retirements would be Midwest ISO, ERCOT, and PJM.

- Retirements represent large portions of existing total regional capacity: 15% in ERCOT, 11-14% in Midwest ISO, and 6-11% in PJM.
- All merchant coal plants in ERCOT would retire if scrubbers, SCR, and cooling towers are mandated.

### COAL PLANT CAPACITY VULNERABLE TO RETIREMENT BY 2020 - SELECTED REGIONS

<table>
<thead>
<tr>
<th>ISO</th>
<th>Total Coal Capacity (GW)</th>
<th>Total Retirements (GW)</th>
<th>Percentage of Total Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwest ISO Total</td>
<td>12-15</td>
<td>16-20</td>
<td>21-28%</td>
</tr>
<tr>
<td>Merchant</td>
<td>11-12</td>
<td>14</td>
<td>93-94%</td>
</tr>
<tr>
<td>Regulated</td>
<td>1-3</td>
<td>2-6</td>
<td>3-11%</td>
</tr>
<tr>
<td>ERCOT ISO Total</td>
<td>9-12</td>
<td>13</td>
<td>72</td>
</tr>
<tr>
<td>Merchant</td>
<td>9-12</td>
<td>13</td>
<td>100%</td>
</tr>
<tr>
<td>Regulated</td>
<td>0</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>PJM ISO Total</td>
<td>8-15</td>
<td>12-19</td>
<td>15-26%</td>
</tr>
<tr>
<td>Merchant</td>
<td>8-15</td>
<td>12-19</td>
<td>33-54%</td>
</tr>
<tr>
<td>Regulated</td>
<td>0</td>
<td>0</td>
<td>0-1%</td>
</tr>
</tbody>
</table>
Key conclusions – coal plant retirements (cont’d)

About **1/3rd of the economic retirement capacity are younger (< 40 years) and larger (> 500 MW) units**, highlighting the importance of considering regional market conditions in addition to unit age and size in retirement decisions.

**Capacity revenues are moderately important**, reducing them by half would add another 7 GW of retirements under the EPA mandate to install scrubbers and SCRs.

**Another 8 GW of regulated units would retire** under scrubber and SCR mandates (~ half of them in the MRO region) *if a 20% discount is applied to the cost of replacement power* as a proxy for potential externality penalties imposed by regulators (such as “Probable Environmental Cost” assessments)
Key conclusions – other impacts

Retirements would reduce reserve margins in 2020 below targets in ERCOT and RFC in the absence of additional new resources coming online:

- ERCOT: from 10% to 1%, compared to target of 13%
- RFC: from 19% to 13%, compared to target of 15%
- Most retirements occur in 2015 (beginning of assumed mandates)

Coal demand falls by about 15% relative to base case in 2020 (due to retirements and lower CFs for the remaining units that installed scrubbers and SCRs).

The retirements and reduced capacity factors due to scrubber and SCR requirements would increase U.S. gas demand by at most 5.8 Bcfd (about 10% of total demand), with significant regional variation

- RFC-MISO gas demand increase about 0.7 Bcfd, compared to 0.1 Bcfd in FRCC.

CO₂ emissions would decrease by 150 million tons in 2020 (~10% of coal CO₂ emissions) if the lost coal generation (due to retirements and lowered capacity factors) is replaced by gas generation (@ 8000 Btu heat rate).
Comparison to other studies

Recent studies estimate **10-75 GW coal capacity at risk** for retirement.

<table>
<thead>
<tr>
<th>Study</th>
<th>Projected coal capacity to retire or &quot;at risk&quot;</th>
<th>Criteria to identify coal capacity at risk</th>
<th>Models future revenues from energy and capacity markets?</th>
<th>Models future capacity factors of coal units?</th>
<th>Distinguishes between merchant vs. regulated units?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brattle, December 2010</td>
<td>50-65 GW by 2020</td>
<td>Regulated units: 15-year PV of cost &gt; replacement power cost from a gas CC or CT; Merchant units: 15-year PV of cost &gt; revenues from energy and capacity markets</td>
<td>Yes, based on dispatch against projected hourly prices</td>
<td>Yes, based on dispatch against projected hourly prices</td>
<td>Yes</td>
</tr>
<tr>
<td>NERC, October 2010</td>
<td>10-35 GW by 2018 (in addition to ~20 GW committed/announced retirement, or not relied upon by NERC as a capacity resource)</td>
<td>Levelized costs (@ 2008 CF) after retrofitting each unit for the environmental regulations compared to the cost of a new gas-fired unit</td>
<td>No</td>
<td>No</td>
<td>Yes – uses different cost of capital for regulated vs. merchant units</td>
</tr>
<tr>
<td>ICF (October 2010)</td>
<td>75 GW by 2018</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>Credit Suisse, September 2010</td>
<td>60 GW</td>
<td>Size and existing controls</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ICF/INGAAA, May 2010</td>
<td>50 GW</td>
<td>Age, efficiency and existing controls</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ICF/EEI (May 2010)</td>
<td>25-60 GW by 2015</td>
<td>Cost of retrofitting coal plant compared to cost of new gas CC</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Outline

