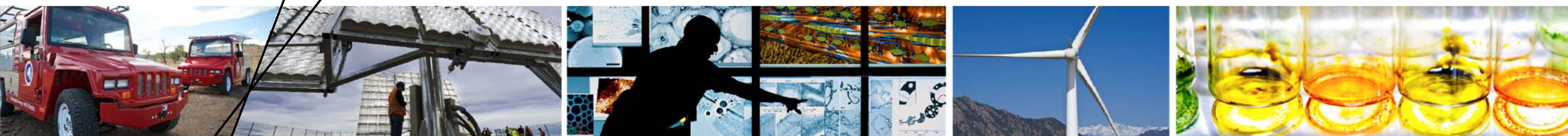
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

U.S. Electric Power Futures: Preliminary Results



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Clean Energy Regulatory Forum III: Background Study

National Renewable Energy Laboratory

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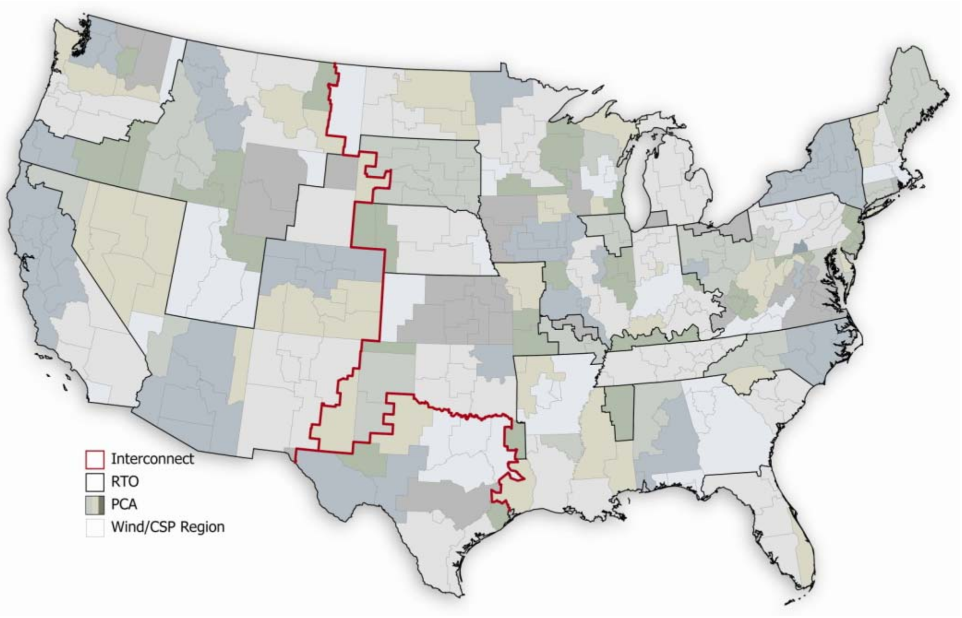
Approach

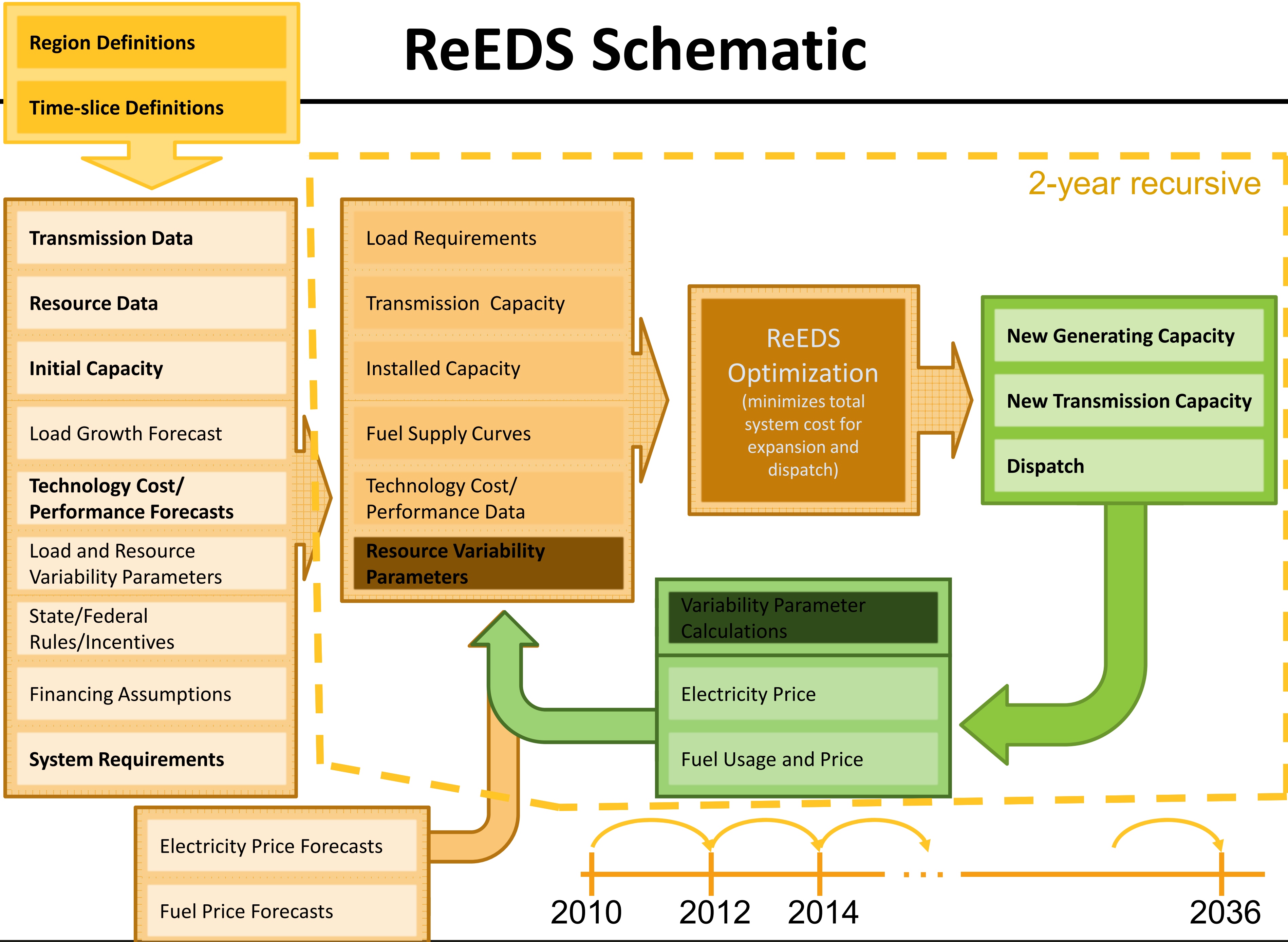
- We use our Regional Energy Deployment Systems (ReEDS) capacity expansion model to simulate the evolution of the U.S. power sector under a number of policy and technology variables over the mid-term (2036).
- Technology cost and performance assumptions are based on Black & Veatch (2012); fuel cost assumptions 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

