Energy+Environmental Economics

Least Cost Carbon Reduction Policies in PJM

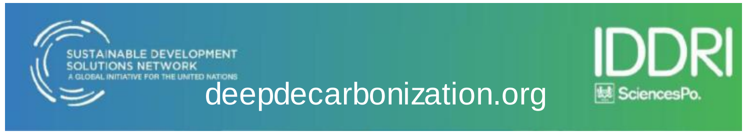
Prepared for PJM Carbon Pricing Senior Task Force

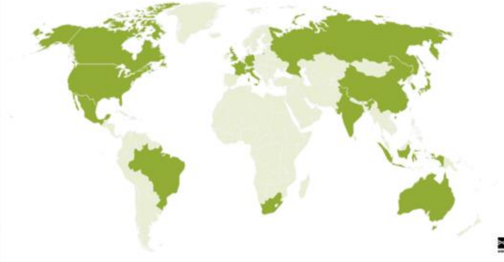
December 8, 2020

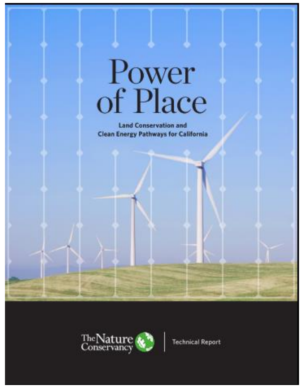
Arne Olson, Senior Partner
Sandy Hull, Director

E3 has worked with a wide range of clients to understand the challenges of deep decarbonization and high renewable penetration

+ **United Nations Deep Decarbonization Pathways Project:** US-wide study (2016)
+ **California:**
  - Support for state agencies including **CPUC**, **CEC**, **CARB** and **CAISO** on various aspects of California's clean energy goals
  - 100% RPS studies for **LADWP**, **SMUD** and **Calpine**
  - Deep decarbonization studies for **The Nature Conservancy** and **Environmental Defense Fund**
+ **100% Clean Energy Studies in Other Regions:**
  - **Hawaii:** HECO
  - **Pacific Northwest:** numerous utilities
  - **Upper Midwest:** Xcel Energy
  - **New York:** NYSERDA
  - **New England:** Calpine
  - **PJM:** Electric Power Supply Association
+ **E3 provides strategic advisory services to numerous asset owners across North America**



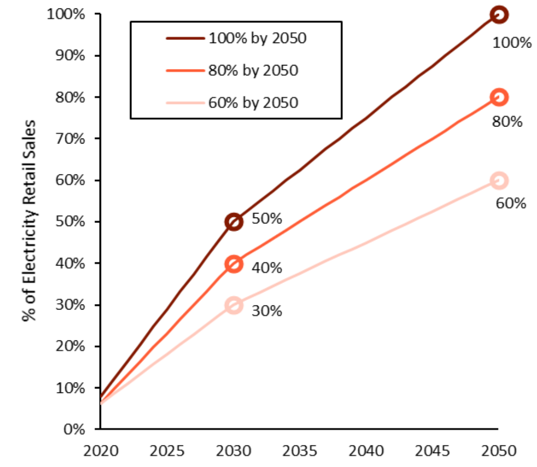




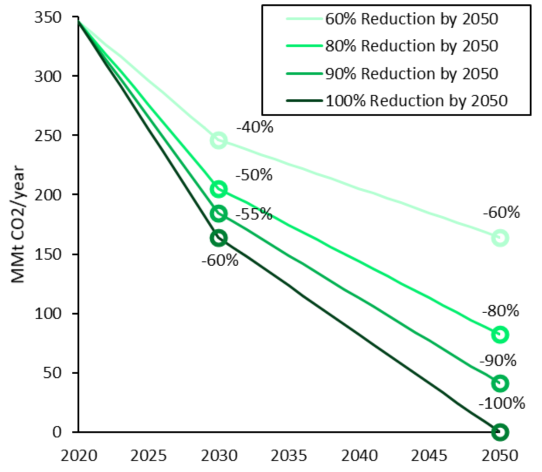
Study explores the implications of carbon reduction policy options in PJM

+ **E3 modeled a Reference case (no clean energy policies), enhanced existing policies, and three sets of alternative PJM-wide policy scenarios:**
  - **Regional RPS policy:** systemwide RPS with trading of credits across system
  - **Regional CES policy:** systemwide Clean Energy Standard that credits nuclear in addition to RPS resources with partial credit for gas
  - **Regional GHG policy:** systemwide carbon price scenario representative of cap-and-trade program or carbon tax
+ **Policy constraints are scaled upward over time to reach 2050 targets**
+ **Different levels of stringency were modeled for each type of policy**
  - 80% RPS, 80% GHG reduction from 2005 levels, and equivalent Mid CES case each yield similar emissions levels and are used as focus scenarios for comparison

RPS Policy Scenarios

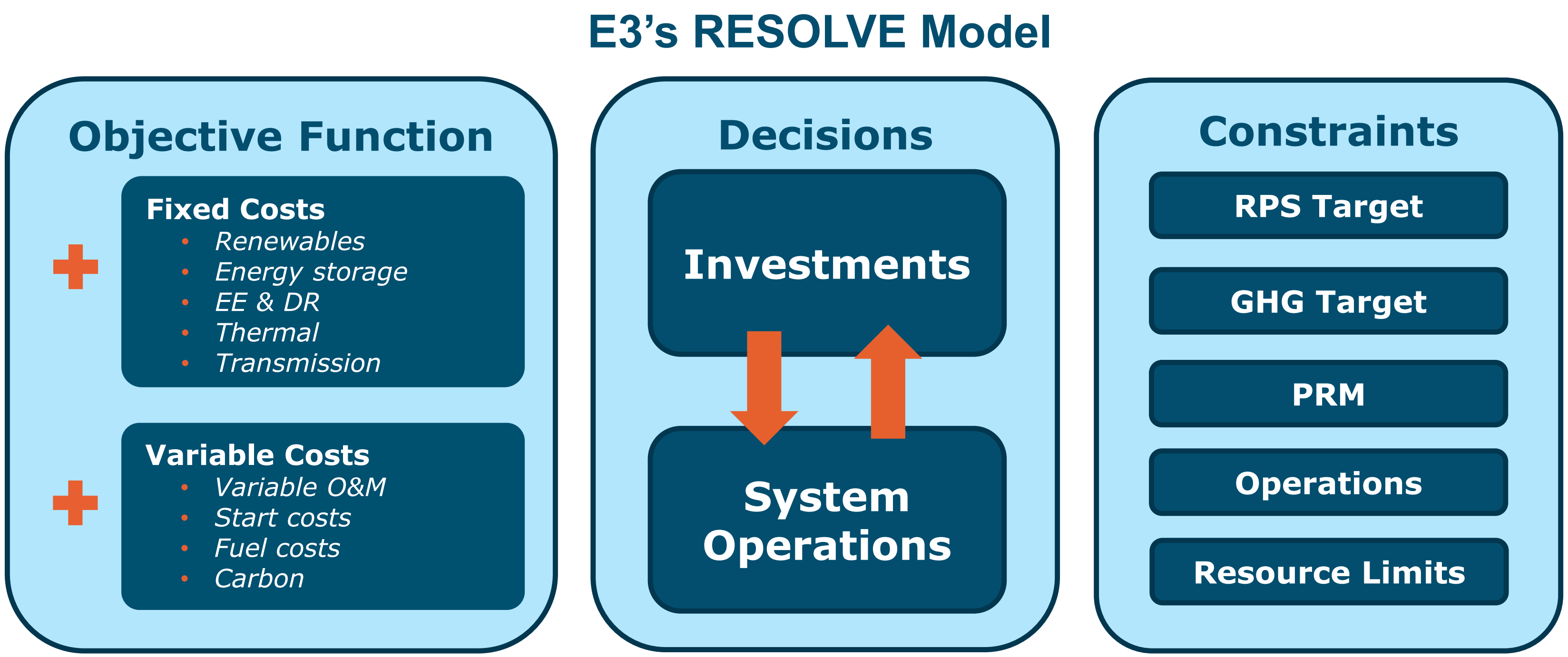


GHG Reduction Policy Scenarios



Study used E3's RESOLVE model to develop least-cost resource portfolios over time

+ **E3's RESOLVE capacity expansion and production simulation model used to determine least-cost resource portfolios and hourly system dispatch under each policy**
  - What are resource portfolio needs?
  - What are resulting system costs?
  - What are associated system emissions?