Introduction and key conclusions

EPA regulations and coal plants

Economic retirement model

Results

Appendix
Overview of environmental pressures

EPA is in the process of promulgating a series of new regulations to more tightly control all of the following:

- “Criteria air pollutants,” especially NOx, ozone, SOx, and particulates
- Hazardous air pollutants (HAPs), especially mercury
- Cooling water discharge
- Coal combustion byproducts

The nature of most of these regulations, and the way states must implement these more stringent air quality standards, is expected to be highly tilted toward command-and-control (i.e., with no choice but to comply or retire on a strict schedule), less toward cap-and-trade of emission allowances that are fungible over space and time.

However, there has been some recent movements that suggest at least the coal ash and water regulations (316b) may be delayed

- a more flexible time table or conditional slate of control options would reduce the economic impacts we find arising under a more strict interpretation of the potential rules
Criteria air pollutants (ozone, NOx, SOx, particulates)

EPA promulgates regulations based on the Clean Air Act: Clean Air Interstate Rules (CAIR), Haze Rules, and National Ambient Air Quality Standards (NAAQS)

♦ States must file State Implementation Plans to demonstrate commitment to progress towards compliance with NAAQS

EPA Developments Affecting Future Regulations

♦ Transport Rule – Regulates NOx and SOx emissions in 31 states (Mid 2011)
  • State-specific SOx and NOx budgets starting in 2012/14; restricts interstate allowance trading
  • Reduce SOx emissions by 71%, NOx emissions by 52% (relative to 2005 levels)

♦ NAAQS – Stricter ozone concentrations likely in place in 2011
  • Will likely cause states to implement command-and-control regulations

♦ Both of these move away from market-based cap-and-trade and toward command-and-control

♦ Many existing units will need to add expensive scrubbers and SCRs or retire
Hazardous air pollutants (HAPs)

HAPs are pollutants (mercury, phosphoric acid, lead and selenium compounds, etc.) that are associated with cancer or other serious health affects.

EPA has not regulated HAPs from electric generators before.

As soon as EPA does regulate HAPs, the Clean Air Act dictates strict controls by EPA (Maximum Achievable Control Technology -- MACT), with little flexibility for sources to comply.

Coming EPA MACT rulemakings for mercury and other HAPs:
- EPA is expected to issue rules in March 2011
- Affects coal and oil units
- May require scrubbers (ACI may not be enough) on all coal plants in 3-4 years
Cooling Water

- EPA and states are beginning to apply the Clean Water Act (CWA) to force generators to replace once-through cooling, sometimes subject to cost/benefit tests.
- EPA is expected to issue rules in 2011/12 regarding cooling water intake structures and waste water discharges.

Ash

- Currently exempt from EPA hazardous waste regulations.
- EPA proposed two options:
  - Regulate as hazardous waste under Subtitle C of Resource Conservation and Recovery Act (RCRA).
  - Regulate similar to those for municipal and non-hazardous solid waste, hence less stringent than Option 1.
The US coal fleet has a total of 316 GW capacity (~1/3rd of all capacity), and generates roughly half of all electrical output. About 75% of the coal fleet is owned by regulated entities (IOUs, munis, federal power agencies, etc.). Capacity factors of coal units in U.S. averaged 61% in 2009.