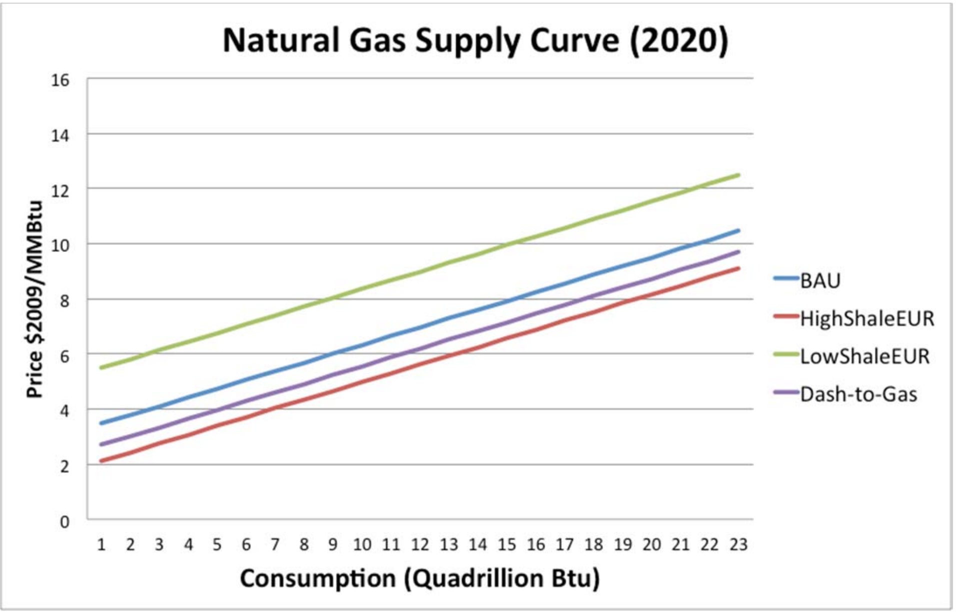


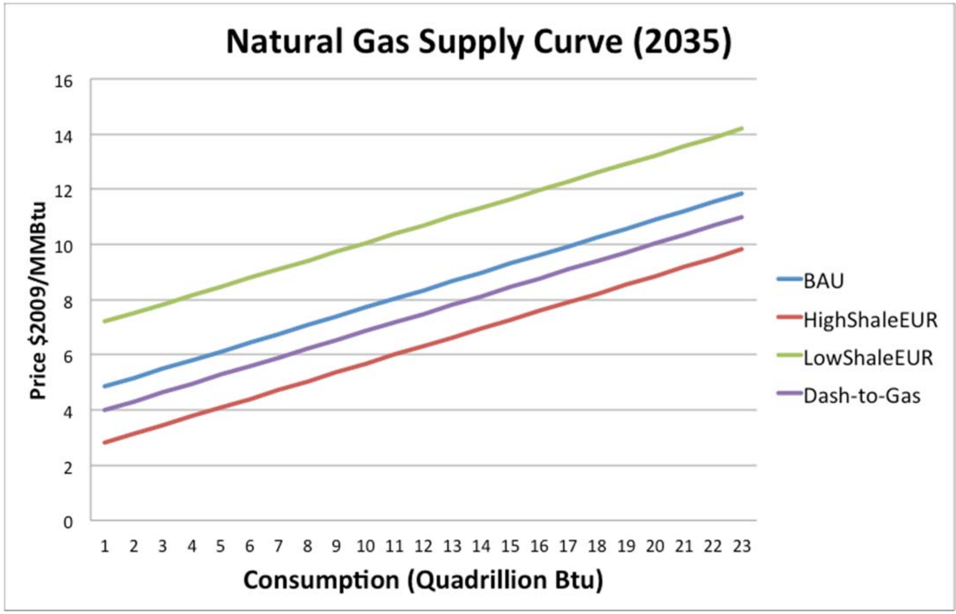
Endogenous Retirement within ReEDS

- **ReEDS will endogenously retire all power plants according to criteria.**
  - Coal: Age-based standard (65-75 years, depending on size) and/or usage-based (minimum generation needed)
  - Oil/Gas Steam: Age-based (55 years)
  - Nuclear: Age-based standard (60-80 years, depending on year deployed)
  - NG-CC: 55 years
  - 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

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.

Sensitivities:

Mid-EUR

Low-EUR

Low-Demand

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.

High-EUR

No CCS technologies available
- High-EUR

Low-EUR

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.

Retire 80GW of coal by 2026
- Mid-EUR
- See retirement map

No New Non-CCS Coal
- Mid-EUR

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.

