The Clean Power Plan: Understanding Conflicting Modeling Results

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"Essentially, all models are wrong, but some are useful".

-- George Edward Pelham Box

EPRI Clean Power Plan Analysis

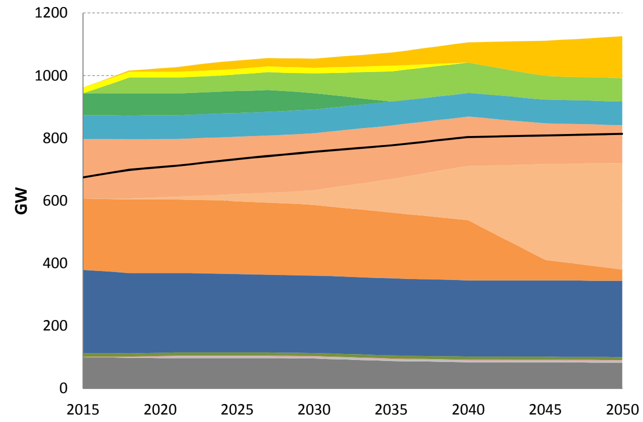
- Started over three years ago, before there was a Clean Power Plan, thanks to member foresight
- One year spent reconstructing the US-REGEN model to better capture CPP nuances
- Now working with over 30 utilities in EPRI Program 103 to study CPP insights and national outcomes
- Working with another 20 utilities in 8 states to help understand the implications of the CPP for a given state
- Part of the Stanford Energy Modeling Forum – an inter-model comparison exercise to compare models of the CPP

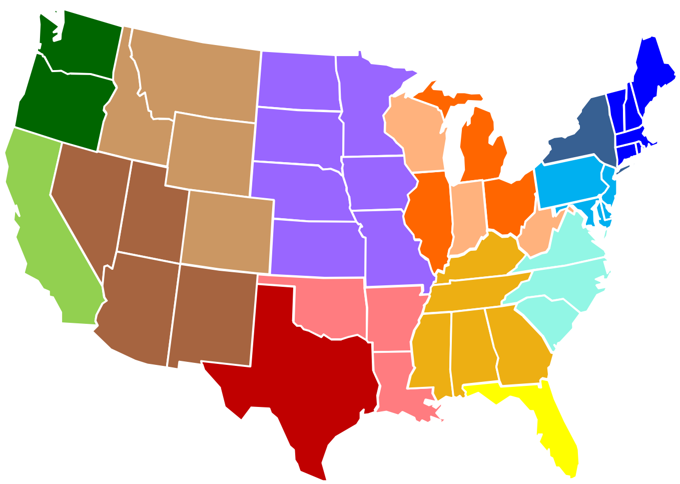
Outline

- The Reference Case
  – Every model has one or more reference cases. What metrics do you need to compare reference cases when looking ahead to the CPP?
- CPP Compliance Modeling:
  – Trading Assumptions
    - Types of trading and impact on CO_2/ERC prices
  – Capacity Modeling
    - Impact of exogenous/endogenous capacity modeling on CO_2/ERC prices
  – Intermittent Resource Assumptions and Modeling
- Conclusions
  – Recommendations for metrics to improve cross-model comparisons for state CPP modeling

US-REGEN 48 State Version:
EPRI's In-House Electric Sector Model

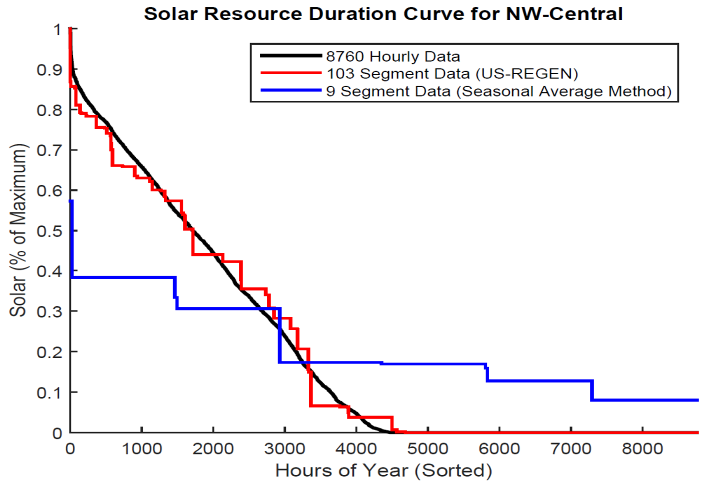
Capacity Expansion Economic Model, Long Horizon to 2050





State Level Resolution for Policy and Regulation Analysis

Innovative Algorithm to Capture Wind, Solar, & Load Correlations in a Long Horizon Model



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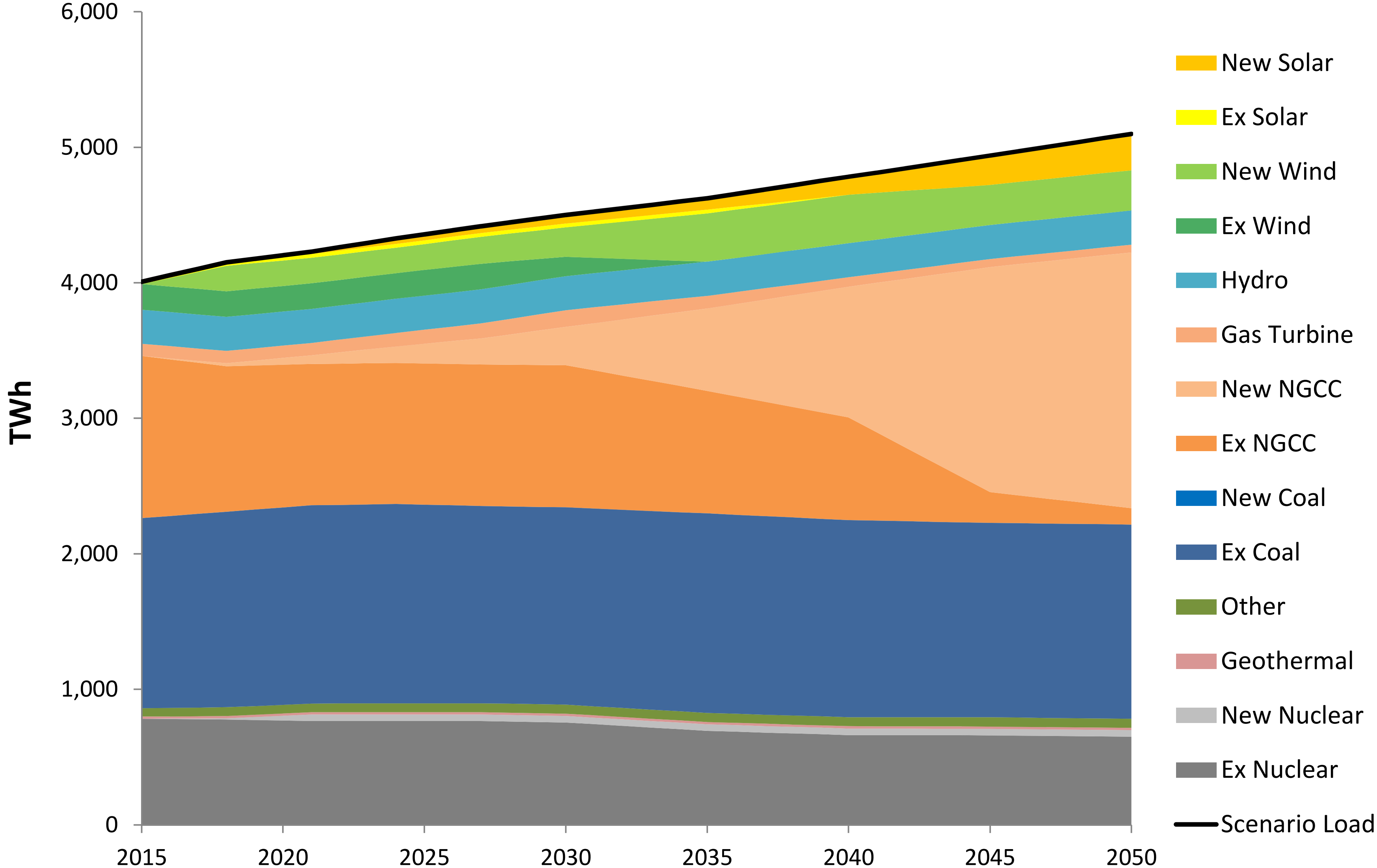
EPRI EEA Reference Case: U.S. Generation



