U.S. Electric Power Futures: Preliminary Results

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Approach

• We use our Regional Energy Deployment Systems (ReEDS) capacity expansion model to simulate the evolution of the U.S. power sector under a number of policy and technology variables over the mid-term (2036).

• Technology cost and performance assumptions are based on Black & Veatch (2012); fuel cost assumptions are based on the Energy Information Administration’s (EIA) Annual Energy Outlook 2011 unless otherwise noted.

• Results presented here are preliminary.
Regional Energy Deployment Systems (ReEDS)

• **Capacity Expansion and Dispatch**
  - For the contiguous U.S. electricity sector, including transmission and all major generator types.

• **Minimize Total System Cost** *(20-year net present value)*
  - All constraints (e.g. balance load, planning and operating reserves, etc.) must be satisfied
  - Linear program (with non-linear statistical calculations for variability)
  - Sequential optimization (2-year investment period 2010-2050).

• **Multi-regional** *(356 wind/solar resource regions, 134 balancing authorities)*
  - Regional resource characterization
  - Variability of wind/solar
  - Transmission capacity expansion.

• **Temporal Resolution**
  - 17 timeslices in each year
  - Each season = 1 typical day = 4 timeslices
  - 1 summer peak timeslice.

• **Full Documentation**
  - Complete documentation of the ReEDS model is available at: http://www.nrel.gov/analysis/reeds/.
ReEDS Schematic

Region Definitions
Time-slice Definitions

Transmission Data
Resource Data
Initial Capacity
Load Growth Forecast
Technology Cost/Performance Forecasts
Load and Resource Variability Parameters
State/Federal Rules/Incentives
Financing Assumptions
System Requirements

Load Requirements
Transmission Capacity
Installed Capacity
Fuel Supply Curves
Technology Cost/Performance Data

ReEDS Optimization
(minimizes total system cost for expansion and dispatch)

New Generating Capacity
New Transmission Capacity
Dispatch

Variability Parameter Calculations
Electricity Price
Fuel Usage and Price

2-year recursive

2010 2012 2014 ...
2036

PRELIMINARY – DO NOT CITE OR DISTRIBUTE
Endogenous Retirement within ReEDS

• ReEDS will endogenously retire all power plants according to criteria.
  o Coal: Age-based standard (65-75 years, depending on size) and/or usage-based (minimum generation needed)
  o Oil/Gas Steam: Age-based (55 years)
  o Nuclear: Age-based standard (60-80 years, depending on year deployed)
  o NG-CC: 55 years
  o Others: Age-based standard.
• Other plants can be retired with exogenous user-inputs.
Fossil Fuel Representation in ReEDS

- Natural gas fuel supply curves in ReEDS to capture response of price to power sector demand
- Captures full-economy effects through multivariate linear regression analysis of ~40 scenarios from EIA’s Annual Energy Outlook
- Low-, high-, and mid-Estimated Ultimate Recovery (EUR) supply curves developed for separate scenarios in ReEDS
- Electricity and power sector NG demand excludes CHP.
Scenarios Considered

• Baseline Family: Status quo projection. For comparison only, not a prediction.
• Coal Retirement: 80 GW by 2026.
• Clean Energy Standard: 80% Clean Energy by 2036 with crediting similar to Bingaman CES.
• Advanced Technology: Nuclear capital costs decline by half (2020); PV costs decline substantially.
• Results summarized in table format on penultimate page.
Scenario Framework & Assumptions

Clean Electricity Scenarios
- 80% clean electricity by 2035
- Crediting:
  - 100% for Nuclear and RE
  - 95% for NG-CCS
  - 90% for Coal-CCS
  - 50% for NG-CC
  - 0% for all others.

Coal Retirement Scenario
- Considers full set of EPA rule impacts that result in 80 GW of coal retirements by 2025.
- Also considers NSPS-like future (no new coal w/o CCS)
- See retirement map for distribution of retirements.

Technology Improvement Scenarios
- Considers breakthrough in nuclear capital cost reductions (half of current value by 2020)
- Considers most advancement in PV and wind deployment costs
- See capital cost matrix table.

Reference Scenarios
- No new policy
- Conservative technology costs (B&V 2012, see capital cost matrix)
- AEO 2010 electricity demand, reference case non-electric sector gas demand
- Standard retirements (~25 GW of coal by 2026)
- Exogenously input 53 GW of dist. PV by 2036.
## Capital Cost Matrix

- Technology Cost and Performance data, including capital costs, developed by Black and Veatch (2012)
- Black and Veatch Technology Cost and Performance projections used for all scenarios except for the Technology Improvement Scenarios
- Fuel cost assumptions are similar to those used by AEO 2011 (O&M and fuel).

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>All Other Scenarios</td>
<td>Gas-CC</td>
<td>Gas-CT</td>
</tr>
<tr>
<td>All Other Scenarios</td>
<td>1,083</td>
<td>573</td>
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<tr>
<td>Technology Improvement Scenarios</td>
<td>Advanced RE</td>
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<tr>
<td>Technology Improvement Scenarios</td>
<td>Advanced Nuclear</td>
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</table>

Assumptions for Utility-scale PV and Wind cost reductions are outlined in the forthcoming NREL report “Renewable Electricity Futures,” 2012.
Fraction of national total EPA regulation-driven retirements for Coal Retirement scenario.
Reference Scenarios

• In Mid-EUR case, natural gas generation accounts for 35% of the total in 2036, coal 35%, non-hydro RE 12%, nuclear 11%, and hydro 7%
• Low natural gas EUR leads to small amount of new coal generation by 2036.

