Since 2009 the US Environmental Protection Agency (EPA) has been working to reformulate and reissue a set of comprehensive regulations affecting both coal-fired and oil-fired power generation facilities. Collectively these regulations have been mandated for a number of years, originally authorized under the Clean Air Act Amendments (1990), the Clean Water Act (1972), and the Resource Conservation and Recovery Act (1986).

The regulations include:

- The Cross-State Air Pollution Rule (CSAPR), currently suspended by a recent court decision.
- Mercury and Air Toxics Standards (MATS) Rule\(^1\) with compliance by 2015.
- Clean Water Act (CWA) 316(b)\(^2\) for Cooling Water Intake Structures with compliance by 2018.

In addition to the above, several other regulations are anticipated in the near future, and these have been incorporated into EPRI’s analysis as well:

- National Ambient Air Quality Standards (NAAQS) for SO\(_2\), to control haze, are anticipated in the 2018 time frame.
- National Ambient Air Quality Standards (NAAQS) for NO\(_x\), to control ozone and haze, are also anticipated by 2018.

EPRI has been asked to contribute its analysis of these regulations, and this document summarizes the results of EPRI’s efforts. EPRI has been developing the US Regional Economy, Greenhouse Gas and Energy (US-REGEN) model - a new energy-economy model of the US with a special focus on the electric power sector - since 2010. The current analysis is EPRI’s first application of the model, and related studies are planned in the near future.

The US-REGEN model has been developed with appropriate attention to sectoral data and detail in electric power production and in energy demand. US-REGEN also takes into account regional differences in generating costs and resources, especially for renewables, carbon capture and storage, and land use. The model necessarily treats the rest of the economy and key interactions at a higher level.

The results of EPRI’s analysis are briefly summarized just below, and discussed at more length in the

\(^{1}\) The MATS includes the National Emission Standards for Hazardous Air Pollutants (NESHAP) from Electric Utility Steam Generating Units and the revised New Source Performance Standards (NSPS) for Electric Utility Steam Generating Units. See the http://www.epa.gov/mats and ww.epa.gov/ttn/atw/nsps/boilernsp/boilernsp.html

\(^{2}\) http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/

\(^{3}\) http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ccr-rule/index.htm
body of this document. Key findings of EPRI’s study include:

- The regulations in question will impose multiple environmental control requirements on the coal fleet. Required equipment retrofits on existing coal-fired power plants will have significant implications for asset management and generation planning decisions, and substantial effects on electricity generation costs in the future.
- Some significant portion of the US coal fleet (perhaps as much as 20% of existing capacity) is likely to become uneconomic to operate once these requirements take effect, and will be retired or switch to natural gas. The overall cost to retrofit the remaining resources will be in the several hundred billion dollar range. If natural gas prices continue their current low trajectory into the future the level of retirement or conversion could reach as high as 100 GW.
- These decisions - whether to retrofit, retire or fuel-switch existing coal-fired power plants - are complex, with multiple uncertainties, interactions, and implications for electricity generators and the broader economy. Further, the decision is in principle unique for each generating resource, due to each resource’s unique starting point – age, size, type of coal used, inventory of pollution control equipment already in use, and historical effectiveness of the equipment.
- Granting extra time for compliance appears likely to reduce costs significantly for the power system overall, with little change in overall emission reductions. This finding is, however, contingent on a degree of regulatory flexibility in timing and in technology choice.

In the following sections of this document these issues are developed and discussed more fully. In the next sections the key regulations of interest (both existing and anticipated) are discussed. Following this, the specifics of the analysis process EPRI developed is detailed. Finally the results of the analysis – including energy sector and overall economy findings – are presented.

**Regulatory Impacts for Asset Owners**

A key modeling assumption of EPRI’s analysis is that coal asset owners will look at the full collection of regulations – both those currently being considered and those anticipated – to evaluate their responses. To the extent that individual companies do not undertake a comprehensive approach to their compliance decisionmaking, the total costs to address the collected regulations will likely be higher.

Each owner of coal-fired generation assets will face this fundamental decision presently: continue to operate with new pollution control investment, or retire the asset. The above regulations taken collectively will impose a set of complex requirements on such owners. These will include emissions limits on a wide range of pollutants, as well as requirements for specific technology retrofit in some circumstances. Ultimately the response of asset owners to these regulations will be through technology addition or modification.