Advanced RE
- Mid-EUR
- 176GW of dist. PV by 2036
- Reduced cap costs

Advanced Nuclear
- Low-EUR
- See cap cost matrix

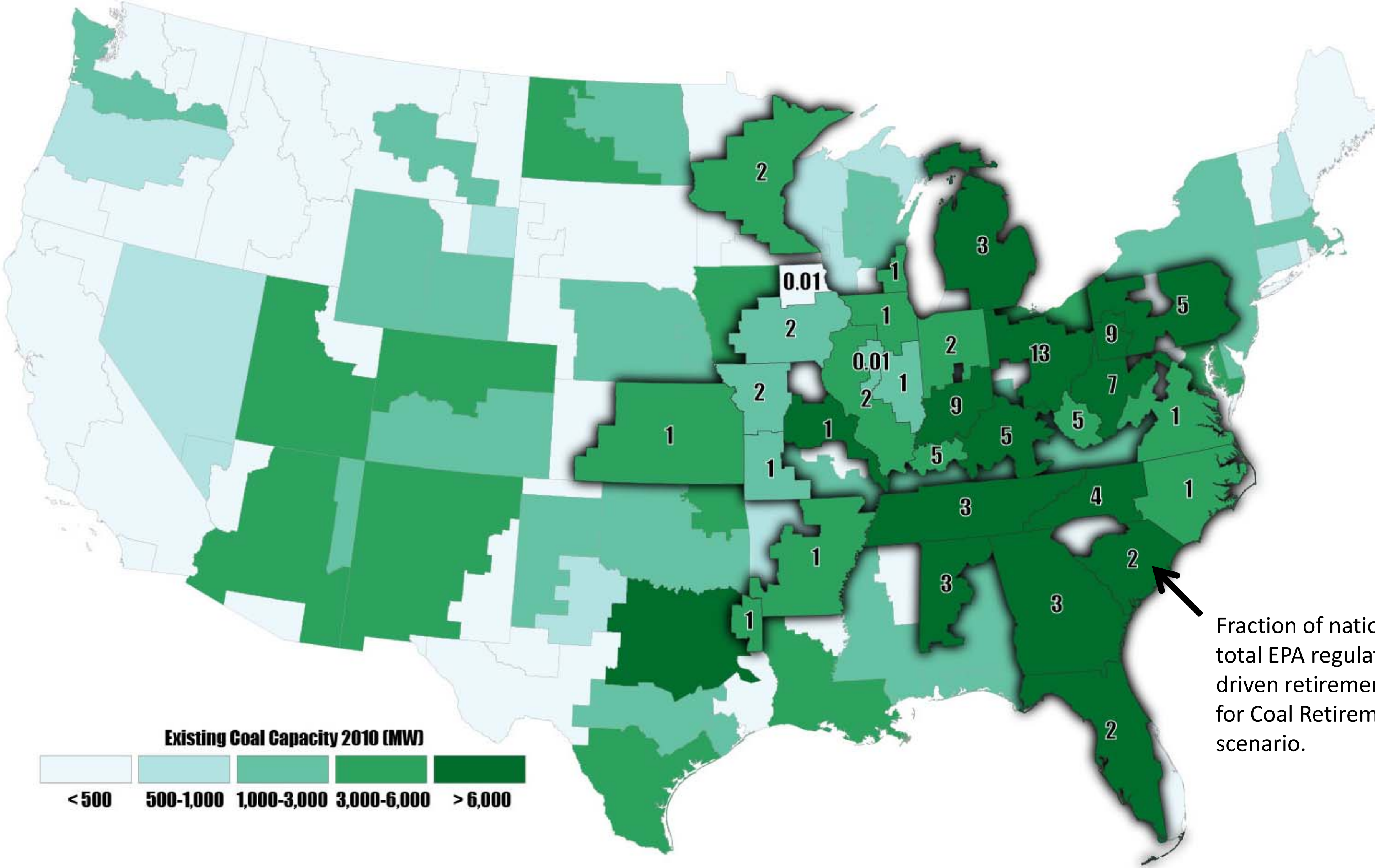
Capital Cost Matrix

• 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).

	2020 (2004$/kW)							2036 (2004$/kW)						
	Gas-CC	Gas-CT	Coal	Nuclear	Wind	CSP	Utility-scale PV	Gas-CC	Gas-CT	Coal	Nuclear	Wind	CSP	Utility-scale PV
All Other Scenarios	1,083	573	2,544	5,370	1,743	3,996	2,209	1,083	573	2,544	5,370	1,743	3,510	1,964
Technology Improvement Scenarios														
Advanced RE	1,083	573	2,544	5,370	1,701	3,996	1,917	1,083	573	2,544	5,370	1,564	3,510	1,606
Advanced Nuclear	1,083	573	2,544	2,685	1,743	3,996	2,209	1,083	573	2,544	2,685	1,743	3,510	1,964

Assumptions for *Utility-scale PV* and *Wind* cost reductions are outlined in the forthcoming NREL report “Renewable Electricity Futures,” 2012.

Retirement Scheme



Fraction of national total EPA regulation-driven retirements for Coal Retirement scenario.

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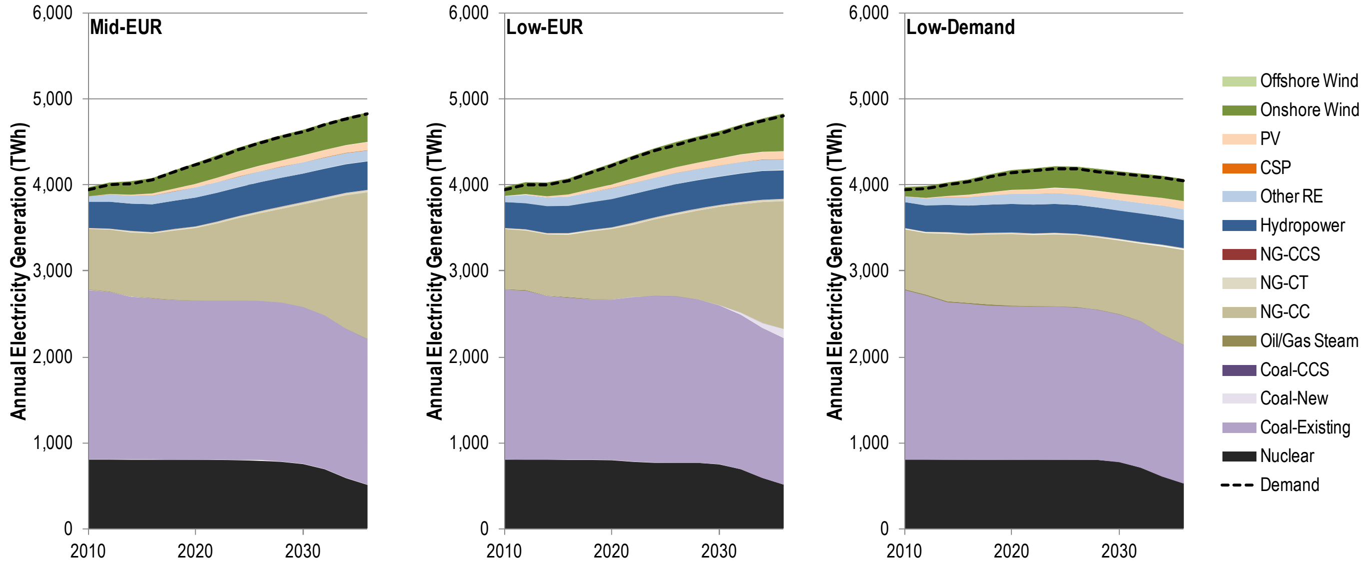
Generation Comparison

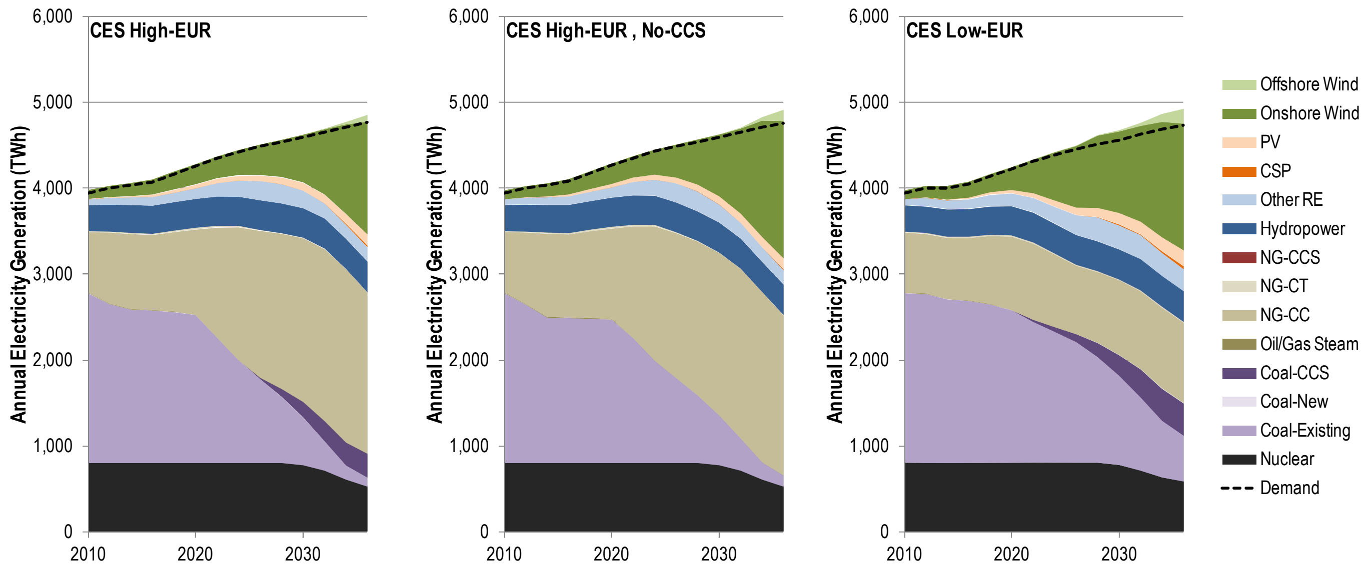
Reference Scenarios

•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.