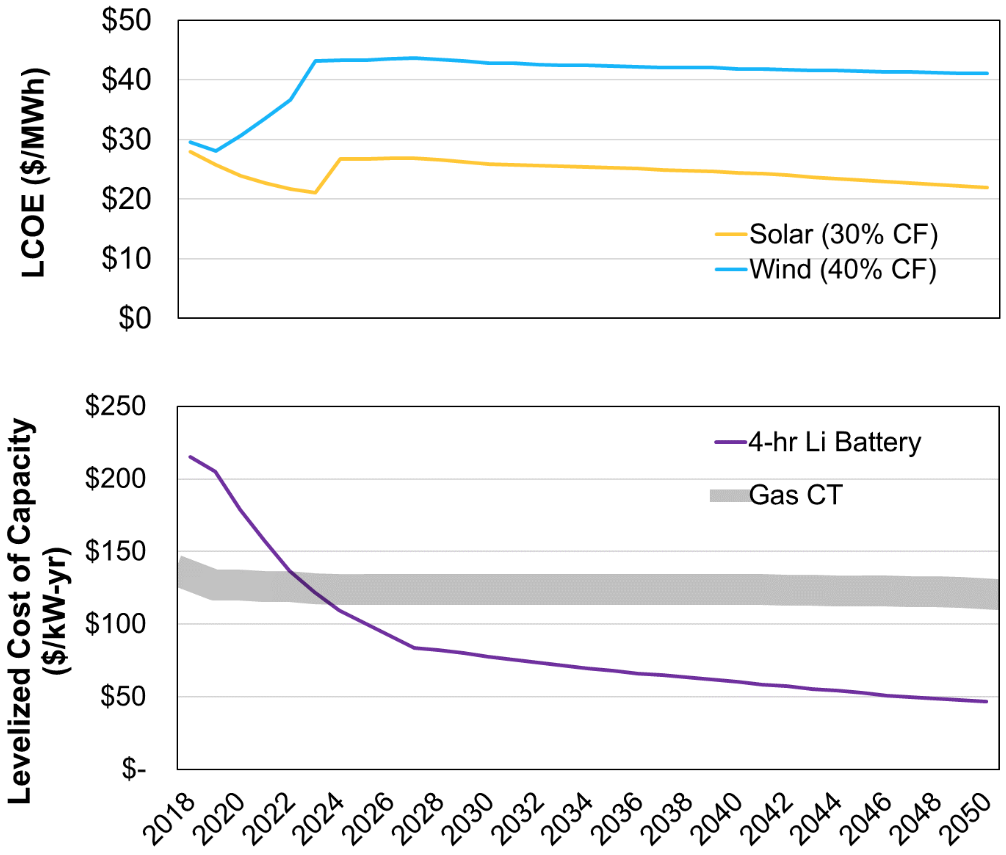
Current Drivers of Decarbonization

+ Favorable solar, wind, and storage economics

- Costs have been declining over the past decade
- Federal tax incentives have enabled investment
- Resources are competitive, even if/when tax credits expire
- NREL projections show continued cost declines into the future

Even without more aggressive state policies or incentives, renewable and battery storage capacity are expected to grow

Levelized Cost Forecasts for Example Capacity Factor

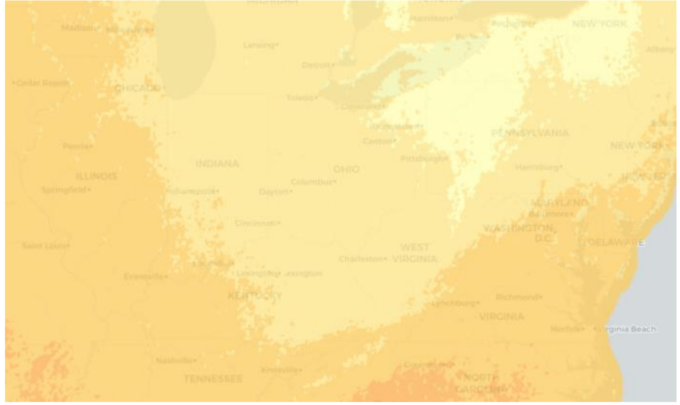


*** Costs shown above are based on the NREL 2019 ATB ***

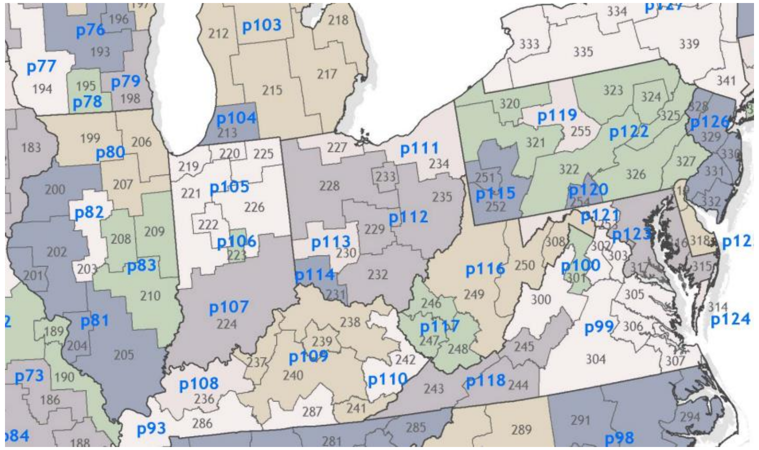
New candidate resource data based on NREL models

- **NREL's ReEDS regions used for quantifying resource potential**
  - Contains MW potential for solar, wind, and other resources
- **NREL's Wind Toolkit and National Solar Radiation Database used for profiles**
  - Ability to simulate hourly output at any coordinates specified
- **E3 limits resource availability to max of 4% farmland and 2% forested land in each state**

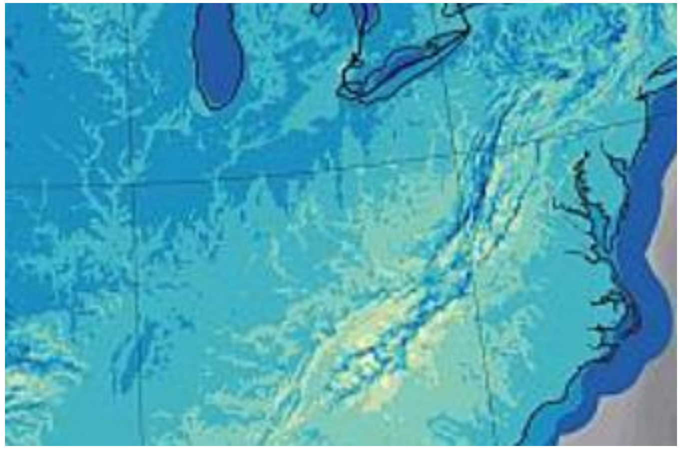
NSRDB Solar Potential



ReEDS Regions



WTK Wind Potential



Energy+Environmental Economics

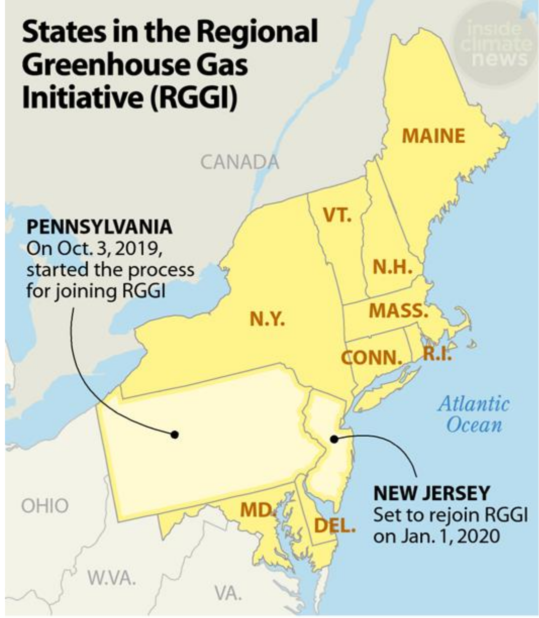
Impact of Current State Policies

Current carbon reduction policies in PJM are driven by state legislation and take several forms