<table>
<thead>
<tr>
<th>NERC Region</th>
<th>Coal Capacity (GW)</th>
<th>% Owned by Regulated Entities</th>
<th>2009 Capacity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFC</td>
<td>105</td>
<td>63%</td>
<td>61%</td>
</tr>
<tr>
<td>SERC</td>
<td>100</td>
<td>88%</td>
<td>62%</td>
</tr>
<tr>
<td>WECC</td>
<td>32</td>
<td>89%</td>
<td>78%</td>
</tr>
<tr>
<td>MRO</td>
<td>27</td>
<td>96%</td>
<td>70%</td>
</tr>
<tr>
<td>SPP</td>
<td>20</td>
<td>98%</td>
<td>72%</td>
</tr>
<tr>
<td>ERCOT</td>
<td>18</td>
<td>28%</td>
<td>77%</td>
</tr>
<tr>
<td>FRCC</td>
<td>10</td>
<td>92%</td>
<td>58%</td>
</tr>
<tr>
<td>NPCC</td>
<td>6</td>
<td>16%</td>
<td>58%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>316</strong></td>
<td><strong>77%</strong></td>
<td><strong>65%</strong></td>
</tr>
</tbody>
</table>

Large portion of the current coal fleet lacks major environmental controls:

- ♦ 165 GW (52%) without scrubbers, majority of them in RFC and SERC regions
- ♦ 180 GW (57%) without SCRs, about half in RFC and SERC regions
- ♦ ~300 GW (96%) without ACI and baghouse, majority of them in RFC and SERC regions
About **50 GW** of existing **small** (< 500 MW) and **old** (> 40 years) coal units have **no environmental controls***. Most of these units are in RFC and SERC regions.

*Environmental controls here refer to scrubber for SO₂ and SCR/SNCR for NOₓ.*
EPA regulations – implications

Potential technology-based environmental restrictions in air (SO\textsubscript{2}, NO\textsubscript{x}, Mercury), water and coal ash disposal in lieu of market-based approaches.

**SCR:** $50-60 million for a 300 MW plant

**ACI+Baghouse:** ~$30 million (300MW)

**Cooling tower:** $60-90 million (300MW)

**Scrubber:** $100-120 million (300MW)
A new regulation that requires scrubbers would add $8-34/MWh (in O&M and carrying costs) to the existing costs of coal plants. If NOx controls (SCR) and/or mercury controls (ACI) are also required, this would bring the total increase in levelized costs to $12-46/MWh.

Costs of compliance

COST OF ENVIRONMENTAL CONTROL EQUIPMENT FOR COAL PLANTS

<table>
<thead>
<tr>
<th>Controls</th>
<th>Scenario I</th>
<th>Scenario II</th>
<th>Scenario III</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGD</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>SCR</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>ACI (No Existing Baghouse)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td>Million 2009 $'s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 MW unit at 70% CF</td>
<td>$153</td>
<td>$233</td>
<td>$199</td>
</tr>
<tr>
<td>600 MW unit at 30% CF</td>
<td>$149</td>
<td>$227</td>
<td>$194</td>
</tr>
<tr>
<td>300 MW unit at 70% CF</td>
<td>$118</td>
<td>$168</td>
<td>$149</td>
</tr>
<tr>
<td>300 MW unit at 30% CF</td>
<td>$116</td>
<td>$165</td>
<td>$147</td>
</tr>
</tbody>
</table>

Current energy margins (excluding capacity revenues) already low for merchant coal plants due to low gas prices, low demand growth, and new renewables

- Current dispatch costs for an existing coal plant ~$20-35/MWh
- Low wholesale power prices in 2009
  - PJM West: ~$40/MWh
  - Southeast: ~$30/MWh
Some implications of coal plant retirements

- Electric reliability (grid and reserves) at risk

- Decrease in coal demand
  - Effect on rail transport (2/3rd of coal shipped by rail, approximately 20% of rail freight revenues from coal)

- Likely increase in gas demand
  - Possibly offset partially by increased renewable expansion
  - Effect on gas prices and volatility? – not examined in this study
  - Effect on pipeline basis prices? – not examined in this study

- Increase in electricity prices (energy and capacity) – not examined in this study

- Potential stranded costs for regulated utilities – not examined in this study
Introduction and key conclusions

EPA regulations and coal plants

Economic retirement model

Results

Appendix
Brattle coal plant retirement screening tool – details

Hourly Energy Prices
- 2009 hourly shapes for each NERC subregion (LMPs and system lambdas)
- Annual growth rates from AEO2010 generation costs

Hourly Dispatch of Coal Units
- 24-hour commitment horizon
- 3 modes: off, min load, max load

Variable Costs for Coal Units
- 2009 unit-specific coal prices, grown to 2010-2035 using AEO2010 regional coal prices
- Unit-specific VOM and start-up costs
- Additional VOM for operating control equipment