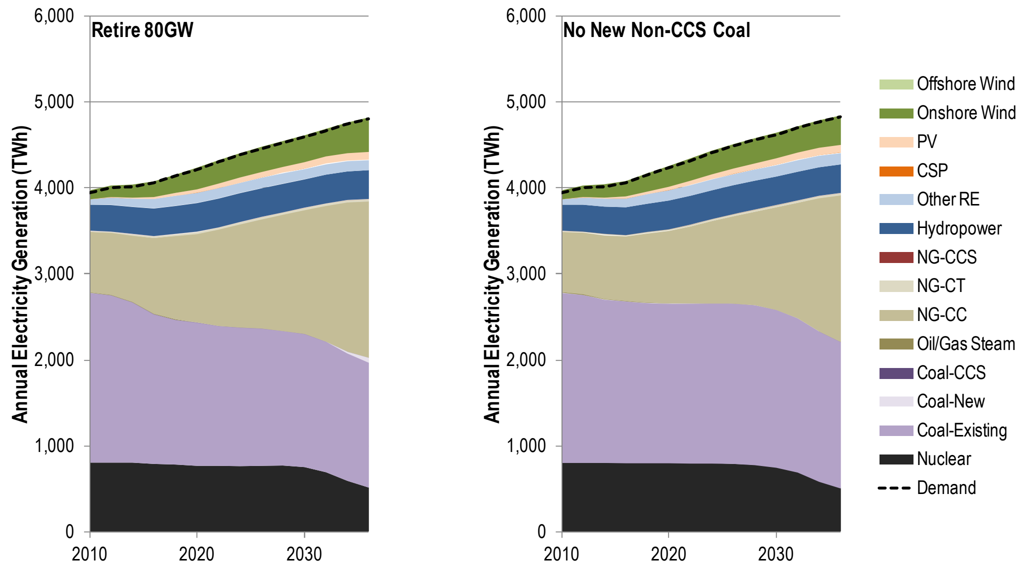


Generation Comparison

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

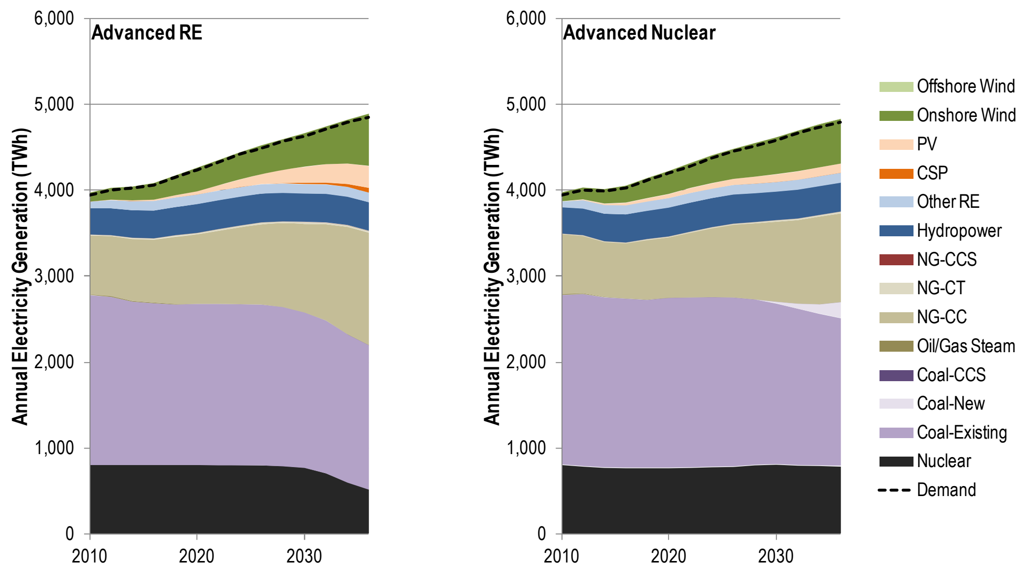
•NSPS (with only 25 GW of coal retirement by 2025) is very similar to the baseline reference case.



Technology Improvement Scenarios

•In the advanced RE case, non-hydro RE generation increases from 10% of the total in 2020 to 20% in 2036

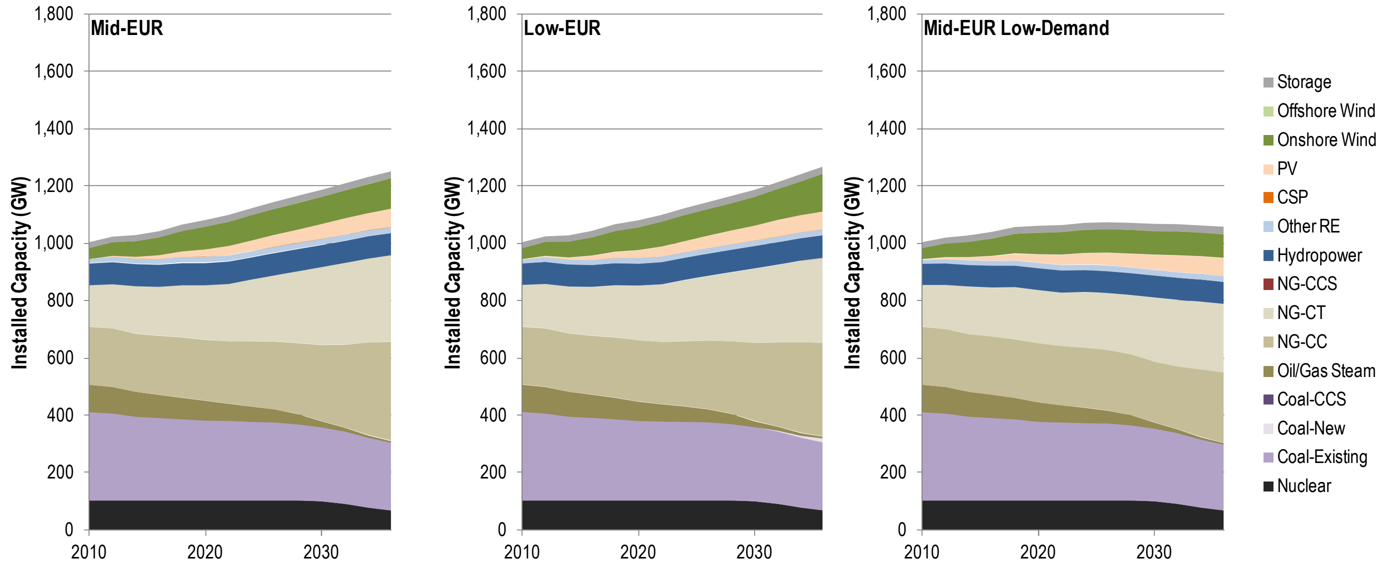
•Nuclear advancements coupled with Low-EUR shifts generation mix away from NG toward new nuclear, and to a lesser extent, new coal and RE.