The response will be unique to each asset in the fleet, again depending on the starting point (age, size, fuel used, technologies in place, control effectiveness). In some cases one or more technology retrofits will be necessary to address a specific regulatory requirement. At the same time, often one technology addition will effectively address multiple regulations (the co-benefits concept). As well, for some assets there may be a choice among alternative technologies to address key regulations. Figure 1 below summarizes the regulation-to-technology-choice environment in which the US coal-fired fleet will soon find itself.
### Figure 1
**Summary of Regulations and Technology Remedies for the US Coal Fleet**

<table>
<thead>
<tr>
<th>Pollutant Category</th>
<th>Pollutant/Concern</th>
<th>Compliance Threshold</th>
<th>Governing Regulations</th>
<th>Technology Remedies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>SO$_2$</td>
<td>&lt; 0.15 lb/mmbtu</td>
<td>CSAPR regulations cover 28 Eastern and Midwestern states by 2014 NAAQS haze regulations assumed to cover all units by 2018</td>
<td>Units in compliance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Units out of compliance</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Units out of compliance</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Lignite coal SCR</td>
<td>SCR</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>&lt;0.10 lb/mmbtu</td>
<td>CSAPR regulations cover 28 Eastern and Midwestern states by 2014 NAAQS ozone and haze regulations assumed to cover all units by 2018</td>
<td>Units in compliance</td>
<td>All coals</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Units out of compliance</td>
<td></td>
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<td>Units out of compliance</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Lignite coal SCR</td>
<td>SCR</td>
</tr>
<tr>
<td>Mercury, acid gases (HCl), other metals</td>
<td>Specified technology adoption implies compliance</td>
<td>MATS regulations; compliance by 2015</td>
<td>All units</td>
<td>All coals</td>
</tr>
<tr>
<td>Water Protection of aquatic species</td>
<td>Conversion to closed-cycle cooling</td>
<td>Section 361(b) of the Clean Water Act; compliance by 2018</td>
<td>Plants with intake flow &gt;125 MG/D</td>
<td>All coals</td>
</tr>
<tr>
<td>Solid Waste</td>
<td>Coal combustion residuals (coal ash)</td>
<td>Treat as Subtitle D waste stream</td>
<td>Reclassification of coal ash under the existing Resource Conservation and Recovery Act; compliance by 2020</td>
<td>All units</td>
</tr>
</tbody>
</table>

**Key to acronyms:**

- **FGD**: Flue Gas Desulfurization (Scrubber)
- **WWT**: Waste Water Treatment
- **SCR**: Selective Catalytic Reduction
- **LSD**: Lime Spray Dryer
- **SD-FGD**: Spray-Dry Flue Gas Desulfurization (cheaper than scrubber)
- **FF**: Fabric Filter (Baghouse)
- **ESP**: Electro-Static Precipitator
- **ACI**: Activated Carbon Injection
Future impacts on coal-fired generation assets will be further conditioned by a set of fundamental uncertainties, the chief ones being:

- **Natural gas prices:** The key near-term substitute for coal-fired generation in the US power market is natural gas combined cycle technology, which is for the most part minimally impacted by these regulations. If gas prices stay ultra-low as they have been in recent years, more coal generators will choose against further investment and will instead retire their assets. More technology substitution in the fleet will be the overall result. If gas prices start to rise in future, the decision for many coal-fired assets in the “bubble” zone could well be quite different.

- **Greenhouse gas policy:** The notion of a future carbon tax or some similar mechanism in the US power market could well be a game-changer. As suggested above, this regulatory possibility was not analyzed as part of the EPRI study, but it looms on the horizon as an important uncertainty nevertheless. If such a policy appears to be more likely as time goes on, there is no doubt that more coal-fired assets in the “bubble” will be affected.

**US-REGEN Model**

The US Regional Economy, Greenhouse Gas, and Energy Model (US-REGEN) is a new model being developed by the Electric Power Research Institute (EPRI). It combines a detailed dispatch and capacity expansion model of the United States electric sector with a high-level dynamic computable general equilibrium (CGE) model of the US economy. The two models are solved iteratively to convergence, allowing analysis of policy impacts on the electric sector taking into account economy level responses. This makes US-REGEN capable of modeling a wide range of environmental and energy policies in both the electric and non-electric sectors.