Energy Revenues

Capacity Revenues

All-in cost of replacement power from gas CC/CT

Merchant Unit
Retire when PV(revenues) < PV(costs)

Regulated Unit
Retire when PV(coal costs) >> PV(gas CC/CT costs)

Variable Costs (fuel, VOM)

CO₂ prices

CapEx for required controls (FGD/SCR/ACI)

FOM Costs (as-is and for control equipment)

Output by Region
- Retired coal capacity
- Reduction in coal generation

Note: Dashed lines and boxes represent factors and feedback effects that are planned to be incorporated into the model.
Key assumptions on markets

**Wholesale power prices**
- Hourly actual prices in 2009 projected to 2010-2035 using AEO2010 escalation rates for generation prices
- Annual average prices in the range of $25-35/MWh (2008 dollars), largely remain flat in the future
  - except for increasing prices in ERCOT, NYISO, and PJM

**Capacity prices**
- Only applied to regions with capacity markets
- In the range of $10-80/kW-year until 2020, then growing to $40-190/kW-year based on *Brattle* forecasts
- *Brattle* has developed region-specific capacity price outlooks based on reserves, planned additions and retirements, cost of new entry, and RTO market rules. Similar to other inputs in this study, only one scenario for capacity price outlook is examined.

**Natural gas prices**
- Regional annual projections based on AEO2010
- Steep growth from $4-6/MMBtu range in 2010 to $5.5-8.5/MMBtu in 2020 (all in real dollars)

**Coal prices**
- Regional annual price projections based in AEO2010
- Most regions with flat real prices over time

**More details in the Appendix**
Illustration of coal hourly dispatch

No generation since operating margins during the day not sufficient to recover start-up costs.

Unit started up and generation output at min load (280 MW) or max load (584 MW) since operating margins during the day were enough to recover start-up costs.
Cost of continued coal operations is compared to **cost of replacement power** from a gas CC/CT (amortized over 40 years of capital recovery at a utility ATWACC).

Even though the CapEx for installing a scrubber and an SCR on the unit is ~$220M in 2015, 15-year present value (at 7% discount rate) of continued coal operations with CapEx is roughly half of new gas CC/CT costs. Therefore, **the unit does not retire** in the model.
Cost of continued coal operations is compared to revenues from energy and capacity markets. The required $90 million CapEx in 2015 makes the 15-year PV (at 7% discount rate) of costs higher than revenues, hence the unit retires in 2015.
Outline

Introduction and key conclusions

EPA regulations and coal plants

Economic retirement model

Results

Appendix
Economic retirements **mostly from merchant units**, but more than half of coal capacity (~235 GW) could experience **small (<10% of costs) or negative energy margins** under an EPA mandate to install scrubbers and SCRs.

U.S. COAL PLANT CAPACITY VULNERABLE TO RETIREMENT BY 2020

<table>
<thead>
<tr>
<th>Retirement Criterion</th>
<th>BASECASE</th>
<th>MANDATORY SCRUBBERS AND SCRs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GW</td>
<td>% of coal capacity</td>
</tr>
<tr>
<td>Age (&gt; 40 yr old) and size (&lt; 500 MW)</td>
<td>Merchant 13.6 18.4% 65.7 17.4%</td>
<td>Merchant 17.7 23.8% 66.1 17.5%</td>
</tr>
<tr>
<td>Energy margins &lt; 10% of costs</td>
<td>Merchant 17.7 23.8% 66.1 17.5%</td>
<td>17.7 23.8% 66.1 17.5%</td>
</tr>
<tr>
<td>Energy and capacity revenues for merchant units, replacement power for regulated units (+20% stranded cost adder)</td>
<td>Merchant 5.8 7.8% 12.2 3.2%</td>
<td>5.8 7.8% 12.2 3.2%</td>
</tr>
</tbody>
</table>

No CO₂ prices assumed, and no additional controls or operating constraints (e.g., cooling water, or ash handling).
Sensitivities on regulatory shutdown criteria

Default retirement criteria for regulated units is whether the present value of:

- future coal plant operation, FOM and environmental CapEx costs exceed
- the cost of replacement power from a gas CC/CT plus an assumed 20% stranded cost adder

Two sensitivities are performed on this assumed regulatory criteria for retirements:

1. With no 20% stranded cost adder: slightly higher (+2 GW) retired capacity
2. With 20% discount to gas CC/CT replacement cost: significantly higher (+8 GW) retirements
   - This sensitivity is a proxy for potential externality penalties imposed by regulators (e.g., future state/federal CO₂ legislation)
Coal retirements by age and size groups

About half of the economic retirements are from younger units (< 40 years in 2009) due to unfavorable regional power prices even though younger units have cost and efficiency advantages.