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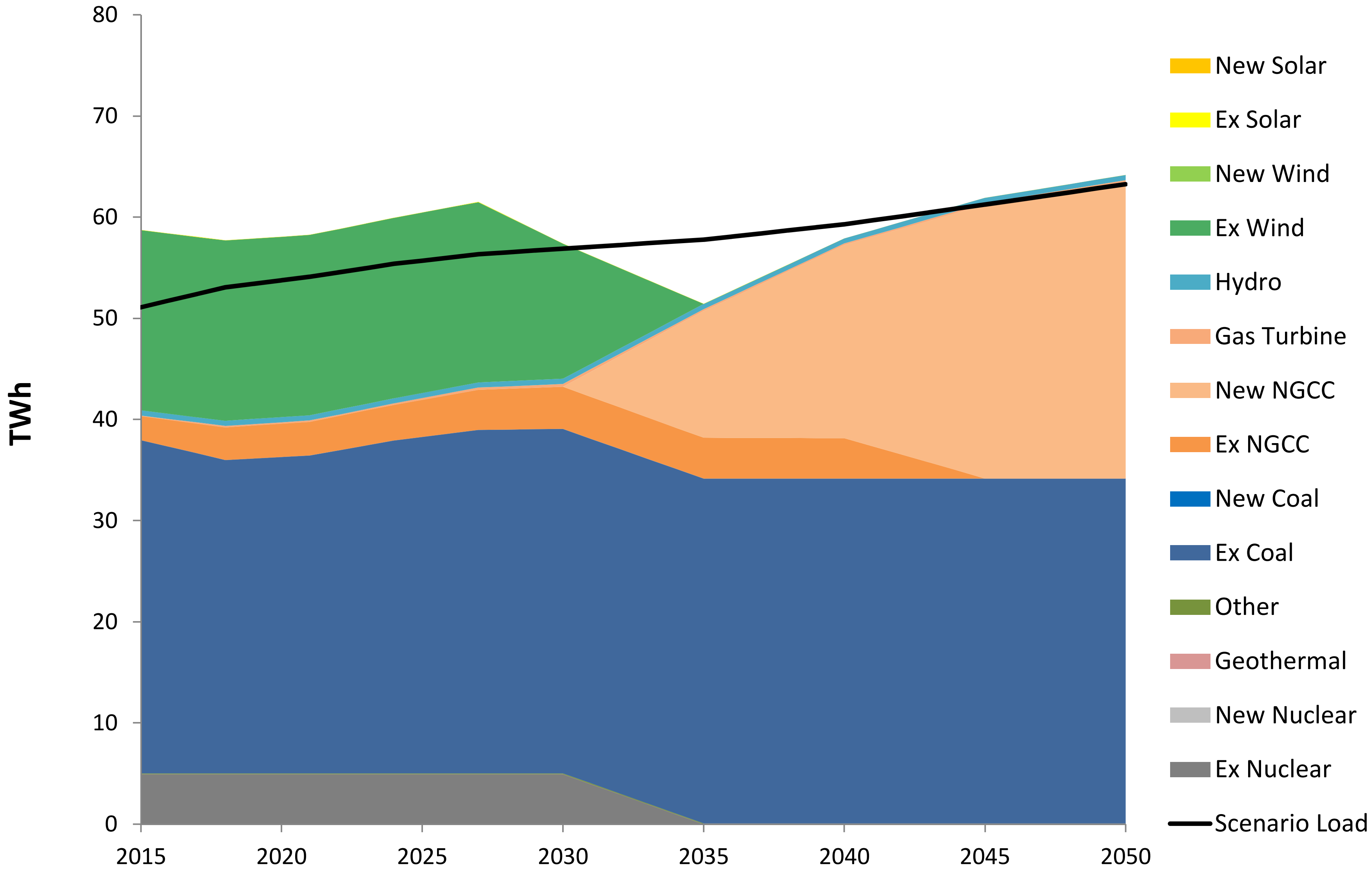
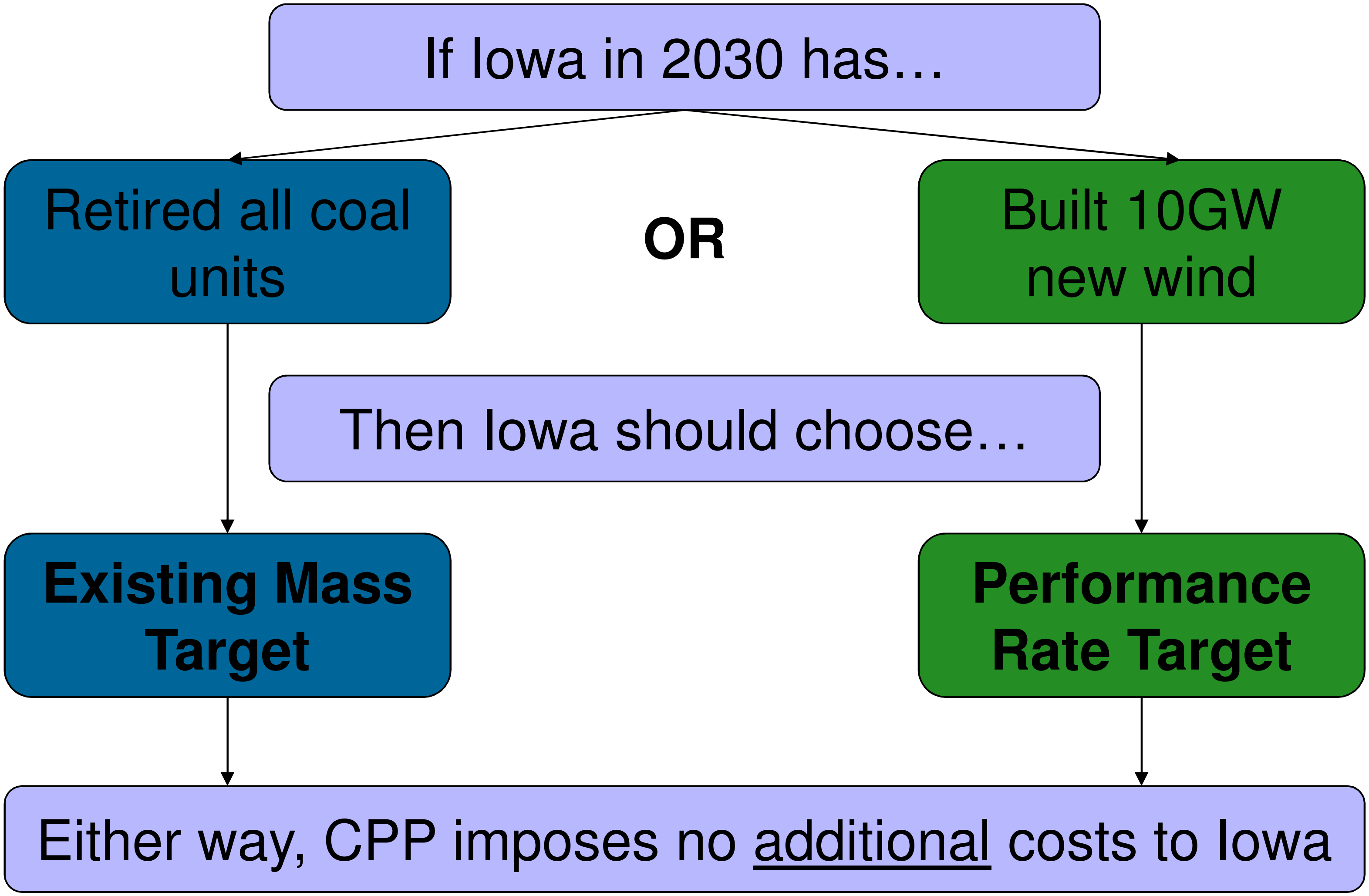
EPRI EEA Reference Case: Iowa Generation



