State-Level Modeling of CPP Compliance Pathways with EPRI's US-REGEN Model

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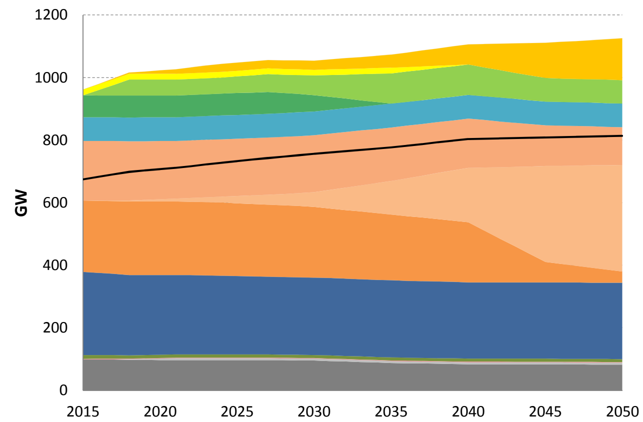
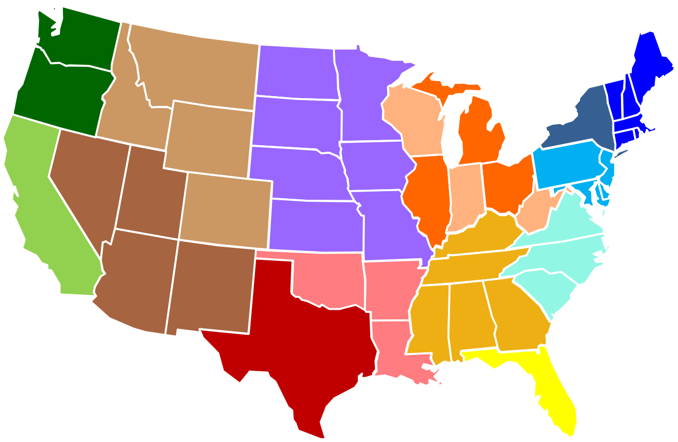
EPRI Clean Power Plan Analysis

- 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

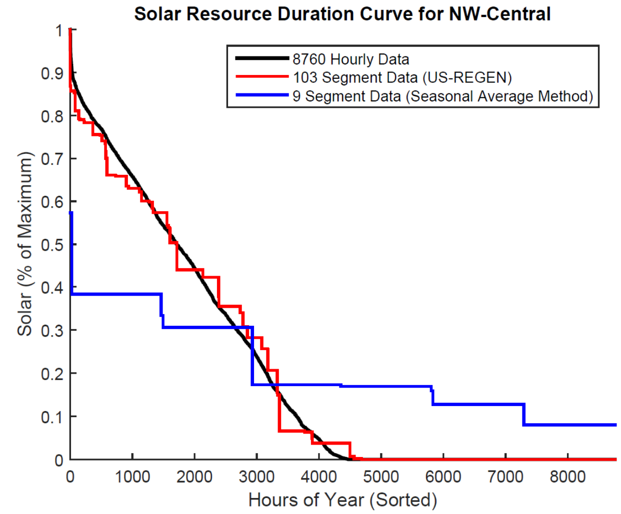
US-REGEN 48-State Version: EPRI's In-House Electric Sector Model for CPP Modeling