Not surprisingly, smaller units account for a large portion of the retirements.

<table>
<thead>
<tr>
<th>Total Retired Coal Capacity by 2020 (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>&lt; 500 MW</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td><strong>Basecase</strong></td>
</tr>
<tr>
<td>Age &lt;40 years</td>
</tr>
<tr>
<td>Age &gt;=40 years</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Scrubber+SCR Mandate</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &lt;40 years</td>
</tr>
<tr>
<td>Age &gt;=40 years</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
Regional summary

Six NERC subregions account for about 80% of the likely retirements under the EPA mandate scenario.

<table>
<thead>
<tr>
<th>NERC Subregion</th>
<th>Basecase</th>
<th>Mandatory Scrubbers and SCRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERCOT</td>
<td>2.5</td>
<td>9.4</td>
</tr>
<tr>
<td>RFC-PJM</td>
<td>-</td>
<td>7.5</td>
</tr>
<tr>
<td>SERC-Gateway</td>
<td>0.2</td>
<td>6.5</td>
</tr>
<tr>
<td>RFC-MISO</td>
<td>0.1</td>
<td>4.8</td>
</tr>
<tr>
<td>Northwest</td>
<td>1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>MRO</td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Top 6 Regions</strong></td>
<td><strong>4.6</strong></td>
<td><strong>32.1</strong></td>
</tr>
<tr>
<td><strong>Other Regions</strong></td>
<td><strong>1.3</strong></td>
<td><strong>7.4</strong></td>
</tr>
<tr>
<td><strong>Total US</strong></td>
<td>5.8</td>
<td>39.6</td>
</tr>
</tbody>
</table>

Most of the retirements are in ISO/RTO regions (33 GW under the EPA mandate), with Midwest ISO being the largest one (12 GW).

<table>
<thead>
<tr>
<th>ISO/RTO Region</th>
<th>Basecase</th>
<th>Mandatory Scrubbers and SCRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwest ISO</td>
<td>0.3</td>
<td>12.3</td>
</tr>
<tr>
<td>ERCOT ISO</td>
<td>2.5</td>
<td>9.4</td>
</tr>
<tr>
<td>PJM ISO</td>
<td>-</td>
<td>8.3</td>
</tr>
<tr>
<td>New York ISO</td>
<td>-</td>
<td>1.2</td>
</tr>
<tr>
<td>New England ISO</td>
<td>0.1</td>
<td>0.8</td>
</tr>
<tr>
<td>SPP</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>California ISO</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Total ISO/RTO</strong></td>
<td><strong>3.2</strong></td>
<td><strong>33.2</strong></td>
</tr>
<tr>
<td><strong>Other Regions</strong></td>
<td><strong>2.6</strong></td>
<td><strong>6.4</strong></td>
</tr>
<tr>
<td><strong>Total US</strong></td>
<td>5.8</td>
<td>39.6</td>
</tr>
</tbody>
</table>
Economic retirements with mandatory scrubber and SCRs

If all coal units are required to install scrubbers and SCRs by 2015, 39 GW of coal capacity would find it economic to retire by 2015. Under base case assumptions (no equipment mandates), only 6 GW would retire.
Regional detail and reduced coal generation

Most retirements are in ERCOT, RFC-PJM and SERC-Gateway (IL, MO) regions.

EPA mandate would result in 275 TWh (16%) decrease in U.S. coal generation in 2020.