- **The Regional Greenhouse Gas Initiative (RGGI) caps power sector CO_2 emission across its participant states**
- **Various states have set RPS and clean energy targets**
  - State REC markets include differing rules and carveouts
- **Various state ZEC programs and plant-specific subsidies**

State	RPS/CES Target Year	RPS/CES Target (% of sales)	Solar Carveout (% of sales)	Offshore Wind Carveout (GW / % of sales)
DC	2032	100%	5.5%	
Delaware	2026	25%	3.5%	
Illinois	2026	25%	1.5%	1%
Maryland	2030	50%	14.5%	1.2 GW
Michigan	2021	15%		
North Carolina	2021	13%		
New Jersey	2030	50%	2.21%	7.5 GW
Pennsylvania	2021	8%	0.5%	
Virginia	2050	100%		5.2 GW

RGGI Members
(VA set to join in 2021)



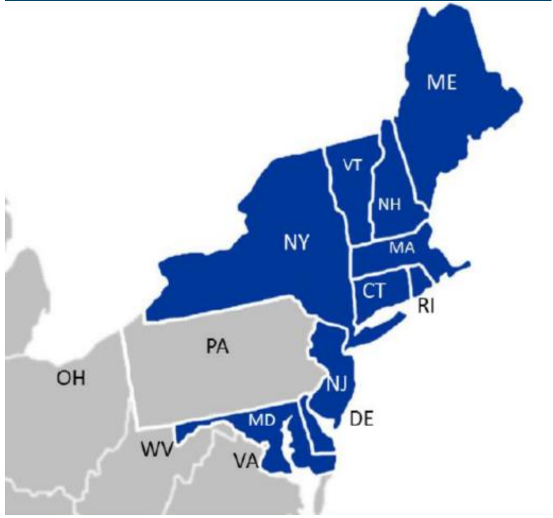
PAUL HORN / InsideClimate News

Some policies in PJM states are counterproductive and bail out higher-emitting coal units

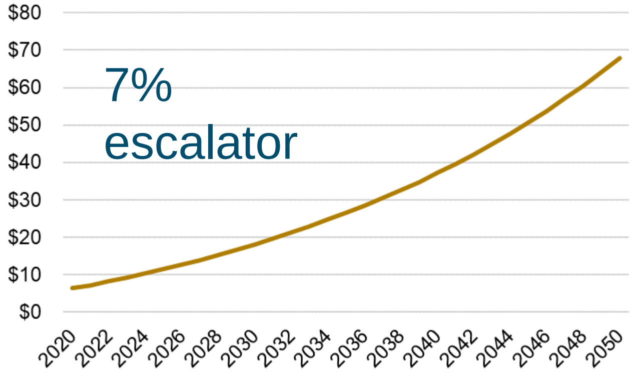
A subset of PJM states put a price on carbon, which E3 represents as escalating throughout the BAU case

- **NJ, MD, DE currently participate in the RGGI cap-and-trade program**
  - VA and PA are planning to join. E3 models them as included in carbon priced region in model
- **RGGI allowance prices are low compared to the social cost of carbon and the cost of REC programs**
  - 2016-2018, the price varied between $2.79 and $5.88 per tonne
- **Currently no mitigation for emissions leakage from generators in RGGI states to generators in other PJM states**
  - E3's model does not to enforce any leakage costs imported power across state lines as in CA
- **E3 represents RGGI via carbon prices starting at today's price of around $6/tonne and escalated at same 7% escalator as "soft cap"**
  - Maintains current distance below price ceiling

States Currently Participating in RGGI

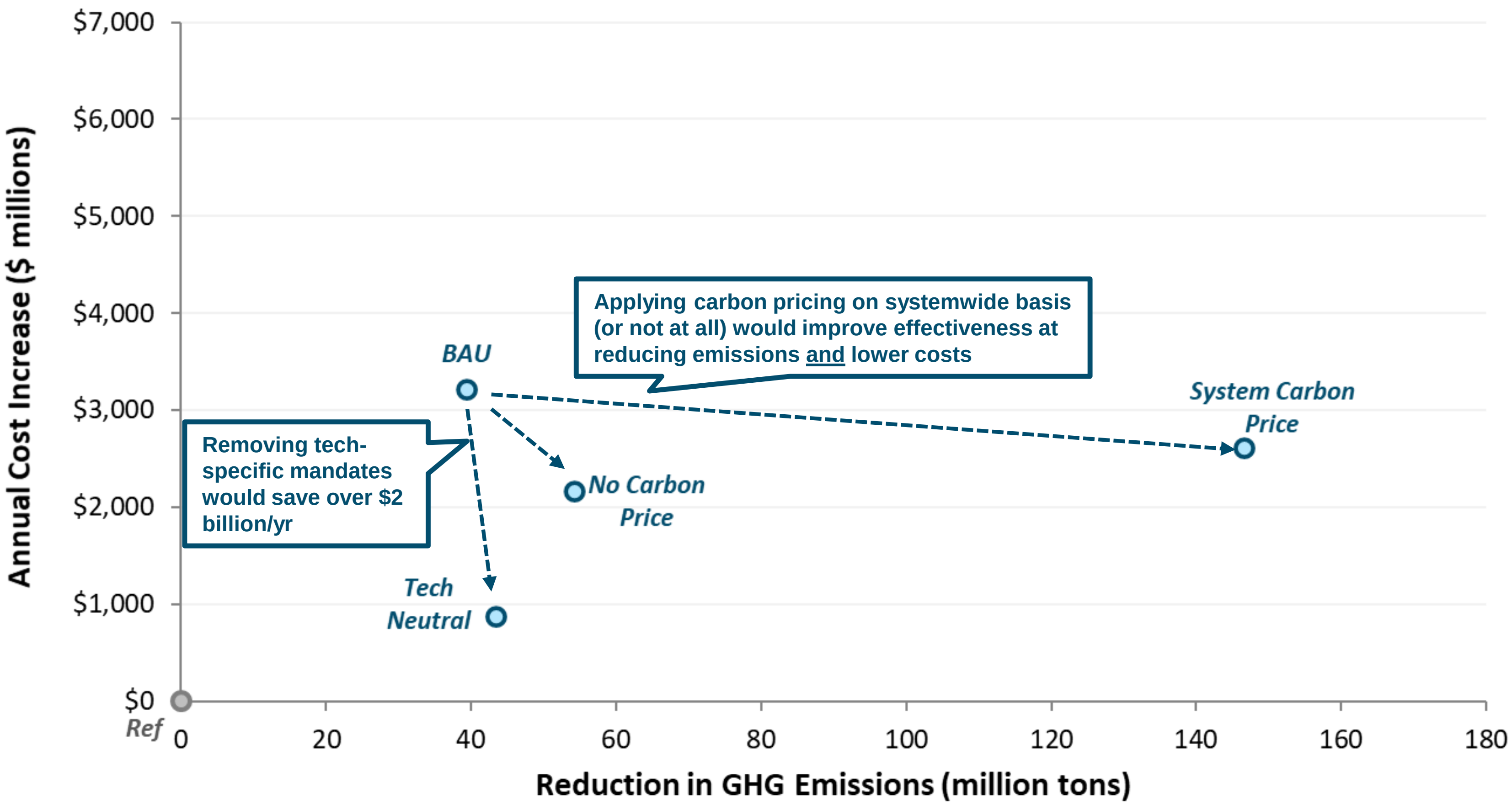


RGGI Carbon Price Assumptions



E3's modeling shows substantial improvement to current policies via technology neutral, systemwide approaches