Capacity Comparison

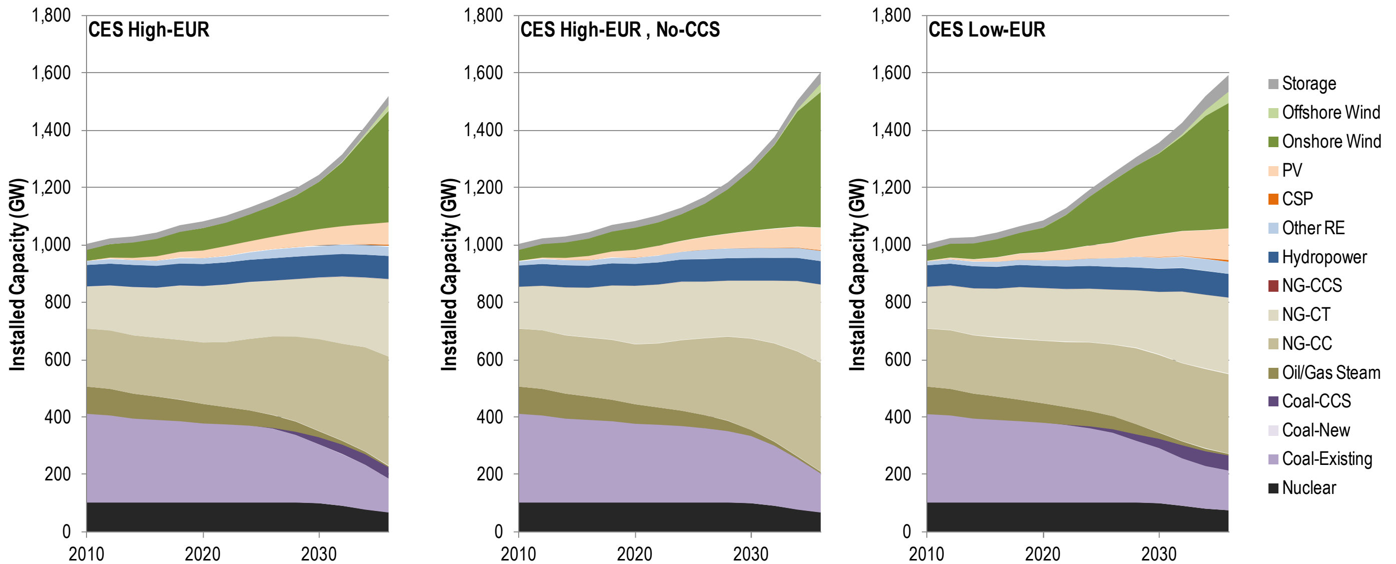
Reference Scenarios

•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 Standard Scenarios

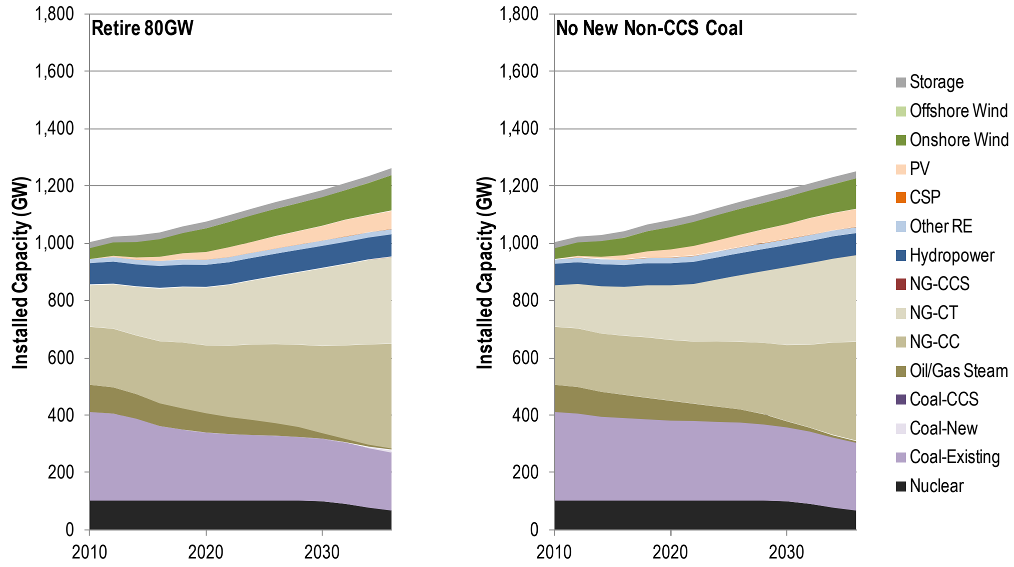
•Large increase in RE starting around 2025; more coal retires since it is not used
•CCS plays minor role in late 2020s
•Low-EUR results in more RE and less NG.



Capacity Comparison

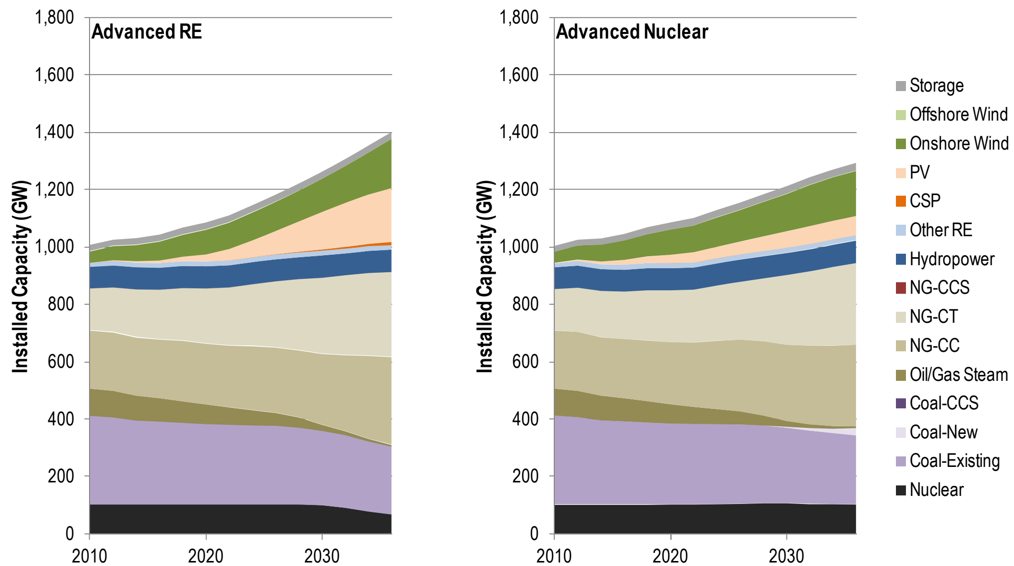
Coal Scenarios

- In the retirement case, coal capacity declines to roughly 200 GW in 2036
- NSPS capacity similar to reference baseline.