<table>
<thead>
<tr>
<th>NERC Subregion</th>
<th>Cumulative Retired Capacity (GW)</th>
<th>Weighted Average Capacity Factor (%)</th>
<th>Generation Output (TWh)</th>
<th>Cumulative Retired Capacity (GW)</th>
<th>Weighted Average Capacity Factor (%)</th>
<th>Generation Output (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERCOT</td>
<td>-</td>
<td>2.5</td>
<td>52%</td>
<td>44%</td>
<td>79.3</td>
<td>58.7</td>
</tr>
<tr>
<td>RFC-PJM</td>
<td>-</td>
<td>-</td>
<td>69%</td>
<td>72%</td>
<td>385.7</td>
<td>402.9</td>
</tr>
<tr>
<td>SERC-Gateway</td>
<td>0.2</td>
<td>0.2</td>
<td>72%</td>
<td>72%</td>
<td>93.2</td>
<td>92.9</td>
</tr>
<tr>
<td>RFC-MISO</td>
<td>0.1</td>
<td>0.1</td>
<td>60%</td>
<td>51%</td>
<td>217.5</td>
<td>185.6</td>
</tr>
<tr>
<td>Northwest</td>
<td>1.8</td>
<td>1.8</td>
<td>85%</td>
<td>85%</td>
<td>77.6</td>
<td>77.6</td>
</tr>
<tr>
<td>MRO</td>
<td>0.0</td>
<td>0.0</td>
<td>65%</td>
<td>51%</td>
<td>152.6</td>
<td>119.9</td>
</tr>
<tr>
<td>NYISO</td>
<td>-</td>
<td>-</td>
<td>46%</td>
<td>45%</td>
<td>11.3</td>
<td>10.9</td>
</tr>
<tr>
<td>Entergy</td>
<td>-</td>
<td>-</td>
<td>75%</td>
<td>75%</td>
<td>52.3</td>
<td>52.3</td>
</tr>
<tr>
<td>TVA</td>
<td>0.0</td>
<td>0.0</td>
<td>68%</td>
<td>68%</td>
<td>148.0</td>
<td>148.6</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>-</td>
<td>0.1</td>
<td>37%</td>
<td>36%</td>
<td>9.0</td>
<td>8.3</td>
</tr>
<tr>
<td>FRCC</td>
<td>0.7</td>
<td>0.7</td>
<td>32%</td>
<td>61%</td>
<td>25.1</td>
<td>47.0</td>
</tr>
<tr>
<td>Southern</td>
<td>0.0</td>
<td>0.0</td>
<td>71%</td>
<td>72%</td>
<td>160.0</td>
<td>161.1</td>
</tr>
<tr>
<td>VACAR</td>
<td>0.0</td>
<td>0.0</td>
<td>62%</td>
<td>62%</td>
<td>144.2</td>
<td>145.6</td>
</tr>
<tr>
<td>California</td>
<td>-</td>
<td>-</td>
<td>78%</td>
<td>78%</td>
<td>15.4</td>
<td>15.4</td>
</tr>
<tr>
<td>SPP South</td>
<td>-</td>
<td>0.3</td>
<td>50%</td>
<td>40%</td>
<td>50.7</td>
<td>39.8</td>
</tr>
<tr>
<td>SPP North</td>
<td>-</td>
<td>0.0</td>
<td>60%</td>
<td>51%</td>
<td>44.3</td>
<td>37.7</td>
</tr>
<tr>
<td>Arizona</td>
<td>-</td>
<td>-</td>
<td>71%</td>
<td>69%</td>
<td>67.1</td>
<td>64.8</td>
</tr>
<tr>
<td>Rocky Mountain</td>
<td>0.0</td>
<td>0.0</td>
<td>72%</td>
<td>68%</td>
<td>40.4</td>
<td>38.3</td>
</tr>
<tr>
<td><strong>Total US</strong></td>
<td><strong>2.9</strong></td>
<td><strong>5.8</strong></td>
<td><strong>65%</strong></td>
<td><strong>63%</strong></td>
<td><strong>1,774</strong></td>
<td><strong>1,708</strong></td>
</tr>
</tbody>
</table>
**Potential impact on gas generation**

Coal retirements could increase gas generation by up to 5.8 Bcf/d in 2020 (assuming all of the decrease in coal generation is replaced with 8000 btu/kWh gas generation).