Incremental Cost of Carbon Reductions Under 2030 Policy Scenarios



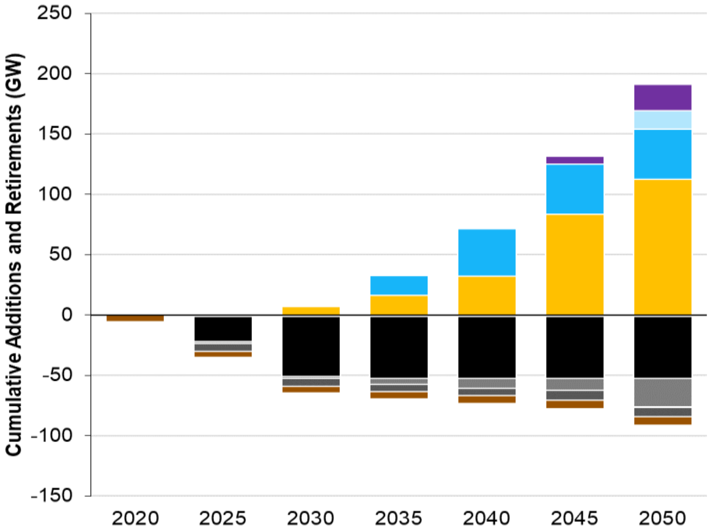
Energy+Environmental Economics

Scenario Walkthrough: 80% GHG Reduction Case

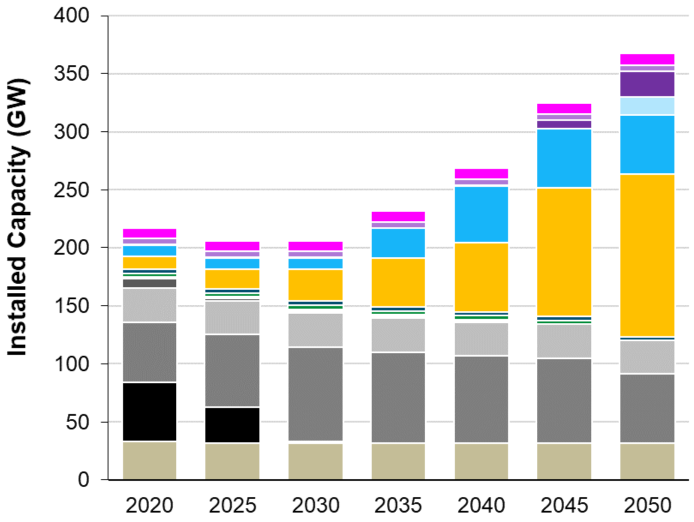
Resource additions and resulting portfolio to meet 80% GHG reduction scenario

- All coal retired in favor of gas and renewables by 2030
- Significant renewable generation added in 2030 and beyond
- Battery storage and offshore wind not selected until 2040s after onshore wind is largely exhausted
- Majority of gas capacity remains online to meet peak needs, despite lower run times

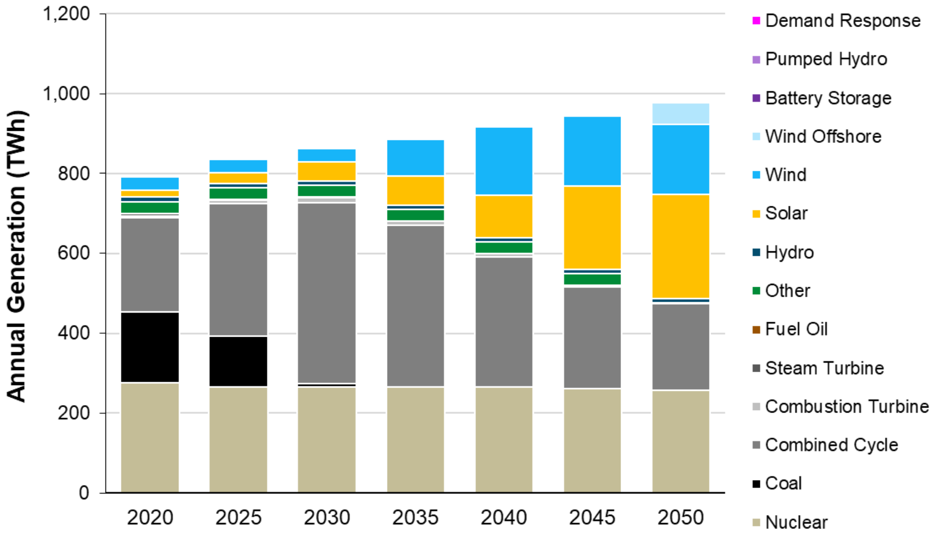
Incremental Resource Additions and Retirements