The Reference Case

To Understand a Model's Preference for Rate or Mass, First Understand the Reference Case



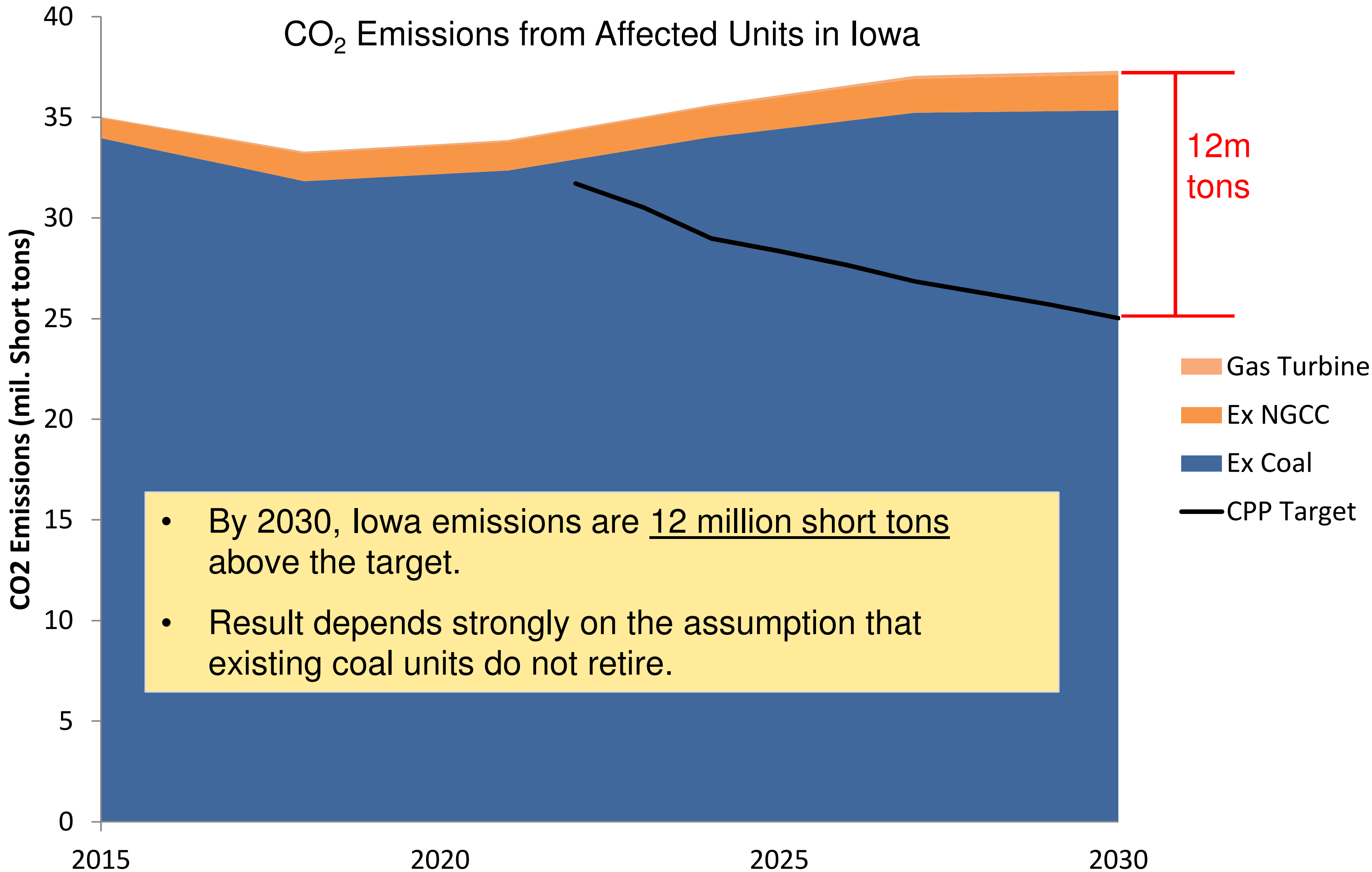
Many Assumptions Underlie A Reference Case. Which Do You Need To Know?

- Reference cases are based upon 1000s of assumptions
  - Fuel prices by unit, investment costs, O&M costs, heatrates by unit, model foresight, discount factor, load shape, wind shapes, solar shapes, new renewable resources by state, etc
- Which do you need to know to compare reference cases?

None of the above!