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

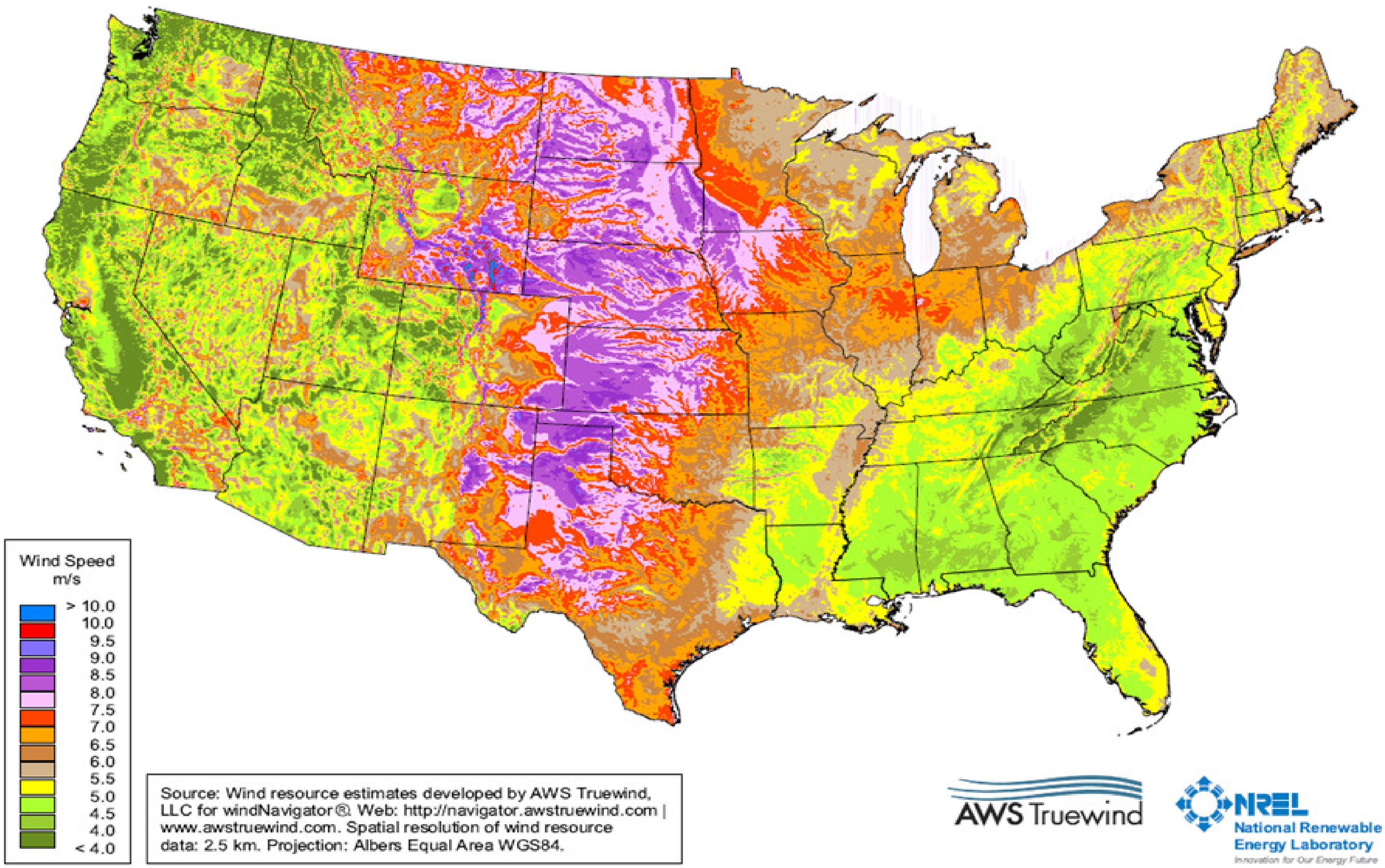
Electric Model: Key Features

- Endogenously builds/retrofits/retires capacity in each model time period according to the economics
  – Coal (+ retrofit to gas, biomass, CCS, co-firing, heatrate improvements), Gas NGCCs, Gas Combustion Turbines, Nuclear, Hydro, Geothermal, Wind (Onshore, Offshore), Solar (CSP, PV, Rooftop PV), Diesel/Oil, Coal/Gas with CCS, new biomass
- Endogenously builds inter-state transmission if needed and economic
- We select representative hours to capture load-wind-solar correlations across the year
  – i.e. US-REGEN knows when load is high and there's no wind!
- Based on a dataset of every unit in the country
  – Last updated November 2015