US-REGEN is a regional model of the United States. It considers 15 sub-regions of the continental U.S. to account for differences in resource endowments, energy demand, costs, policies, and policy impacts. US-REGEN is an inter-temporal optimization model. It solves in five-year time steps through 2050.

The electric sector component of US-REGEN is a detailed generation planning model. In each time step, the model makes decisions about capacity (e.g. new investment, retrofit, or retire) and dispatch to meet energy demand for both generation and inter-region transmission. It uses a bottom-up representation of power generation capacity and dispatch across a range of intra-annual load segments. It models transmission capacity between regions, and requires that generation and load plus net exports and line losses balance in each load segment and for each region.

The macroeconomic component of US-REGEN is a CGE model applied to the US. It uses a classical Arrow-Debreu general equilibrium framework to describe the entire economy over time, calibrated to observed U.S. economic data covering all transactions amongst firms and households, and forecasted economic growth into the future. Production in each sector is described by a constant-elasticity-of-substitution (CES) production function. Firms are assumed to maximize profits, and households maximize utility (assumed to be a function of consumption across the time horizon of the model). US-REGEN is designed to show how changes in policy impact economic activities relative to a baseline case.

The two models comprising US-REGEN are built on economic data sourced from the IMPLAN database, energy data from the Energy Information Administration (EIA) of the U.S. Department of Energy, U.S. generation fleet data from Ventyx, and a variety of other sources providing economic growth, wind, solar, and biomass data.
**EPRI’s Analysis Structure**

EPRI’s analysis defines a “full control” policy as the stringent control of SO₂, NOₓ, mercury (and related hazardous air pollutants), aquatic species protection, and coal combustion residuals, as specified in the collective regulations discussed above. EPRI has specified three scenarios for “full control”, contrasted in terms of cost and timing assumptions. These scenarios are defined below.

- **A Reference** policy case, using reference cost assumptions and EPA’s mandated timing for implementation (see Figure 2 above).
- **A Flexible** policy case, incorporating lower costs, less stringent aquatic entrainment controls, less stringent FGD requirements, less retrofit cost escalation, and an additional two years for compliance with SO₂ and NOₓ limits.
- **A High Cost** policy case, incorporating less policy flexibility to choose low-cost technologies and higher retrofit cost escalation to meet mandated implementation deadlines.

These three scenarios are contrasted against a “baseline” scenario incorporating the current state of the world before “full control” takes effect. The “baseline” scenario is characterized by:

- Economic growth and energy supply and demand are based on the US Energy Information Administration’s *Annual Energy Outlook 2011*
- Includes all individual state RPS programs
- Does not include any state (CA, RGGI) or federal (CAA) GHG regulations
- Includes the Cross-State Air Pollution Rule (CSAPR) by 2015, which aims to reduce SO₂ emissions by 73 percent and NOₓ emissions by 54 percent from 2005 levels
- Assumes new coal additions are strictly limited to units currently under construction

The overarching premise of EPRI’s analysis is characterized as follows:

- Each coal-fired asset owner faces a single near-term decision (typically by 2015, the MATS deadline) to retrofit or retire coal units
- The decision is informed by a “full control” set of ongoing policy processes (excluding GHG policies, as discussed above). Potential GHG regulation is represented by proxy however, by a 10-year retrofit payback requirement on investments. This acts as a sensitivity on how much expectations of subsequent climate policy would impact retrofit decisions.

The model calculates, for each unit in the fleet, a present value net revenue estimate for continued operation. This is contrasted with an implicit zero net-revenue estimate if the unit is retired. The unit is kept operating if net revenue is positive, retired if not. The net revenue calculation incorporates all needed investment and operations costs to bring the unit into “full control” compliance, as well as ongoing operations costs (fuel, etc.). Revenues are dependent on overall power market dynamics in each model region, and the place of the unit in the dispatch merit order. As discussed above, the investment payback is specified to be arbitrarily stringent, to (imperfectly) reflect the added but un-modeled risk for each coal unit of GHG regulation on the horizon.

Assessing the cost implications for the coal fleet on a unit-by-unit basis presents data development challenges as well. Figure 2 below illustrates in summary form the estimated fleet supply curve for “full control” retrofit compliance costs. These data were developed from each individual unit in the fleet.