Resulting PJM Nameplate Capacity

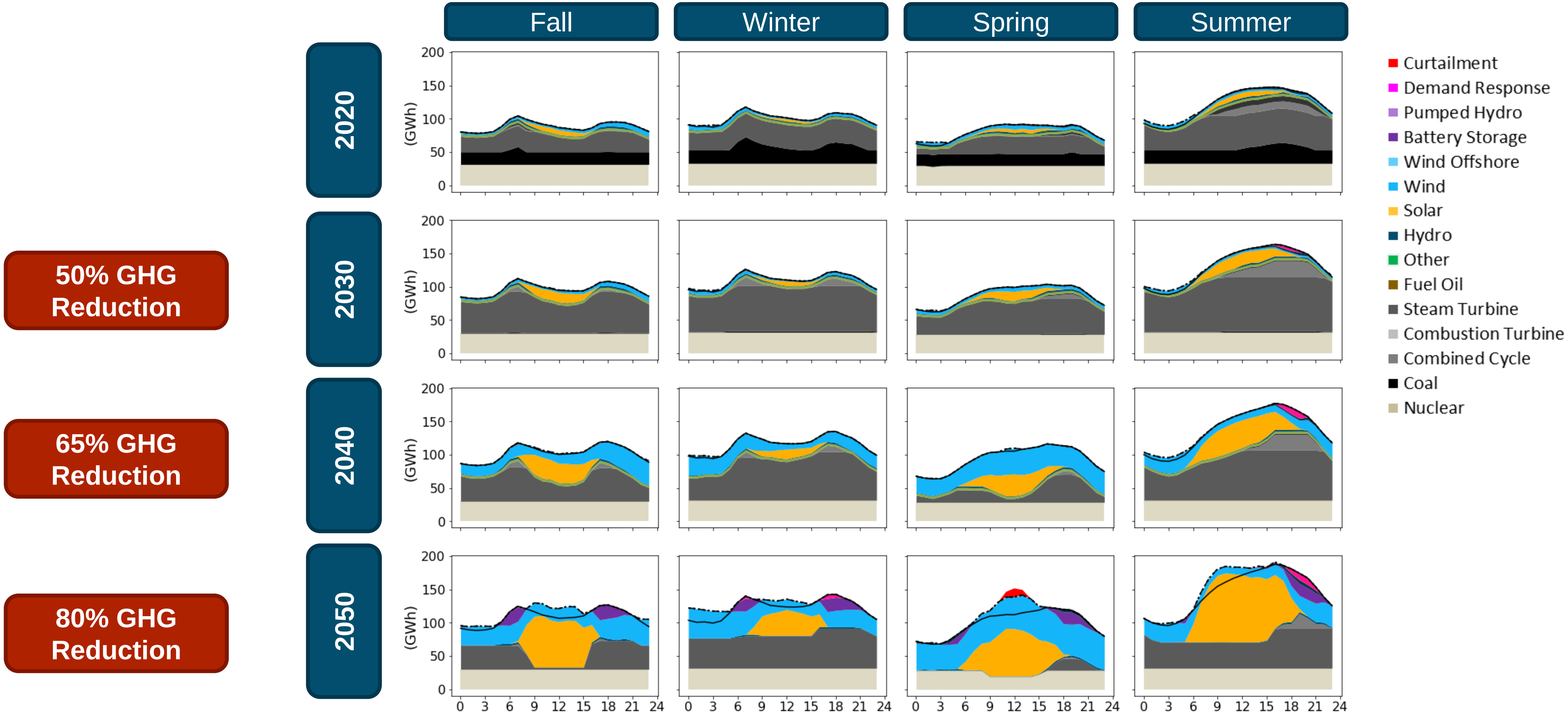


Annual Generation



PJM Operations in a Low-GHG System

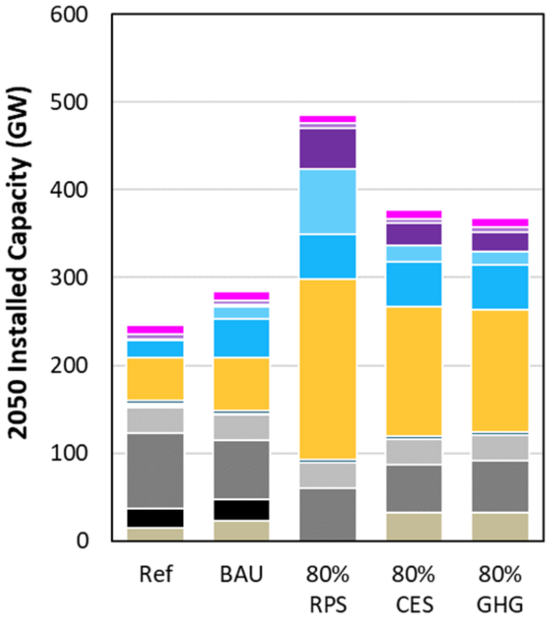
+ **Flexible gas used to complement renewables, minimal need for energy storage**
+ **Less flexible baseload coal drops out of fleet over time**



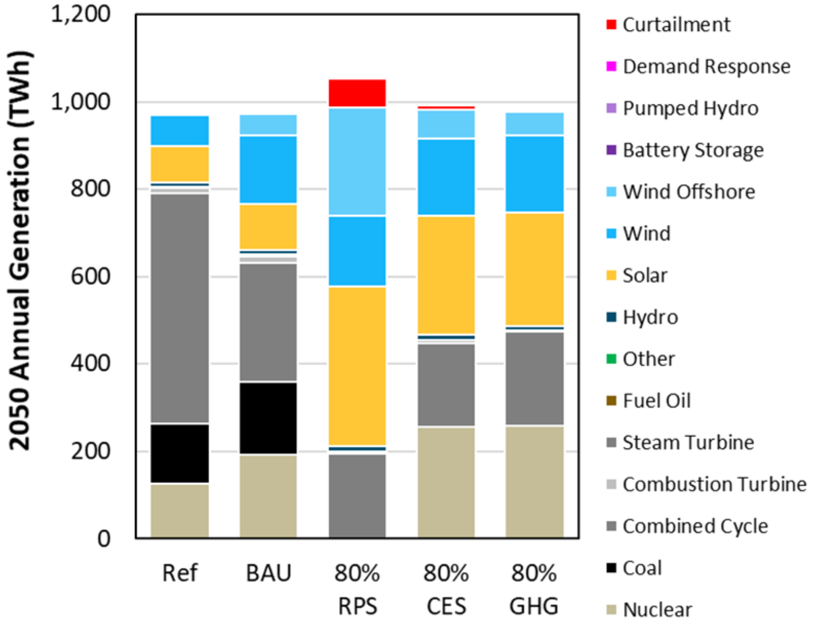
Policy scenarios drive divergent 2050 resource portfolios and resulting costs

+ BAU policies drive early investment in expensive offshore wind while retaining uneconomic coal
+ Alternative policy cases use different combinations of coal retirements, renewable additions, and nuclear retention to achieve goals
+ RPS-driven renewable overbuild leads to significant curtailment by 2050
+ Most gas capacity retained for reliability across all scenarios