- All assumptions should be same for CPP scenarios as for the reference case (except for CPP targets)
- Critical measure is how close the reference case comes to rate or mass compliance (short tons or ERCs)
- Requires model <u>outputs</u> for comparison, not assumptions

Example: Iowa Existing Mass Compliance ‘Gap’ in the EEA Reference Case



- By 2030, Iowa emissions are 12 million short tons above the target.
- Result depends strongly on the assumption that existing coal units do not retire.

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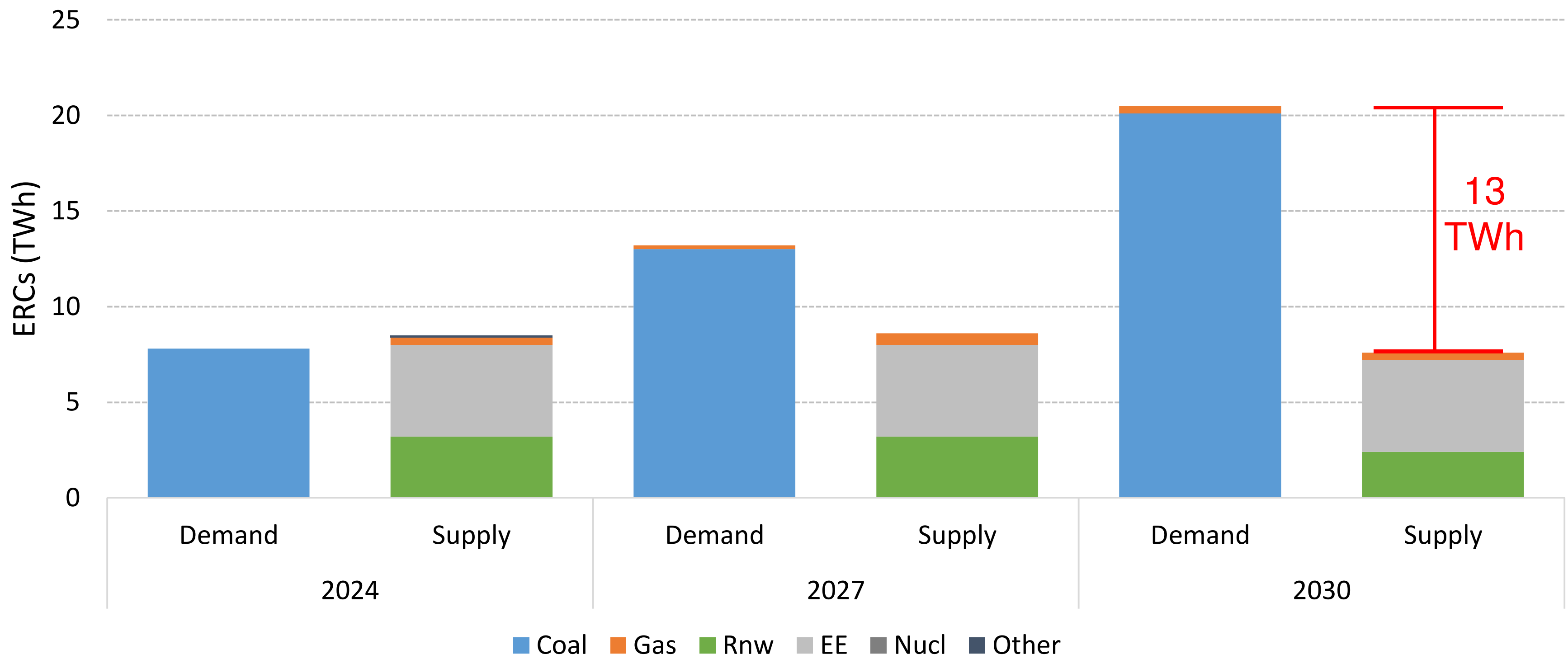
Example: Iowa Performance Rate Compliance 'Gap' in the EEA Reference Case



- Assuming CPP performance rate targets, at reference generation levels, Iowa's demand for ERCs exceeds supply by 13 million MWh.
- Result depends strongly on the assumption that existing coal units do not retire, and on the model result that no new wind is built in Iowa after 2015.

Two Metrics That Define Reference Case CPP Stringency

- These two graphics can be constructed from a small subset of model output data
  - Generation by technology (incl. EE) (TWh)
  - Retirements by technology vs. 2015 (GW)
  - New additions by technology (incl. uprates) vs. 2015 (GW)
  - CO_2 emissions by technology (million short tons)
  - Net load after net imports (TWh)
- Provides a single metric for mass and rate compliance, to compare model starting points
- For Iowa, charts show that the future of the coal fleet and new ERC sources (wind/solar/EE) are key parameters in determining how close Iowa is to CPP compliance
  - Suggests that these are good starting points for sensitivity analysis

Conclusions

- Any model of the electric sector starts from a reference case
- Choice of reference case assumptions can strongly influence whether a state would prefer rate or mass, on a variety of metrics
- Key metrics to compare model reference cases are
  - Million short tons over/under CPP mass target
  - TWh ERCs short/long from in-state sources for CPP rate target
- These can be computed from a short list of output data
- Underlying assumptions are secondary, as they should be the same for reference and CPP compliance scenarios
  -  Big red flag for modeling if they’re not

CPP Compliance Modeling

Modeling Assumptions Matter for CPP Compliance

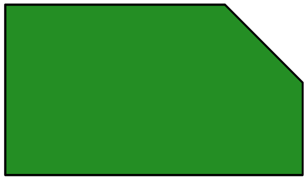
- Modeling assumptions matter for CPP compliance
- Inherent complexity of the CPP implies no model will capture all the nuances, and the scenarios won't cover all the possible outcomes
  - 48 states, trading or not trading, rate vs. mass?
  - Output based subsidies?
  - ERCs from mass-based states with a PPA to a rate-based state?
  - CEIP?
- Very possible to have one model find rate is preferable for a state, and another find mass is preferable for the same state, even if they have identical reference case metrics
  - E.g. If one model only considers in-state resources for CPP compliance, and the other assumes nation-wide trading

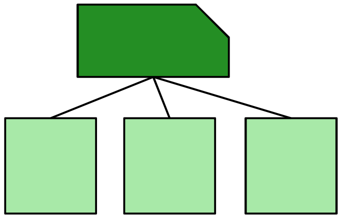
Is The ERC/CO_2 Price a Useful Metric?