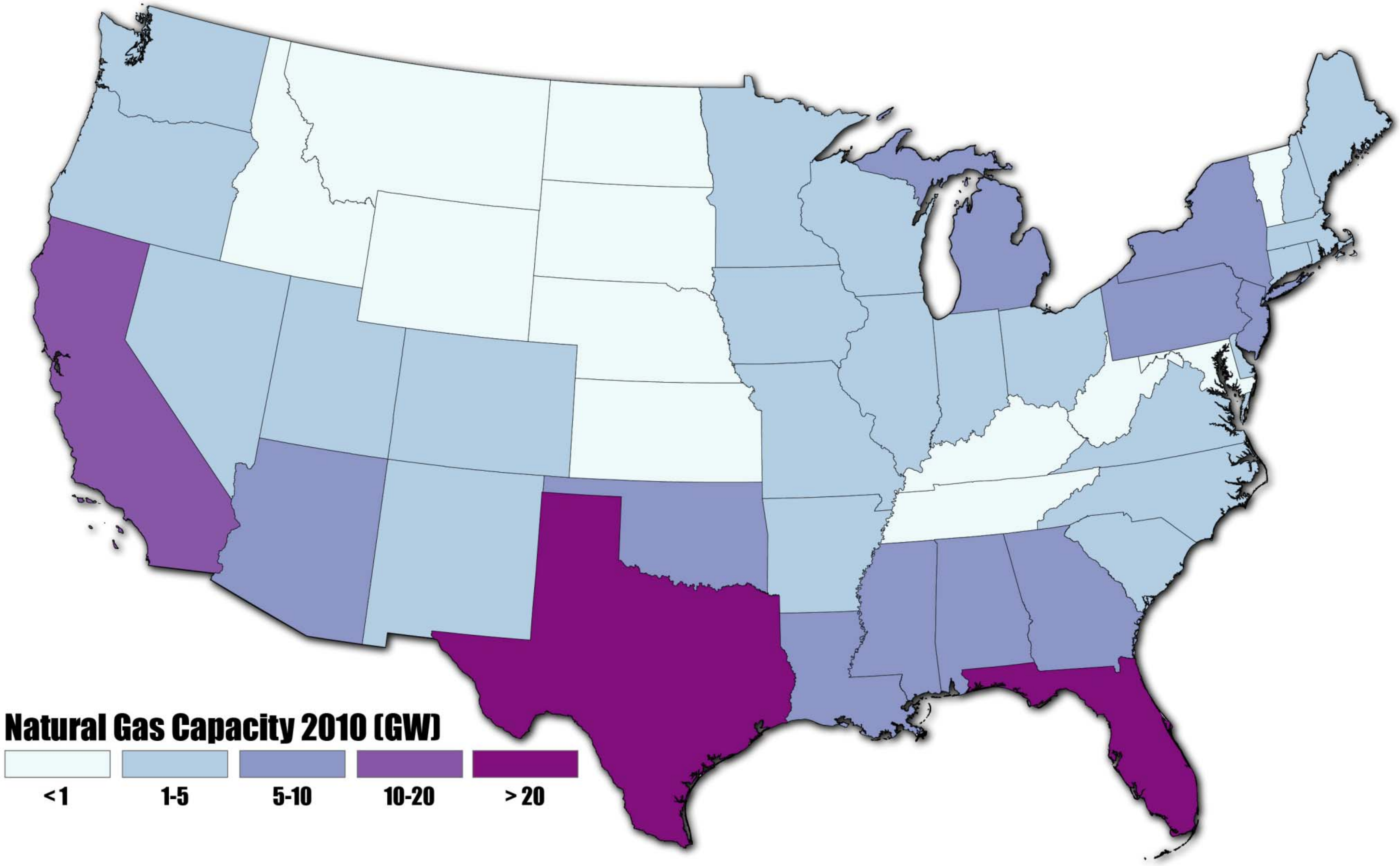


Technology Improvement Scenarios

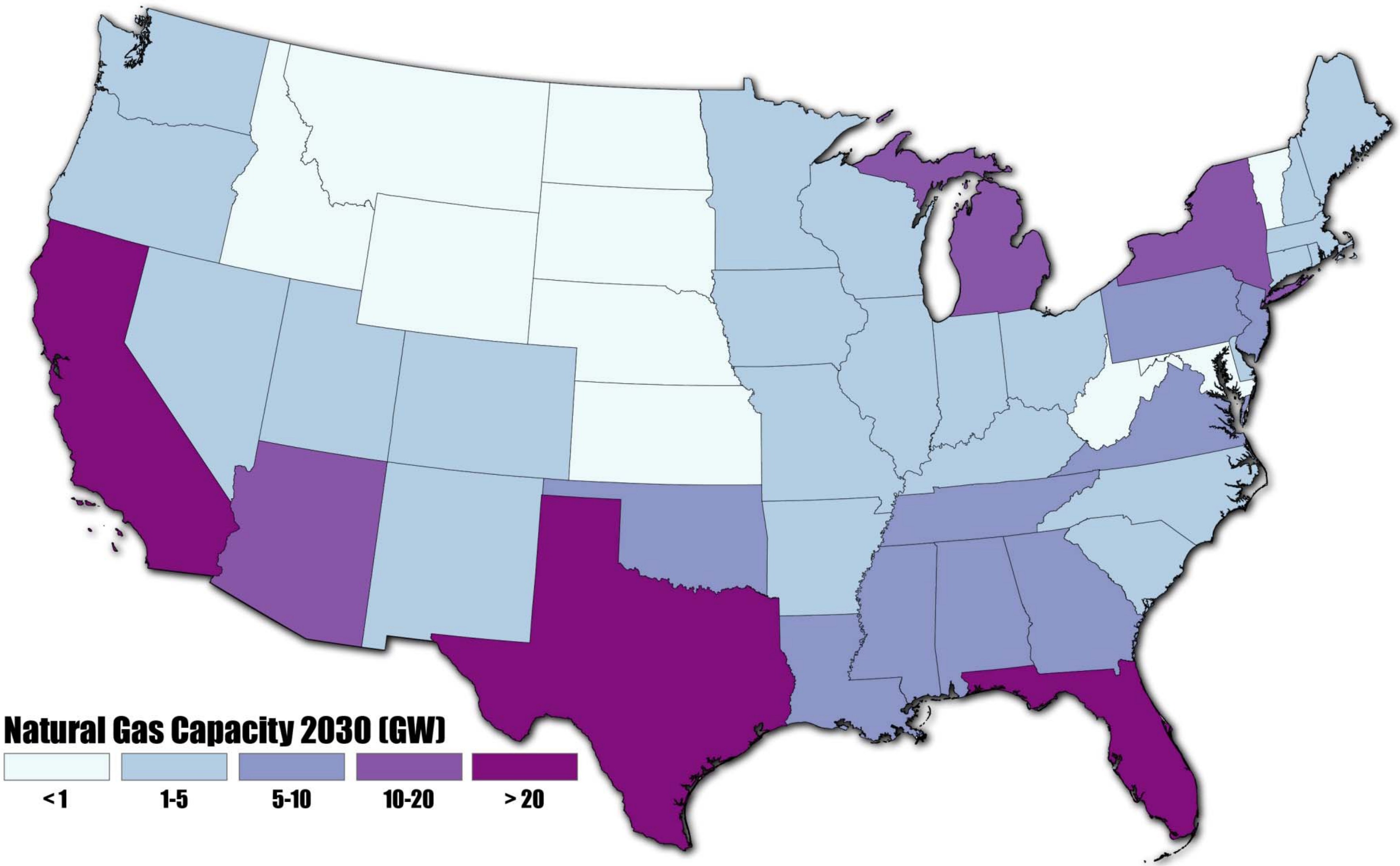
- In the advanced RE case, improvements in RE technologies reduce costs, increasing non-hydro RE capacity to ~386 GW by 2036 (~129 GW in 2020)
- Nuclear advancements coupled with Low-EUR shifts generation.