<table>
<thead>
<tr>
<th>NERC Subregion</th>
<th>Difference in Annual Coal Generation Output (TWh)</th>
<th>Increase in Natural Gas Use Relative to BaseCase (BCF/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2020</td>
</tr>
<tr>
<td>SERC-Gateway</td>
<td>(0.6)</td>
<td>(46.3)</td>
</tr>
<tr>
<td>RFC-PJM</td>
<td>-</td>
<td>(36.9)</td>
</tr>
<tr>
<td>RFC-MISO</td>
<td>(4.4)</td>
<td>(33.3)</td>
</tr>
<tr>
<td>ERCOT</td>
<td>-</td>
<td>(30.7)</td>
</tr>
<tr>
<td>MRO</td>
<td>(0.1)</td>
<td>(22.7)</td>
</tr>
<tr>
<td>TVA</td>
<td>-</td>
<td>(22.2)</td>
</tr>
<tr>
<td>Southern</td>
<td>-</td>
<td>(16.7)</td>
</tr>
<tr>
<td>Entergy</td>
<td>-</td>
<td>(11.1)</td>
</tr>
<tr>
<td>SPP South</td>
<td>-</td>
<td>(10.0)</td>
</tr>
<tr>
<td>VACAR</td>
<td>-</td>
<td>(10.9)</td>
</tr>
<tr>
<td>Northwest</td>
<td>-</td>
<td>(7.3)</td>
</tr>
<tr>
<td>SPP North</td>
<td>-</td>
<td>(5.4)</td>
</tr>
<tr>
<td>NYISO</td>
<td>-</td>
<td>(4.2)</td>
</tr>
<tr>
<td>Rocky Mountain</td>
<td>-</td>
<td>(4.6)</td>
</tr>
<tr>
<td>California</td>
<td>-</td>
<td>(3.1)</td>
</tr>
<tr>
<td>Arizona</td>
<td>-</td>
<td>(3.0)</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>-</td>
<td>(2.8)</td>
</tr>
<tr>
<td>FRCC</td>
<td>-</td>
<td>(3.5)</td>
</tr>
<tr>
<td><strong>Total US</strong></td>
<td>(5.1)</td>
<td>(275.0)</td>
</tr>
</tbody>
</table>
Impact on CO₂ emissions

Reduction in coal generation due to EPA mandates could reduce CO₂ emissions from the coal fleet by 10% in 2020 if the lost generation is replaced by gas CCs.

CO₂ Emissions from US Coal Fleet (million tons)

- Reduction in coal generation due to EPA mandates could reduce CO₂ emissions from the coal fleet by 10% in 2020 if the lost generation is replaced by gas CCs.

- Net Emission Reductions in 2020: 151 million tons

- Others
  - Southern
  - TVA
  - RFC-PJM
  - RFC-MISO
  - SERC-Gateway
  - Others

- 151 million tons
Impact on regional reserve margins

Economic retirements would have significant reductions below target in ERCOT and RFC.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ERCOT</td>
<td>75</td>
<td>85</td>
<td>13%</td>
<td>10% 1% 13% 15%</td>
</tr>
<tr>
<td>RFC</td>
<td>193</td>
<td>230</td>
<td>19%</td>
<td>19% 13% 15%</td>
</tr>
<tr>
<td>MRO</td>
<td>48</td>
<td>54</td>
<td>14%</td>
<td>14% 14% 15%</td>
</tr>
<tr>
<td>NPCC</td>
<td>66</td>
<td>79</td>
<td>20%</td>
<td>19% 16% 15%</td>
</tr>
<tr>
<td>SERC</td>
<td>229</td>
<td>277</td>
<td>21%</td>
<td>21% 17% 15%</td>
</tr>
<tr>
<td>SPP</td>
<td>49</td>
<td>60</td>
<td>24%</td>
<td>23% 23% 14%</td>
</tr>
<tr>
<td>FRCC</td>
<td>50</td>
<td>63</td>
<td>27%</td>
<td>26% 25% 15%</td>
</tr>
<tr>
<td>WECC</td>
<td>157</td>
<td>211</td>
<td>34%</td>
<td>33% 32% 18%</td>
</tr>
</tbody>
</table>
Possible enhancements and applications

♦ Close scrutiny of single regions
  • Dispatch each coal plant against its own price curve

♦ Feedback of plant shutdowns on power prices

♦ Sensitivity to gas and power prices (uncertainty and feedback)

♦ Effect of potential CO₂ prices on retirement and operating margins

♦ Implications for coal shipments on major railroads
APPENDIX
Key assumptions – wholesale power prices

Real Energy Prices by NERC Subregion - Annual Average (8760 Flat)
Key assumptions – coal prices
Key assumptions – natural gas prices

Real Natural Gas Prices by EMM Region (AEO 2010)
Key assumptions – cost of replacement power for regulated coal units by region