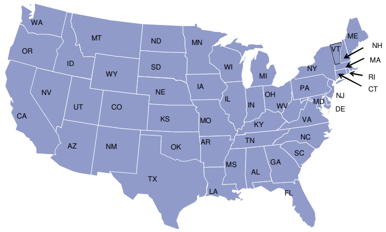
- CO_2/ERC price is defined as the marginal cost of abating 1 short ton of CO_2 or adding 1 MWh of ERCs
- *Within a model*, the higher the price, the more expensive the mitigation options
- *Between models*, price comparisons often invalid, because price depends strongly on model assumptions
  - Reference case assumptions – how far off CPP target?
  - Trading assumptions
    - Can state load/imports/exports change for CPP compliance?
    - Out-of-state trading for ERCs or CO_2?
  - Capacity assumptions
    - Endogenous new investments or retirements for CPP compliance?
  - State resource assumptions
    - Renewable/EE resource/cost assumptions by state

Trading Assumptions

Key Comparison: Trading Assumptions







Can power flows change as part of CPP compliance?	NO	YES	YES
Can states buy/sell CO_2/ERCs into a national market?	NO	NO	YES

‘Island’

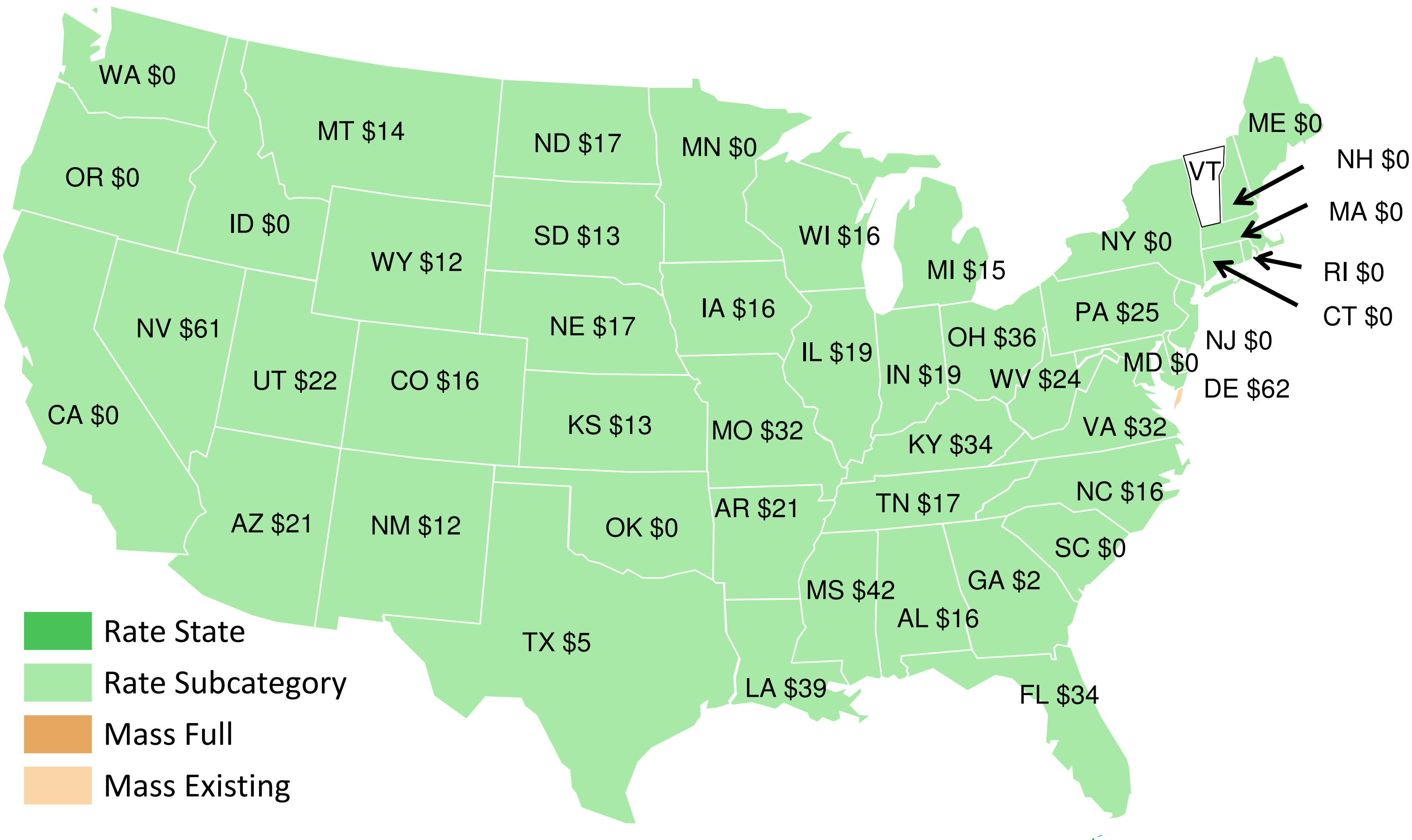
‘Power’

‘National’

Key Assumption: Degree of Trading

- For some states, reducing exports of coal generation is a low cost compliance mechanism
  - Strong incentive to do this when compliance costs exceed returns from power sales
  - Leaves the importing states to make up the load from other sources
- National or regional markets for ERCs or CO_2 are a potential 'backstop' for CPP compliance
  - Size and depth is subject to a lot of uncertainty

US-REGEN Reference Case: Island Rate Compliance



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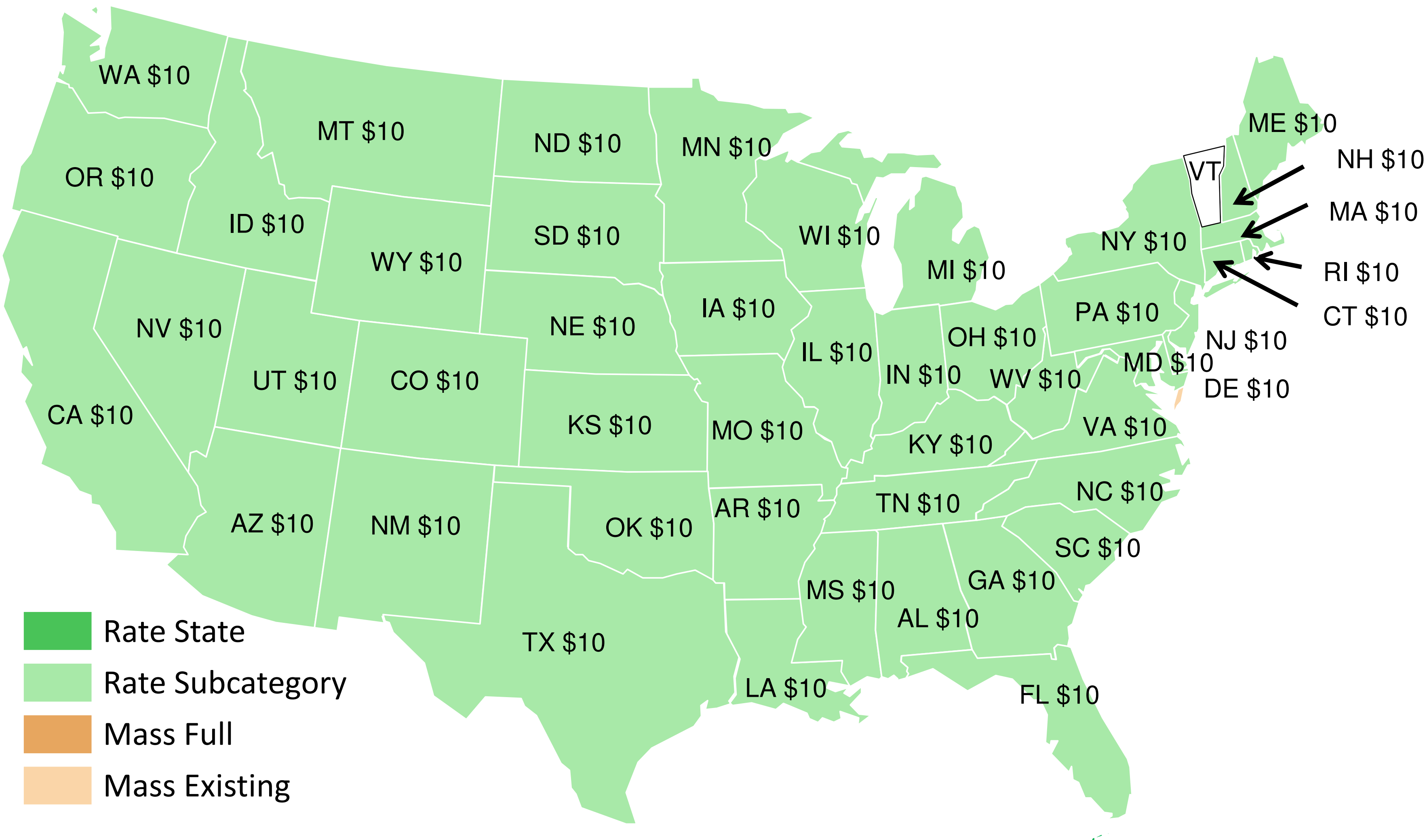
US-REGEN Reference Case: National Rate Compliance