Installed Capacity by Scenario in 2050

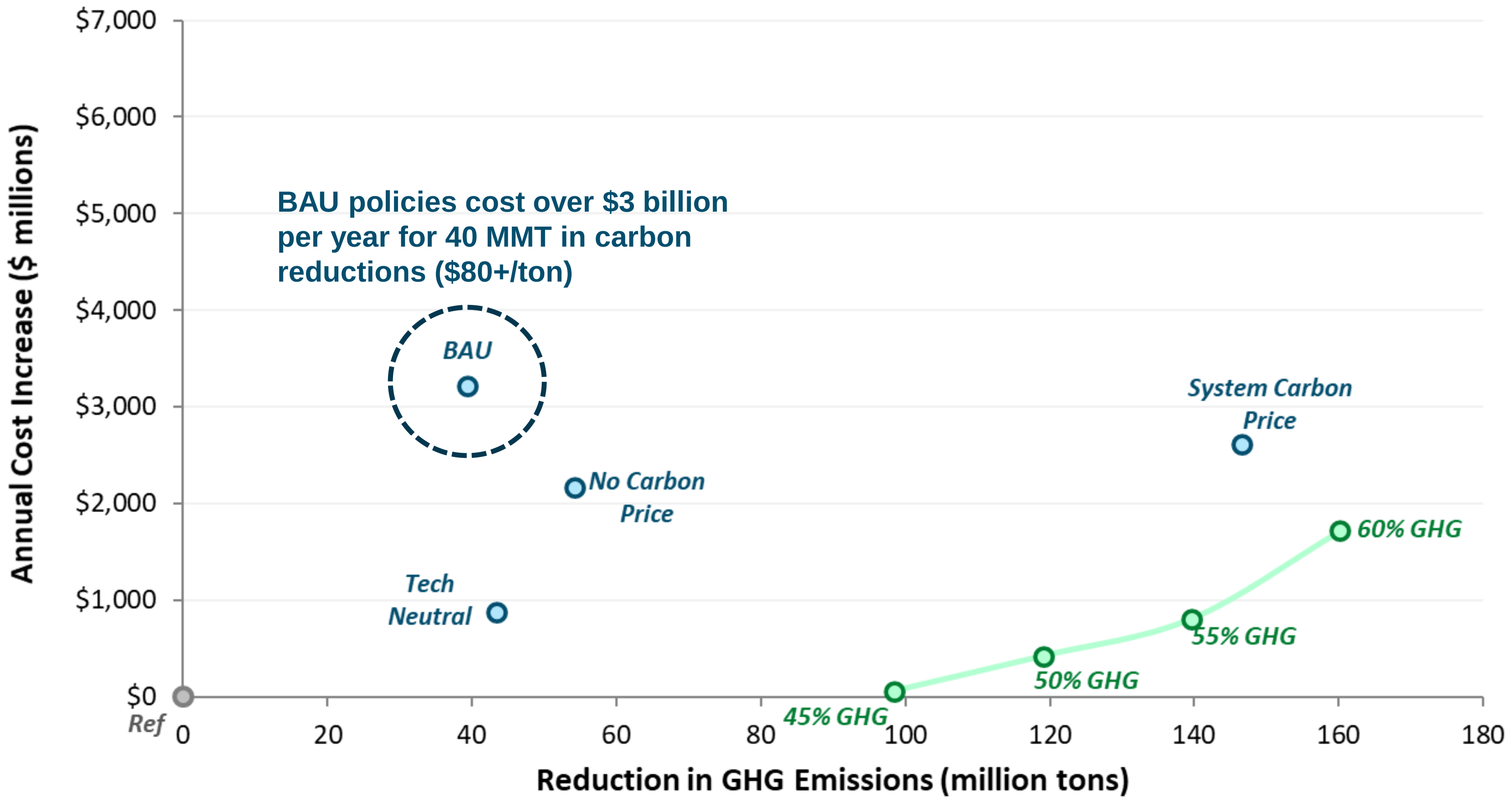


Energy Generation by Scenario in 2050



Policy scenarios show dramatic differences in cost effectiveness

Incremental Cost of Carbon Reductions Under 2030 Policy Scenarios



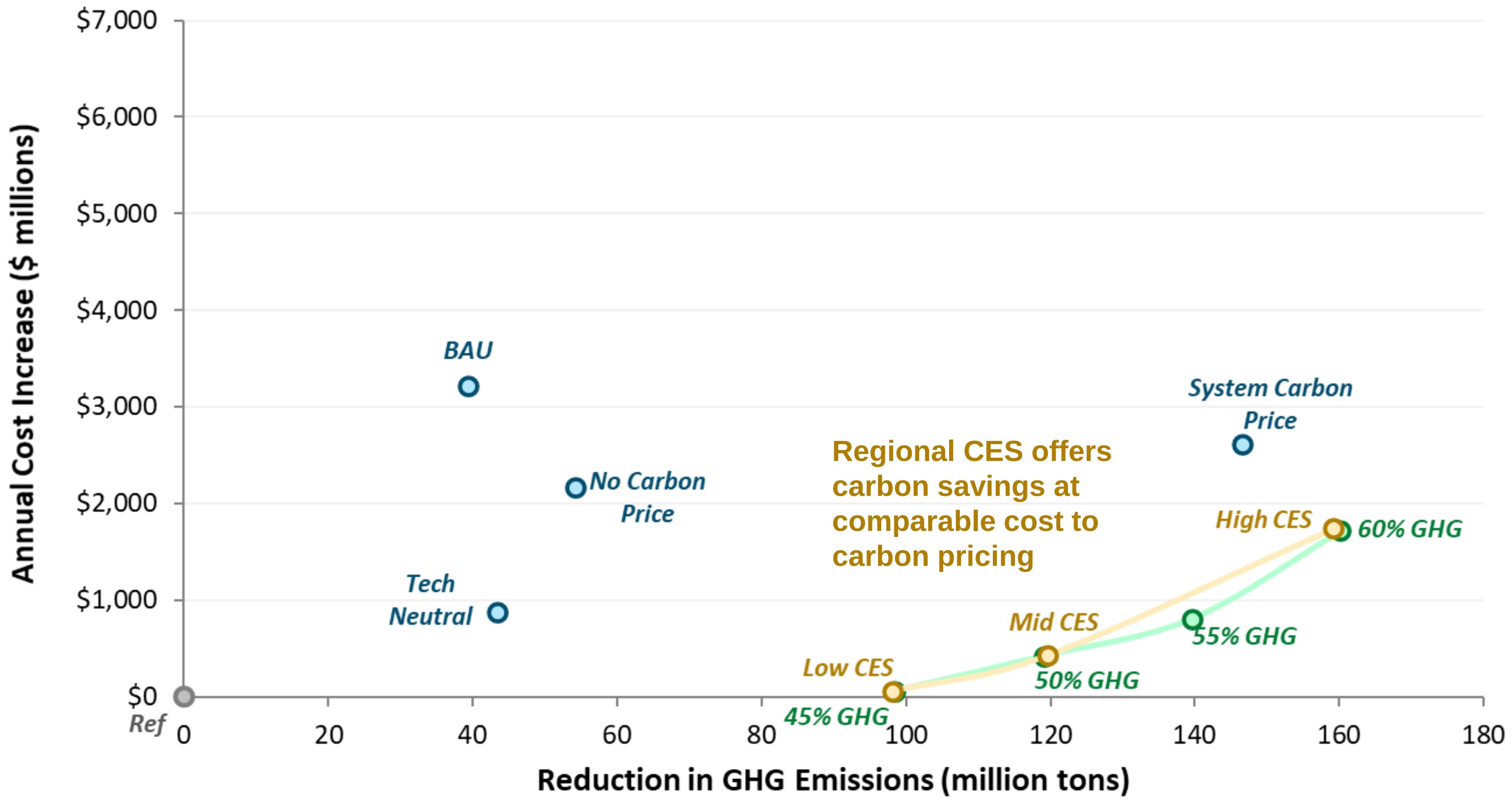
2-4% of total 2030 revenue requirement in PJM

Energy+Environmental Economics

CES and RPS Policy Scenarios

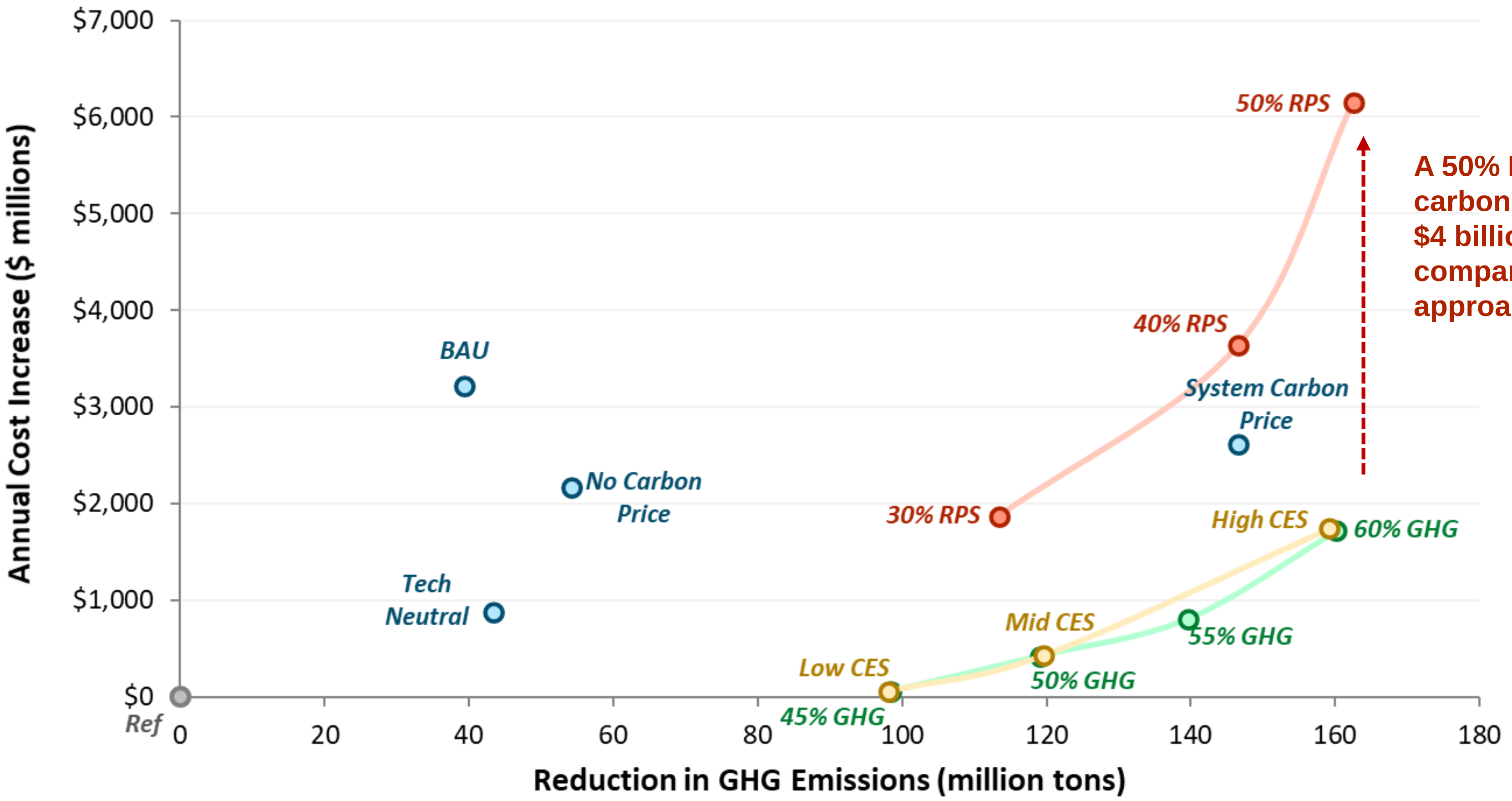
CES that credits nuclear and gas based on emissions intensity approaches cost effectiveness of carbon pricing

Incremental Cost of Carbon Reductions Under 2030 Policy Scenarios



RPS is significantly more costly approach to achieving comparable emissions reductions