### REPLACEMENT COST SUMMARY (NEW CC AND CT)

<table>
<thead>
<tr>
<th>NERC Region</th>
<th>NERC Sub Region</th>
<th>Average NG Price (2010-2020) ($/MMBtu)</th>
<th>Average Fuel Costs ($)</th>
<th>Overnight Cost ($/kW-year)</th>
<th>FOM ($/kW-year)</th>
<th>VOM ($/MWh)</th>
<th>Levelized All-in Cost ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CT</td>
<td>@ 9.5 MMBtu/MWh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CC</td>
<td>@ 6.8 MMBtu/MWh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERCOT</td>
<td>ERCOT</td>
<td>5.48</td>
<td>37</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>FRCC</td>
<td>FRCC</td>
<td>7.70</td>
<td>52</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>MRO US</td>
<td>MRO</td>
<td>5.87</td>
<td>40</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>NPCC</td>
<td>NY</td>
<td>6.26</td>
<td>43</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>NPCC</td>
<td>ISO NE</td>
<td>6.60</td>
<td>45</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>RFC</td>
<td>MISO</td>
<td>5.36</td>
<td>36</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>RFC</td>
<td>PJM</td>
<td>6.47</td>
<td>44</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>SERC</td>
<td>Gateway</td>
<td>6.07</td>
<td>41</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>SERC</td>
<td>TVA</td>
<td>6.07</td>
<td>41</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>SERC</td>
<td>VACAR</td>
<td>6.07</td>
<td>41</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>SERC</td>
<td>Southern</td>
<td>6.07</td>
<td>41</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>SERC</td>
<td>Entergy</td>
<td>6.07</td>
<td>41</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>SPP</td>
<td>SPP South</td>
<td>5.59</td>
<td>38</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>SPP</td>
<td>SPP North</td>
<td>5.59</td>
<td>38</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>WECC</td>
<td>CA</td>
<td>6.27</td>
<td>43</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>WECC</td>
<td>NWPP</td>
<td>6.12</td>
<td>42</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>WECC</td>
<td>AZNMSNV</td>
<td>6.18</td>
<td>42</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>WECC</td>
<td>RMPA</td>
<td>6.18</td>
<td>42</td>
<td>66</td>
<td>109</td>
<td>10</td>
<td>18</td>
</tr>
</tbody>
</table>


Authors*

Dr. Metin Celebi
Senior Associate

Phone: +1.617.864.7900
Email: Metin.Celebi@brattle.com

Dr. Celebi provides expertise in electricity markets and climate policy analysis. He has consulted primarily in the areas of electricity spot pricing and market design, and has experience in developing and analyzing climate policies, assessing generation market power, LMP modeling, and merger analysis.

Mr. Frank Graves
Principal

Phone: +1.617.864.7900
Email: Frank.Graves@brattle.com

Mr. Graves specializes in finance and regulatory economics. He assists clients in securities litigation suits, special purpose audits, tax and contract disputes, investment planning, and risk management issues. His industry focus is primarily in electric power, where he assists utilities in capacity expansion, network modeling, investment and contract prudence reviews, financial simulation, and asset and contract valuation.

Ms. Gunjan Bathla

Ms. Bathla is a senior research associate in The Brattle Group's utility practice.

Mr. Lucas Bressan

Mr. Bressan is a research associate in The Brattle Group’s utility practice.

* The authors thank their colleagues Marc Chupka, Hannes Pfeifenberger, and Kathleen Spees for their useful comments and assistance in this study.
About The Brattle Group – Services

*The Brattle Group* provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governmental agencies around the world.

We combine in-depth industry experience, rigorous analyses, and principled techniques to help clients answer complex economic and financial questions in litigation and regulation, develop strategies for changing markets, and make critical business decisions.

Our services to the electric power industry include:

- Climate Change Policy and Planning
- Cost of Capital
- Demand Forecasting and Weather Normalization
- Demand Response and Energy Efficiency
- Electricity Market Modeling
- Energy Asset Valuation
- Energy Contract Litigation
- Environmental Compliance
- Fuel and Power Procurement
- Incentive Regulation
- Rate Design, Cost Allocation, and Rate Structure
- Regulatory Strategy and Litigation Support
- Renewables
- Resource Planning
- Retail Access and Restructuring
- Risk Management
- Market-Based Rates
- Market Design and Competitive Analysis
- Mergers and Acquisitions
- Transmission
www.brattle.com

<table>
<thead>
<tr>
<th>North America</th>
<th>Cambridge, MA</th>
<th>San Francisco, CA</th>
<th>Washington, DC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+1.617.864.7900</td>
<td>+1.415.217.1000</td>
<td>+1.202.955.5050</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Europe</th>
<th>Brussels</th>
<th>London</th>
<th>Madrid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+32.2.234.77.05</td>
<td>+44.20.7406.7900</td>
<td>+34.91.418.69.70</td>
</tr>
</tbody>
</table>