Reference Mid-EUR Scenario: Natural Gas Expansion (2010)

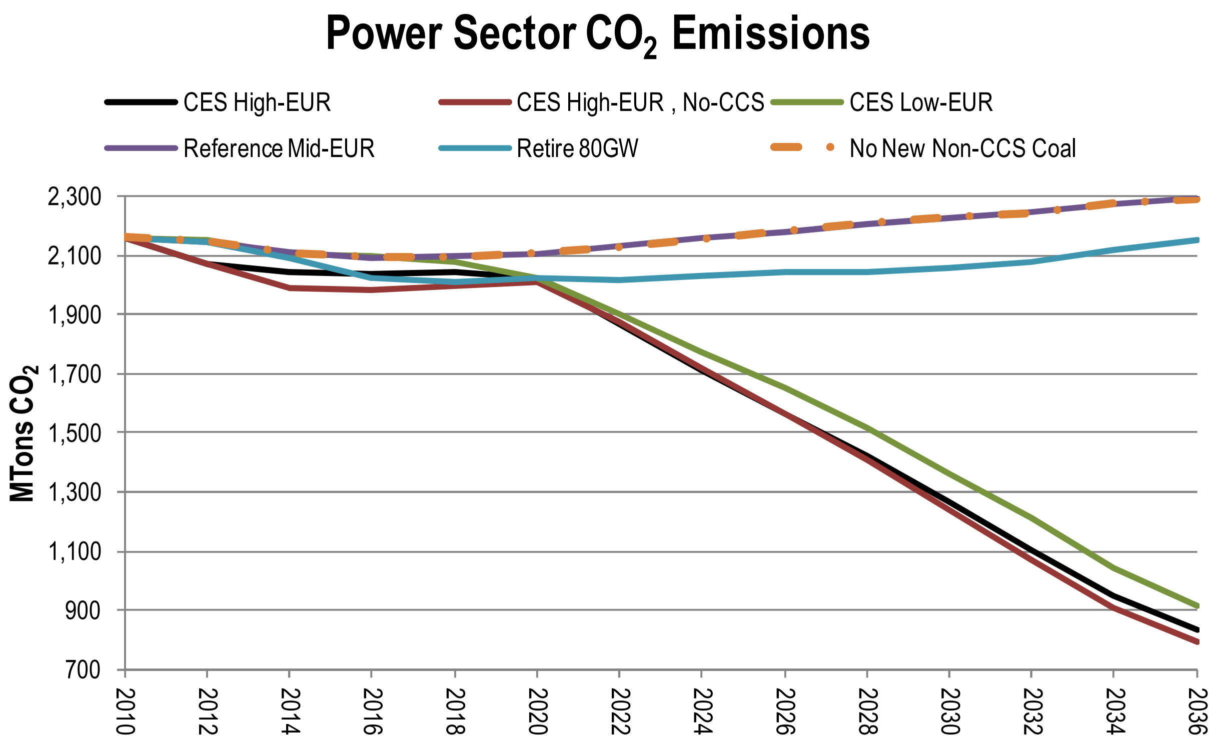


Reference Mid-EUR Scenario: Natural Gas Expansion (2030)



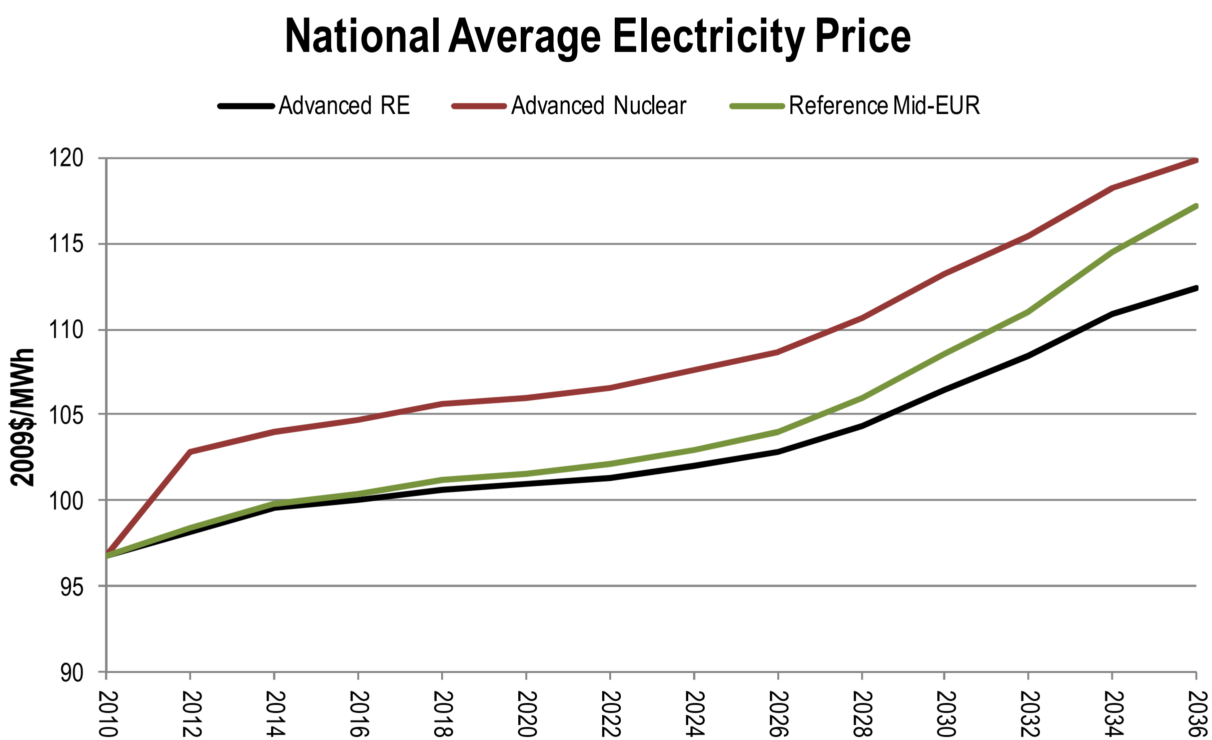
GHG Emissions

- 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 CO_2 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.