Incremental Cost of Carbon Reductions Under 2030 Policy Scenarios

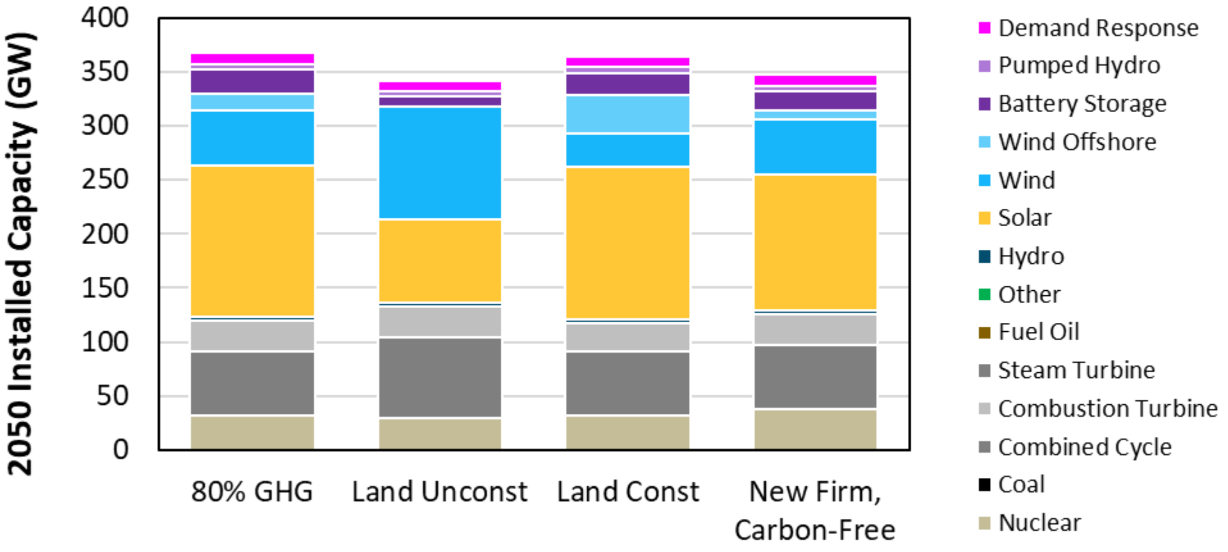


A 50% RPS could increase carbon reduction costs by $4 billion per year versus a comparable carbon pricing approach

Model sensitivities

Sensitivity to Land Use Constraints and Availability of Firm, Carbon-Free Generation

- **The 80% GHG scenario maxes out the onshore wind capacity in 2045**
- **Stricter land constraints drive up costs, as more expensive solar, storage, and offshore wind is built instead of onshore wind**
  - By 2050, over $2 billion per year in additional system costs if land is more constrained or $3.5 billion per year in lower system costs if land use is unconstrained
- **Firm, carbon-free generation like gas with 90% carbon capture and sequestration (CCS) or small modular nuclear (SMRs) would marginally reduce land use, need for renewables and storage**
- **Cost trends would be amplified in higher policy goals**



Land Availability

Base case:
4% farm land
2% forested land

Constrained:
2% farm land
1% forested land

Unconstrained:
No restrictions

Firm, Carbon-Free Generation

Base case:
No gas with CCS or new nuclear available

New Firm, Carbon-Free Available:
Gas with 90% CCS and SMRs available at declining costs reaching ~$65/MWh by 2050 in real 2018$

Firm, carbon-free energy plays larger role for GHG reductions approaching 100%

+ Allowing 90% capture CCS and new nuclear SMR is valuable in higher GHG target scenarios

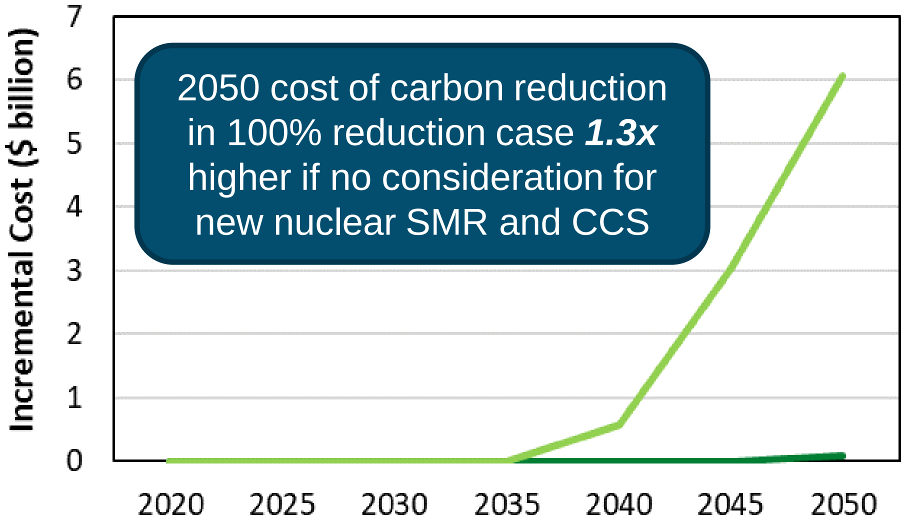
- Need for clean firm resources grows exponentially by 2050 as GHG reductions approach 80%-90%
- Retrofitting existing gas to gas + CCS may be more economic than new SMR

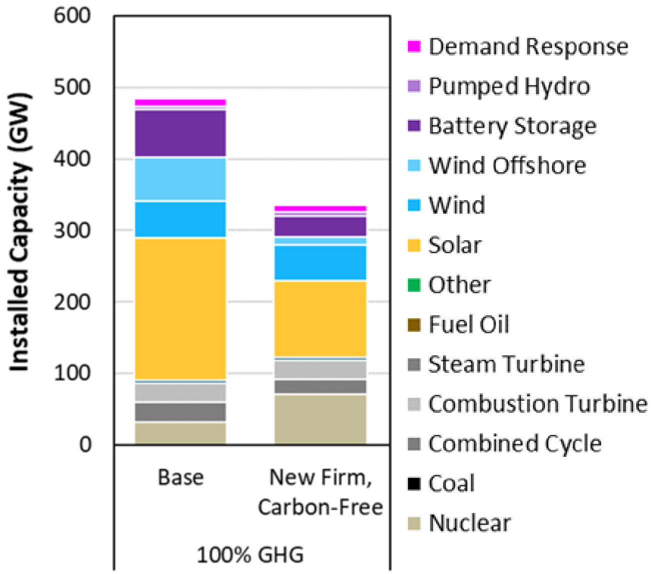
+ In 80% reduction case

- 5 GW new nuclear is built by 2050
- No new CCS is built by 2050 due to favorable SMR economics