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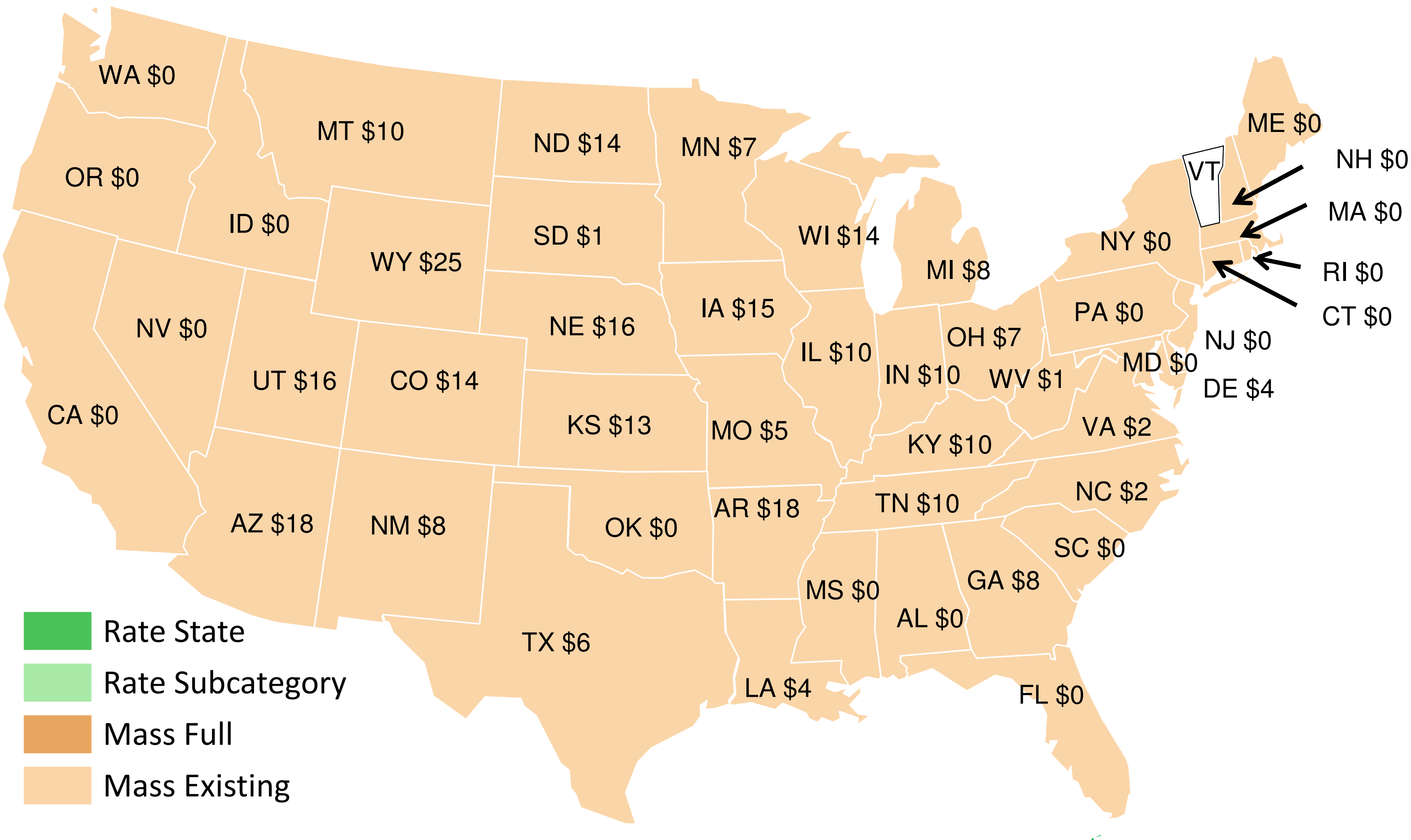
US-REGEN Reference Case: Island Mass Compliance