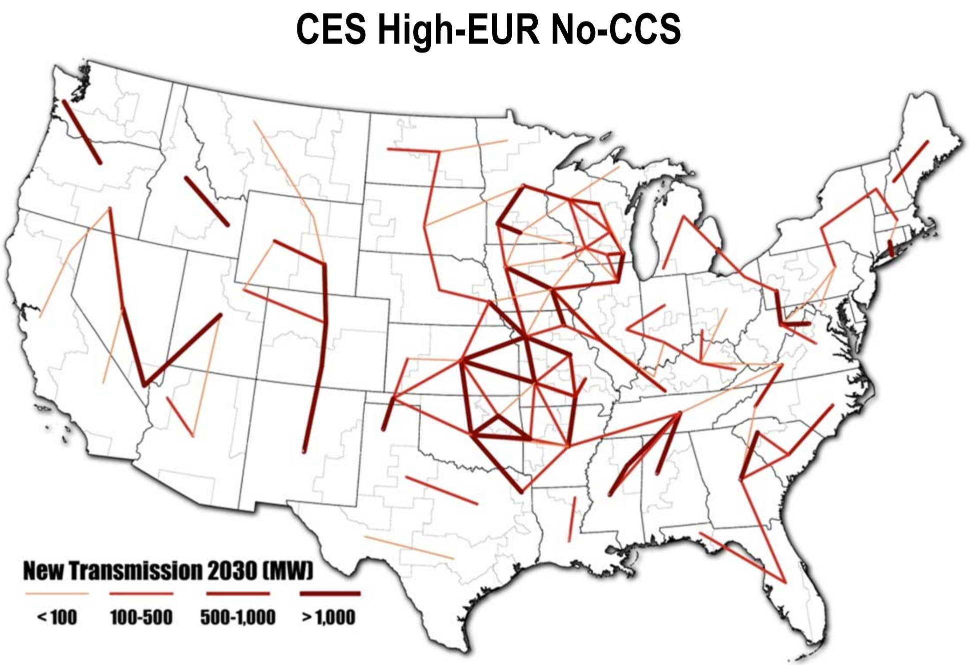


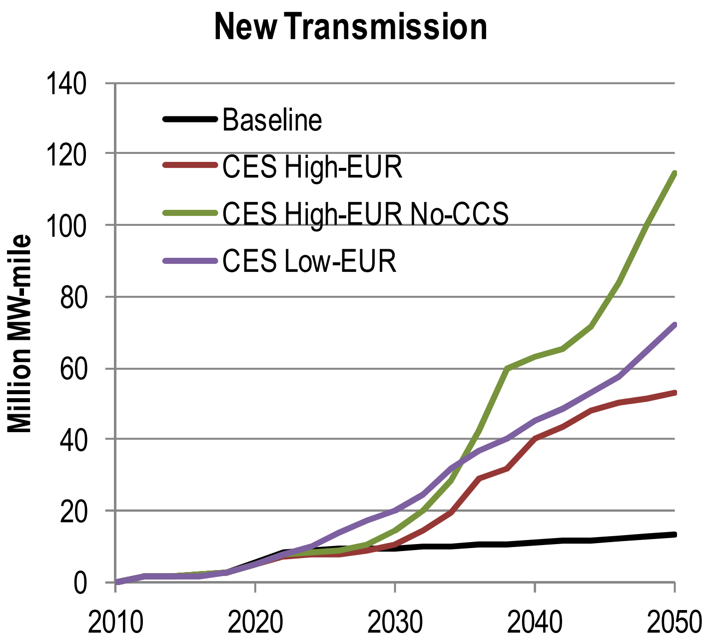
Electricity Price

- 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.



Transmission





- 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

	2020				2036			
	Capacity (GW)	Generation (TWh)	CO2 (Mtons)	NG Price (2009$/MMBtu)	Capacity (GW)	Generation (TWh)	CO2 (MTons)	NG Price (2009$/MMBtu)
Reference Scenarios								
Mid-EUR	1,082	4,259	2,107	5.93	1,252	4,845	2,291	8.13
Low-EUR	1,081	4,252	2,113	6.33	1,254	4,724	2,299	8.75
Mid-EUR Low-Demand	1,061	4,173	2,035	4.59	1,057	4,068	1,966	5.92
CES Scenarios								
High-EUR	1,083	4,280	2,026	4.83	1,478	4,570	835	6.14
High-EUR No-CCS	1,084	4,289	2,006	4.44	1,603	4,289	796	6.24
Low-EUR	1,086	4,249	2,024	7.26	1,541	4,249	917	8.65
Coal Scenarios								
Retire 80GW	1,075	4,238	2,020	7.29	1,252	4,765	2,150	9.56
No New Non-CCS	1,082	4,259	2,107	6.74	1,252	4,845	2,291	9.25
Technology Improvement Scenarios								
Advanced RE	1,084	4,264	2,113	6.64	1,400	4,892	2,114	8.07
Advanced Nuclear (Low-EUR)	1,086	4,227	2,180	9.59	1,267	4,643	2,209	11.06

Percent Generation

	2036									
	Nuclear	Natural Gas	Coal	Coal CCS	Biomass	Hydro	Geothermal	CSP	PV	Wind
Reference Scenarios										
Mid-EUR	10.5%	35.7%	35.1%	0%	2.2%	6.9%	0.4%	0%	1.9%	7.1%
Low-EUR	10.6%	31.4%	37.5%	0%	2.1%	7%	0.4%	0%	1.9%	9.1%
Mid-EUR Low-Demand	13%	27.5%	39.7%	0%	2.5%	8.2%	0.5%	0%	2.3%	6.3%
CES Scenarios										
High-EUR	10.9%	38.8%	2.1%	5.8%	2.5%	7.3%	0.8%	0.4%	2.7%	28.7%
High-EUR No-CCS	10.8%	38%	2.6%	0%	2.6%	7.2%	0.8%	0.2%	2.7%	35.1%
Low-EUR	11.9%	19.1%	10.9%	7.6%	4.3%	7.4%	0.9%	0.7%	3.9%	33.4%
Coal Scenarios										
Retire 80GW	10.7%	38.3%	31.4%	0%	2%	7%	0.4%	0%	1.9%	8.3%
No New Non-CCS	10.5%	35.8%	35.1%	0%	2.2%	6.9%	0.4%	0%	1.9%	7.1%
Technology Improvement Scenarios										
Advanced RE	10.6%	27.2%	34.4%	0%	1.9%	6.7%	0.5%	1.1%	5.3%	12.4%
Advanced Nuclear (Low-EUR)	16.3%	21.9%	39.5%	0%	2%	6.9%	0.5%	0%	2.2%	10.8%

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.**