Clean Electricity Standard Scenarios

• A CES leads to greater NG power generation in the near-term followed by reliance on RE (and to a lesser extent, CCS and nuclear) in the long-term
• Under a CES, 2036 RE power generation is significant, even with High-EUR and CCS deployment
• Without CCS, NG uses peaks around 2030 and then begins to decline as 50% crediting for NG-CC no longer meets target most efficiently
• Low-EUR future results in significantly less NG generation and more RE and coal.
Generation Comparison

Coal Scenarios
• In the 80 GW retirement case, retired coal generation is primarily replaced by NG-CC generation, but some new coal generation picks up around 2032.
• NSPS (with only 25 GW of coal retirement by 2025) is very similar to the baseline reference case.

Technology Improvement Scenarios
• In the advanced RE case, non-hydro RE generation increases from 10% of the total in 2020 to 20% in 2036.
• Nuclear advancements coupled with Low-EUR shifts generation mix away from NG toward new nuclear, and to a lesser extent, new coal and RE.
Reference Scenarios
• Significant natural gas capacity expansion: Up to ~350 GW NG-CC & ~300 GW NG-CT by 2036
• Low-EUR reduces NG capacity growth and increases coal and RE growth
• Limited near-term plant retirements.

Clean Electricity Standards Scenarios
• Large increase in RE starting around 2025; more coal retires since it is not used
• CCS plays minor role in late 2020s
• Low-EUR results in more RE and less NG.
Coal Scenarios
• In the retirement case, coal capacity declines to roughly 200 GW in 2036
• NSPS capacity similar to reference baseline.

Technology Improvement Scenarios
• In the advanced RE case, improvements in RE technologies reduce costs, increasing non-hydro RE capacity to ~386 GW by 2036 (~129 GW in 2020)
• Nuclear advancements coupled with Low-EUR shifts generation.
Reference Mid-EUR Scenario: Natural Gas Expansion (2030)
• CES can lead to deep cuts in carbon emissions (upstream emissions should be considered in setting CES crediting scheme).
• Abundant low cost NG (High-EUR) can help lower CO₂ and cost of meeting a CES.
• A stringent CES target of 80% can be met without CCS, although the cost is likely to be higher.

**Power Sector CO₂ Emissions**

- CES High-EUR
- CES High-EUR, No-CCS
- CES Low-EUR
- Reference Mid-EUR
- Retire 80GW
- No New Non-CCS Coal

MTons CO₂

- 2,300
- 2,100
- 2,000
- 1,900
- 1,700
- 1,500
- 1,300
- 1,100
- 900
- 700

Electricity Price

- Advances in nuclear do little to drive down costs, but this is a result of assuming a Low-EUR natural gas future.
- Advances in RE reduce the national average electricity price due to lower capital cost assumptions.
Among the CES scenarios, non-hydro RE generation reaches 35%-43% of the total in 2036; much of this is wind and would require massive new transmission infrastructure. Barriers to deploying this level of variable RE and operational challenges (e.g. curtailment) need further study.
## Summary Results Matrix

<table>
<thead>
<tr>
<th>Reference Scenarios</th>
<th>2020</th>
<th>2036</th>
<th>2020</th>
<th>2036</th>
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<tbody>
<tr>
<td></td>
<td>Capacity (GW)</td>
<td>Generation (TWh)</td>
<td>CO2 (Mtons)</td>
<td>NG Price (2009$/MMBtu)</td>
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<tr>
<td>Mid-EUR</td>
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<th>CES Scenarios</th>
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<tbody>
<tr>
<td></td>
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<td>Generation (TWh)</td>
<td>CO2 (Mtons)</td>
<td>NG Price (2009$/MMBtu)</td>
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<tr>
<td>High-EUR</td>
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<tr>
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<td>Generation (TWh)</td>
<td>CO2 (Mtons)</td>
<td>NG Price (2009$/MMBtu)</td>
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<tr>
<td>Retire 80GW</td>
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<tr>
<td>Mid-EUR</td>
<td>10.5%</td>
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<td>Advanced Nuclear (Low-EUR)</td>
<td>16.3%</td>
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</table>
Selected Conclusions

- NG generation doubles by 2036 from today’s level in a mid-Estimated Ultimate Recovery (EUR) framework, but is further constrained in low-EUR case. The future of natural gas is highly sensitive to assumptions about EUR.
- NG prices for power generators rise to nearly $6/MMBtu in our baseline scenario in 2020, and just over $8/MMBtu in 2036.
- NG plays a dominant role in substituting for coal plants that retire; wind is more economic in a limited number of cases.
- NG generation peaks in the late 2020s under a Clean Energy Standard unless CCS is available at costs estimated by Black and Veatch (2012).
- Nuclear becomes economically competitive when its capital costs decline by half and gas prices rise, as in the Low-EUR case.