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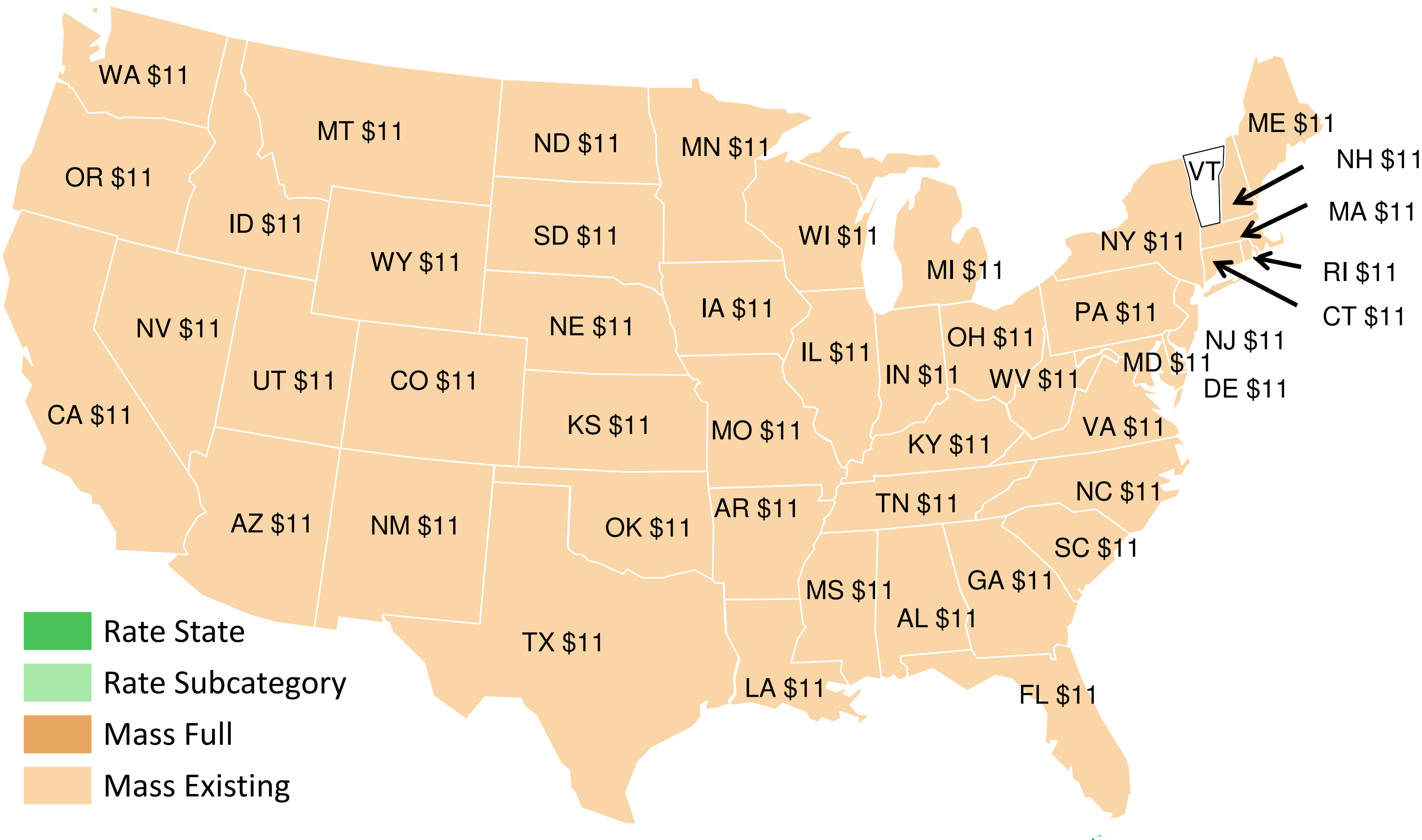
US-REGEN Reference Case: National Mass Compliance



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Observations

- CO_2 or ERC prices are a very common modeling metric to gauge the stringency of CPP compliance
- Trading assumptions can make a big difference to CO_2/ERC prices
- Many state models consider only the 'Island' case
- Ideally, modeling would consider both 'Island' and 'National' results, also 'mixed compliance' results where some states choose mass and some choose rate
  - Island results help to understand a state's local resources for CPP compliance
  - National results help to understand incentives to trade and how that impacts the rate/mass choice

Capacity Modeling

Key Comparison: Capacity Modeling

- Modeling of new capacity additions could be
  - Exogenously specified by modeler
  - Endogenously determined by model in response to complementary policies (CO_2 tax, RPS standard)
  - Endogenously determined by model in response to CPP targets
- Capacity assumptions impact the CO_2/ERC price in two ways
  - Exogenously specified capacity limits the number of mitigation options the model can deploy, which means the CO_2/ERC price is only determined by re-dispatching generation, not by capacity additions
  - Exogenously specified capacity pathways may not find the least cost path to meeting a CPP target, which could increase the CO_2/ERC price

Example: Iowa Chooses Performance Rate

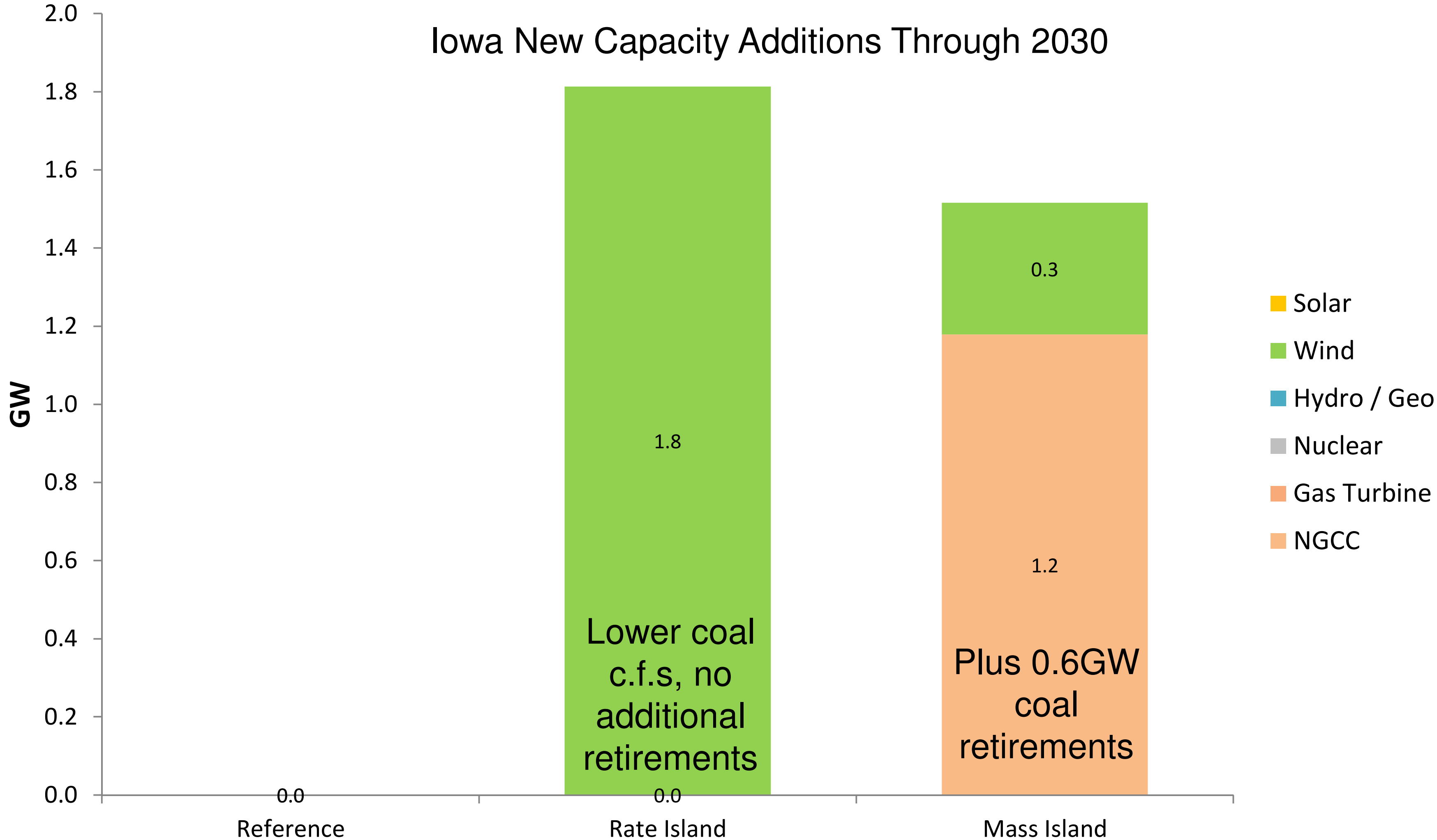
If Iowa in 2030 is short 1 TWh of ERCs…
(Assume NGCC units maxed out)

Dispatch less coal, more NGGTs	Build new wind farm in advance
$60/MWh	**$20/MWh**

Marginal cost (i.e. ERC price) is…

A third path is to overbuild new wind, resulting in over-supply of ERCs, and the ERC price collapses to zero. Compliance options greatly impact the price.