+ In 100% reduction case

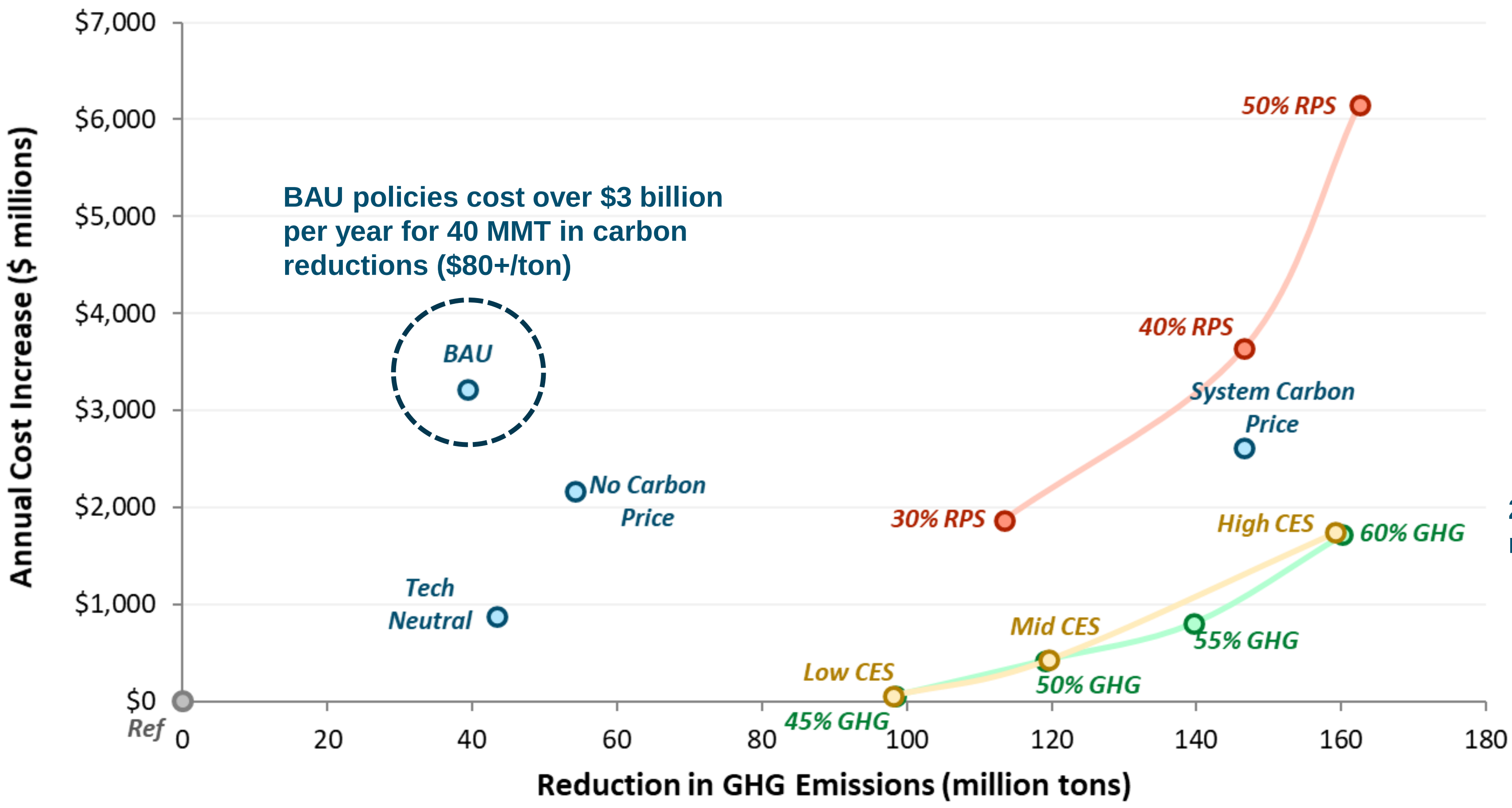
- 39 GW new nuclear is built by 2050
- No new CCS is built by 2050 due to favorable SMR economics





Policy scenarios show dramatic differences in cost effectiveness

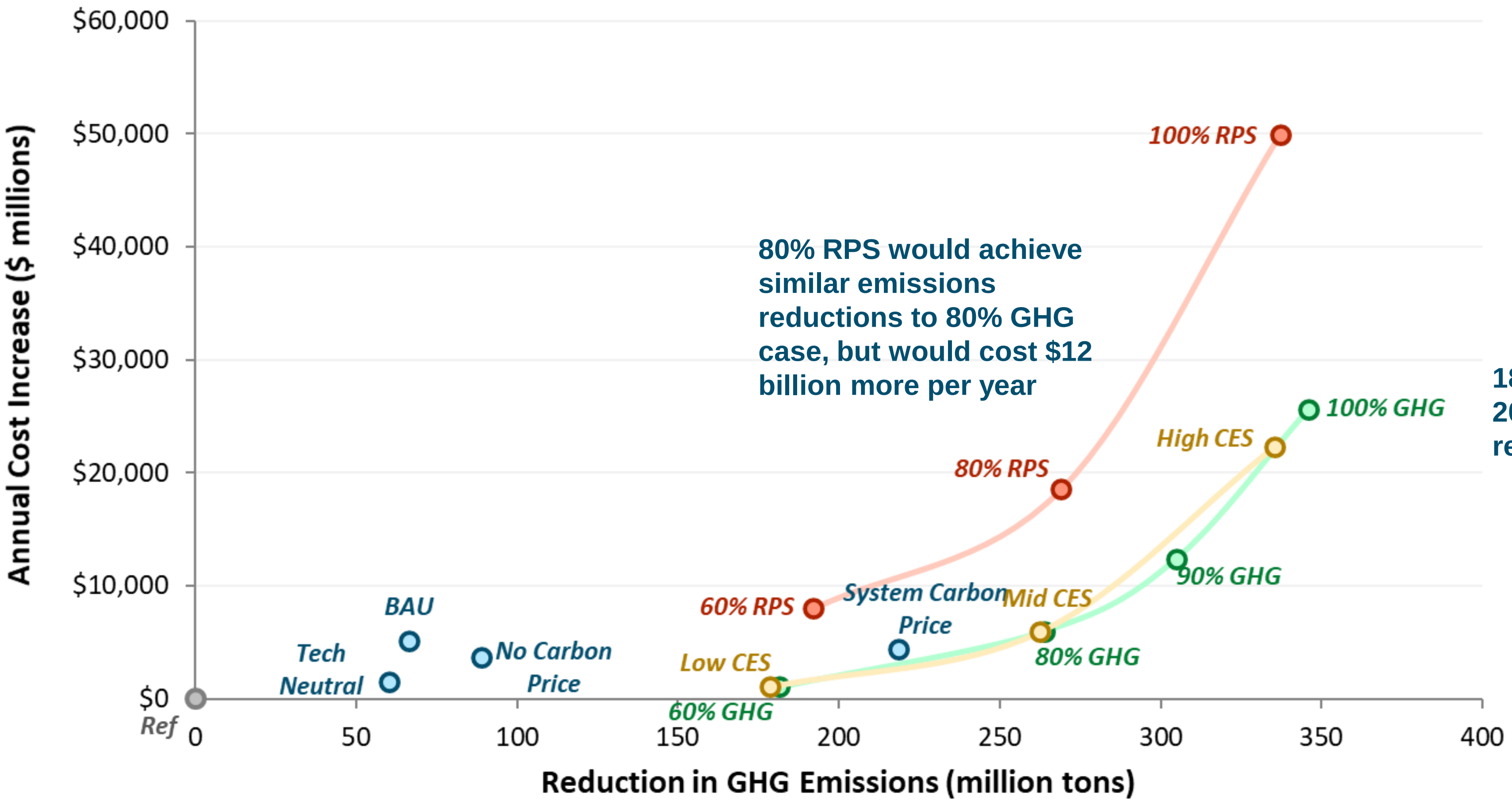
Incremental Cost of Carbon Reductions Under 2030 Policy Scenarios



2-4% of total 2030 revenue requirement in PJM

Policies continue to diverge in cost effectiveness at deeper levels of carbon reductions by 2050

Incremental Cost of Carbon Reductions Under 2050 Policy Scenarios



80% RPS would achieve similar emissions reductions to 80% GHG case, but would cost $12 billion more per year

18%-23% of total 2050 revenue requirement in PJM

Energy+Environmental Economics

Key Findings

Findings illustrate value of regional trading and limits to prescriptive state policy

Key findings

1) **Policies that regulate carbon directly result in the lowest-cost emissions reductions.**
   - Smart carbon policy can achieve significant emissions reductions at a very low cost in PJM.
   - Carbon pricing that does not apply to all generators in the PJM footprint has limited effectiveness due to the potential for resource shuffling.

2) **A regionwide, technology-neutral Clean Energy Standard (CES) approaches the efficiency of a direct carbon policy in achieving low-cost emissions reductions.**
   - Expanding the market's choices leads to lower cost outcomes.
   - However, market distortions created by CES policies would become more meaningful in the long run.

Findings illustrate value of regional trading and limits to prescriptive state policy

Key findings

3) **Renewable resources play a significant role in decarbonizing the PJM system in all scenarios.**
   - Restricting access to some renewable resources significantly increases the cost of achieving carbon reductions.

4) **Current clean energy policies are costly and ineffective at reducing carbon emissions.**

5) **Firm capacity is needed to provide reliable electric load service at each level of decarbonization.**
   - Retaining gas generation is a low-cost means of maintaining reliability on a deeply decarbonized system.
   - Reaching decarbonization targets approaching 100% levels will be cost-prohibitive without a source of clean firm generation, as costs otherwise increase exponentially beyond 80% reduction levels.

Energy+Environmental Economics

Thank you!

Arne Olson, Senior Partner arne@ethree.com

Sandy Hull, Director sandy@ethree.com