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4 This analysis was completed when CSAPR was thought to be settled law. Recently the court has reversed this decision, and sent the regulations back to EPA for further work. However the fallback set of regulations that the court has temporarily substituted for CSAPR has essentially the same cost impacts.
taking into account what technology additions would be needed based on each unit’s legacy configuration.

Results Summary
These results can be divided into four sections. Electric sector findings are highlighted first, followed by a discussion of how these results vary depending on natural gas price uncertainty. The wider economic implications of these findings are discussed next, followed by emissions results. In a concluding section the key uncertainties conditioning all of these results are discussed.

Electric Sector Results
The key result of interest in EPRI’s study is the effect of “full control” policy on the US coal-fired generation fleet.

This question is complicated by other influences on coal resource disposition, notably the ongoing substitution of gas-fired resources for coal in light of historically low natural gas prices. It is generally acknowledged that some degree of coal resource attrition will be observed in the near future, regardless of the policy environment, simply due to the prospect of cheap gas on the horizon.

EPRI’s analysis has compared the policy cases against a baseline (all using the same baseline natural gas forecast) in order to control for the gas price effect, and results are reported as differences. Figures 3 and 4 below show how overall US power generation is expected to evolve over time, under a baseline scenario and, by contrast, under a Reference policy case. This first-pass look at the policy indicates that
much of the coal fleet is likely to make environmental retrofit investments and keep operating, and that the change in TWh produced by fuel is likely to be muted.
The effect on coal-fired capacity, on the other hand, is somewhat more dramatic. As Figure 5 illustrates, while most coal-fired capacity is expected to make the required retrofit investments and keep operating, EPRI’s analysis predicts as much as 50+ GW could be retired or converted to gas by 2017 alone. These MW represent for the most part older, smaller, little-run units in the first place, which helps to explain why the power generation results noted above are more muted. Coal capacity is expected however to be reduced materially.
Figure 6 illustrates the contrast in coal capacity results across EPRI’s scenarios for the snapshot year 2020. All three of the policy scenarios show substantial environmental retrofit investment in contrast to the baseline, but the Flexible policy scenario is notable for materially less capacity retirement. As suggested above, the Flexible scenario is characterized by more flexibility regarding environmental retrofit (more time to achieve compliance, cheaper technology options available), and less consequent pressure to retire coal capacity.
Natural Gas Price Sensitivity
As stated above, all results presented so far assume a nominal trajectory for natural gas price growth in the future. In Figure 7 below this trajectory (AEO 2011 projections) is represented by the red curve.
Historically however, gas prices have been extremely volatile in recent decades, and very recent history is no exception. Gas price futures have declined as much as $.50/mmbtu since early 2012, and as much as $1.30/mmbtu since late 2011. This trend could well continue due to recent discoveries in shale gas, fracking and related unconventional recovery approaches. Figure 8 illustrates recent gas price history.
Further, since gas-fired generation is the chief near-term competitor to coal, it stands to reason that the gas market will have major influence on the future of US coal resources. Future gas price is by far the dominant uncertainty in this analysis. The EPRI study explored this interaction through a systematic sensitivity analysis on gas prices. Figure 7 above illustrates how the nominal price path was altered to illuminate these influences.

As Figure 9 illustrates, movements in gas price projections have a quite material effect on the projected level of coal-fired asset retirements. The nominal EPRI projection illustrated above is in the 50 GW range. Sensitivity around gas price projections swings this from a low of about 30 GW to a high of well over 100 GW.

The key implication of this insight is capital expenditure minimization. For all coal asset owners, flexible compliance strategies with lower fixed costs (despite higher operating costs) will tend to reduce risk and regret.
**Wider Economic Impacts**

EPRI’s analysis using US-REGEN tracks energy-economy interactions, and feedback from the coal-fired power sector to the wider economy. The first obvious measure of wider impact is the level of retrofit investment and operating costs incurred by the coal-fired assets to continue operating. Added to this will be new generation investments and costs in substitute resources (in gas-fired generation for example). Figure 10 charts the level of expenditure for these direct needs predicted by the analysis (undiscounted dollars), through the year 2035.
These costs to the power sector are not the complete story however. Additional costs to the overall economy arise through indirect effects, insofar as the “full control” policy diverts the power sector from a least-cost resource usage, engendering phenomena such as:

- Gas price increases economy-wide caused by increased demand pressures
- Increased power sector capital needs crowding out other requirements and driving up capital prices
- Increased power sector services and materials needs (i.e. engineering, concrete) crowding out other sector requirements and driving up factor prices

US-REGEN measures such indirect costs as well. Figure 11 compares the full cost impacts of the policy with the smaller power sector expenditures, for the three EPRI policy case scenarios (discounted dollars).
As Figure 11 illustrates, the Reference policy case is predicted to incur over $250 B in the next 20+ years. The High Cost policy case is only slightly more expensive. The Flexible policy case, however, has real potential for savings (close to $100 B) if it can be realized. Roughly, the difference between the Reference and Flexible scenarios can be parsed as follows:

- About one half of the difference is attributed to more flexibility in allowed technology options, primarily in FGD technology and in cooling water options
- Another 40% of the difference is attributed to a set of more relaxed cost escalation assumptions
- The remaining 10% is due to more flexible compliance timing

Finally, Figure 12 charts the predicted evolution of US power prices as a result of these policies. These results show differences in the $7-8/MWh range in 2015, and further narrowing over time as more coal-fired generation is retired and replaced with natural gas in all scenarios. These price differences are quite mild.

Such a pricing result may seem puzzling at first glance, given the enormous capital expenditures predicted for compliance. If environmental policy is “technology forcing”, however, (by capital investment mandate) then the impact on marginal wholesale power prices is indirect. In a competitive market dispatch prices will not change very much, as most of the expenditures are capital, and do not enter directly into variable cost. Variable costs of affected generating units somewhat due to efficiency loses and higher variable O&M to operate pollution control equipment, but most of the coal units are inframarginal and the modest increases in dispatch costs only have a limited impact on prices. For rate-regulated entities, the fixed costs can be passed on to customers. In competitive retail markets, however, the fixed costs are largely absorbed out of producer rents.


**Emissions Impacts**

Figures 13, 14 and 15 chart emissions predictions resulting from the “full control” policy, for key pollutants of interest. Several things are notable in these charts. First, it is striking to realize just how much emissions of SO$_2$ and NO$_x$ have been reduced already, over the last 20 years. The current policy will reduce them even more, but from a notably small base. Secondly, the Flexible policy scenario is just as effective in emissions reduction as the more stringent scenarios over time, it just takes a few years longer to ramp down to the same steady state. Lastly, current policy actually does little to address CO$_2$ emissions, not surprising given that most coal-fired resources in the fleet will still continue to operate.
Conclusions
The key findings of EPRI’s study include:

- The “full control” policy will likely have a dramatic impact on coal markets and on US coal-fired generation. An estimated 50 GW of capacity could be retired or fuel converted under Reference case assumptions, a bit more under High Cost assumptions. Under Flexible policy assumptions retirements could well be much less severe, more like 20 GW.

- At the same time coal will likely remain a key source of power generation. Fully 260+ MW of capacity could well keep operating and make the required retrofit investments, under a scenario where gas prices begin to rise in future years. Furthermore, those coal resources retiring are largely older, smaller and run infrequently even now. The effect of these policies on coal-fired power generation is much less dramatic.

- These results depend significantly on expectations about the trajectory of future natural gas prices however. In the low gas price case (which tracks current NYMEX Futures), retirements plus conversions to gas exceed 100 GW. Announced retirements of coal-fired power plants today already total in the 40 MW range.

- Significant resources will be needed to fully implement this policy. The full economic cost – including direct capital and operations costs, as well as indirect costs due to deviations from least-cost power generation – is estimated at around $275B for the Reference policy scenario. For the Flexible policy scenario the estimate is closer to $175B.

- Overall emissions (SO$_2$, NO$_x$) have declined steadily and significantly in the last two decades, today to a level less than 25% of what they were in 1990. Incremental reductions driven by the current policy is relatively modest in comparison, off of a much reduced base.

- The Flexible policy scenario is of notable interest, as it could be implemented about $100B cheaper than the Reference case, with minimal cumulative increase in emissions.
• At the same time the Flexible policy scenario is speculative. It requires a relaxing of the regulatory deadline by two extra years, as well as flexibility regarding technology choice.