Example of Endogenous Capacity Investment: Iowa Island CPP Compliance in US-REGEN



New capacity additions are a key component of Iowa CPP compliance without trading.

CO_2/ERC Price Heavily Influenced By Capacity Modeling

- Production cost or other dispatch only models inherently have limited compliance options for rate or mass
  - Re-dispatch coal to NGCCs, NGGTs, or increase net imports
  - If assumed ERC creating capacity is low, marginal price for compliance will be very high
  - If assumed ERC creating capacity is high, marginal price will collapse to zero
- Capacity expansion models have more compliance options
  - Ability to build ERC creating capacity in advance to perfectly meet the target, will usually be a cheaper option that running NGGTs
  - Risk of under-estimating the price if model has perfect foresight
- New additions are a useful alternative metric for comparing model solutions

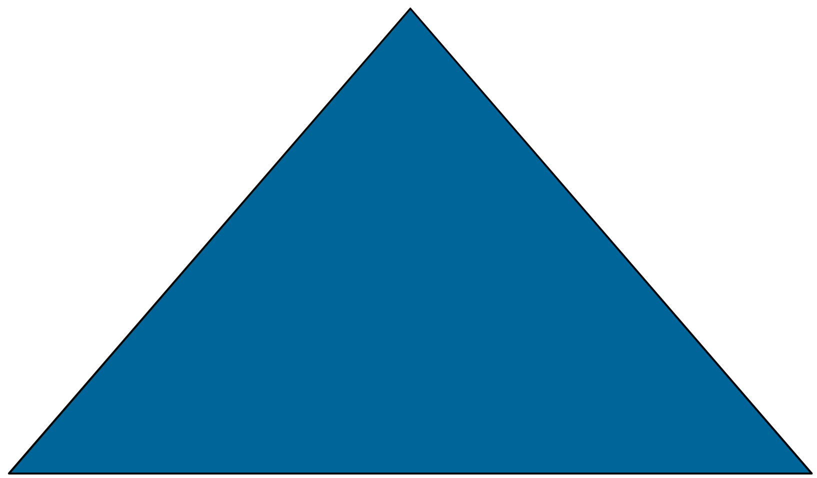
Intermittent Resource Assumptions and Modeling

Intermittent Resource Assumptions and Modeling

- Wind, solar, and EE resource are very important as a source of ERCs for rate compliance
- Where models differ in deployment of these, worth going back to these metrics to compare
  - Capital cost of new wind/solar
  - Capacity factor of new wind/solar
  - Model chronology – hourly ——> annual?
  - How is EE modeled? Endogenous? Exogenous? What is the cost per MWh? Can the model select the mix of EE/wind/solar to use?
- These are second order assumptions that shouldn't make as big a difference to the ERC price, but help to understand the mix of resources a model uses to meet rate targets

Conclusions

Key Model Features to Understand When Comparing Models



Recommendations for Common Model Outputs (1)

Output	Purpose
Additions/Retirements by Year (GW)	Shows new capacity required, and difference from the reference case
In-state ERC supply/demand (MWh)	Shows how rate-based compliance is reached – what mix of technologies the model is supposing
CO_2 emissions from existing coal, existing NGCCs	Shows how mass-based compliance is reached
Net electricity imports (TWh/yr)	Helps to understand the incentives of exporting states to continue exporting after adding on the costs of CPP compliance
Net ERC/CO_2 imports (/yr)	Understand a state's compliance costs relative to other rate/mass states respectively.

Recommendations for Common Model Outputs (2)

Output	Purpose
New transmission (inter-state/intra-state)	Combined with new renewable investments, helps to understand the investments for rate compliance
Capacity factors by technology by year	Gives insight into the role of fossil under the CPP, especially if a model doesn't or can't retire units. Helps to compare renewable resource assumptions.
+ How does the model choose capacity?	Help understand what compliance options the model can use

Note:

No cost measures included above. Cost measures are heavily influenced by the structure of the model equations, and are influenced by many model assumptions. More intuitive to understand and compare 'quantity' outputs first, then costs later.

Conclusions

- Modelers always look to tell a good story, but stories can be contradictory
- Not easy to compare all models, but more insightful to compare quantity outputs (GW, MWh, short tons) first, before dollar outputs (price, cost)
- Always ask to see the reference case outputs – what would Iowa do if the CPP didn't exist?
- All models are wrong, but some are useful: multiple models are usually better than one if you understand the drivers behind the differing results

Together…Shaping the Future of Electricity

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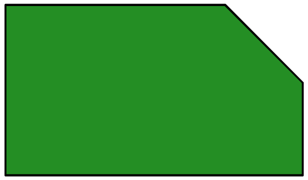
Example of an EPRI State Clean Power Plan Analysis

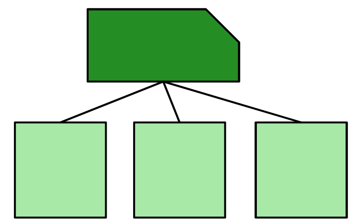


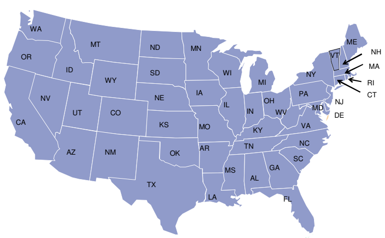
Step 1

Deep dive into the state's compliance options and resources without trading. Work with participants to fine tune state input data.

Step 2

Consider neighboring states' choices and how that might affect local power flows, and thus CPP choices for State X.



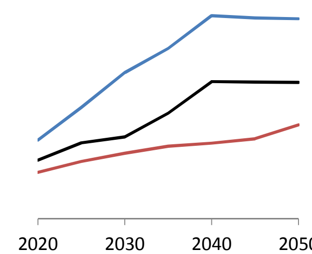


Step 3

Look at potential demand and supply for ERCs or CO_2 across the U.S., and how trading could impact CPP choices for State X

Step 4

Analyze key sensitivities that could change the cost of different CPP pathways in State X.



Each state is unique, and the analysis is tailored accordingly, through an iterative process with participants