Renewable Resource Data

- Wind resource data from AWS Truepower
  - Based on 2010 meteorology
- Solar resource data from AWS Truepower
  - Separate resource for central station PV/CSP versus rooftop solar
  - Based on 2010 meteorology
- Geothermal resource data based on NREL (2009) estimates for the Western states
  - New potential additions of ~40GW by 2050 (8GW in CA)
  - Assume capacity factor improves from 50% to 80% due to technical progress

Location of Wind Resource by State



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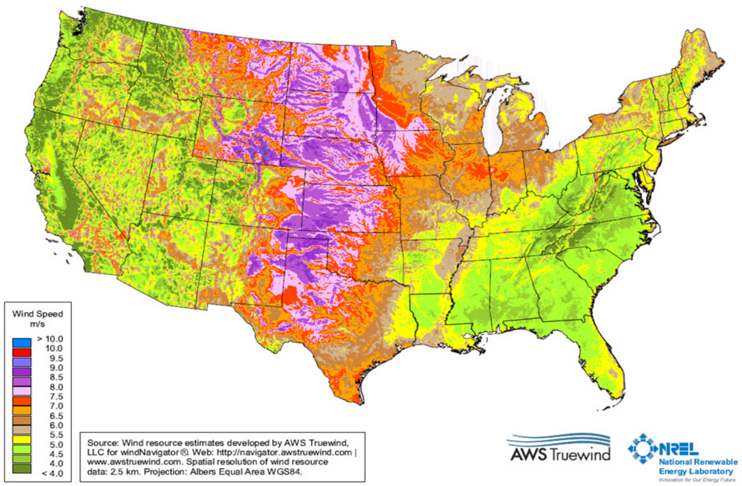
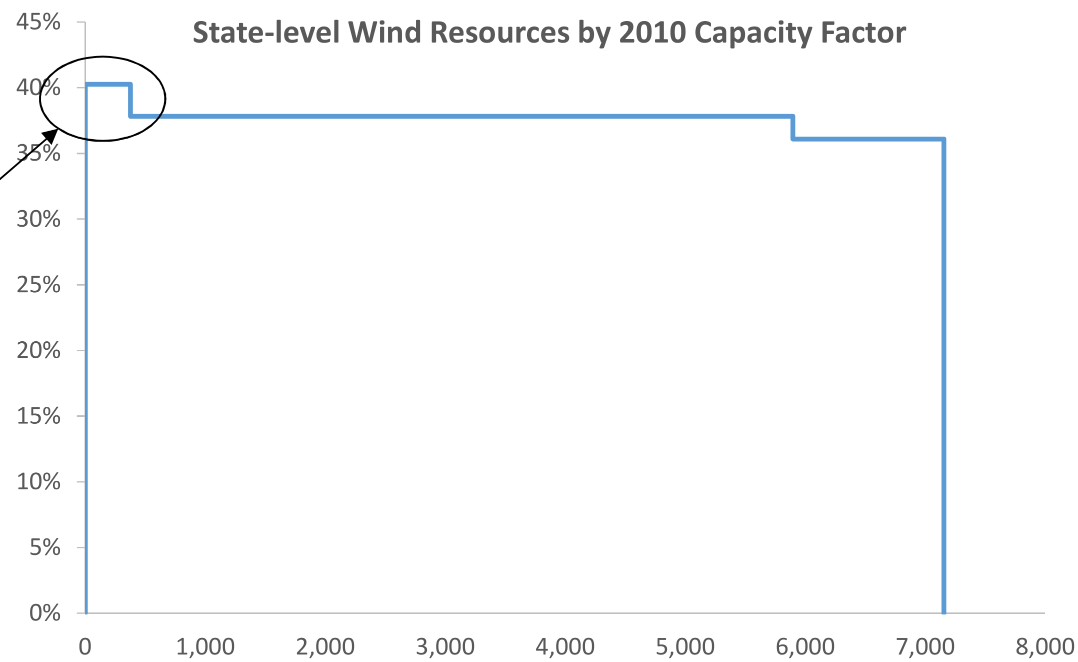
Location of Wind Resources by State

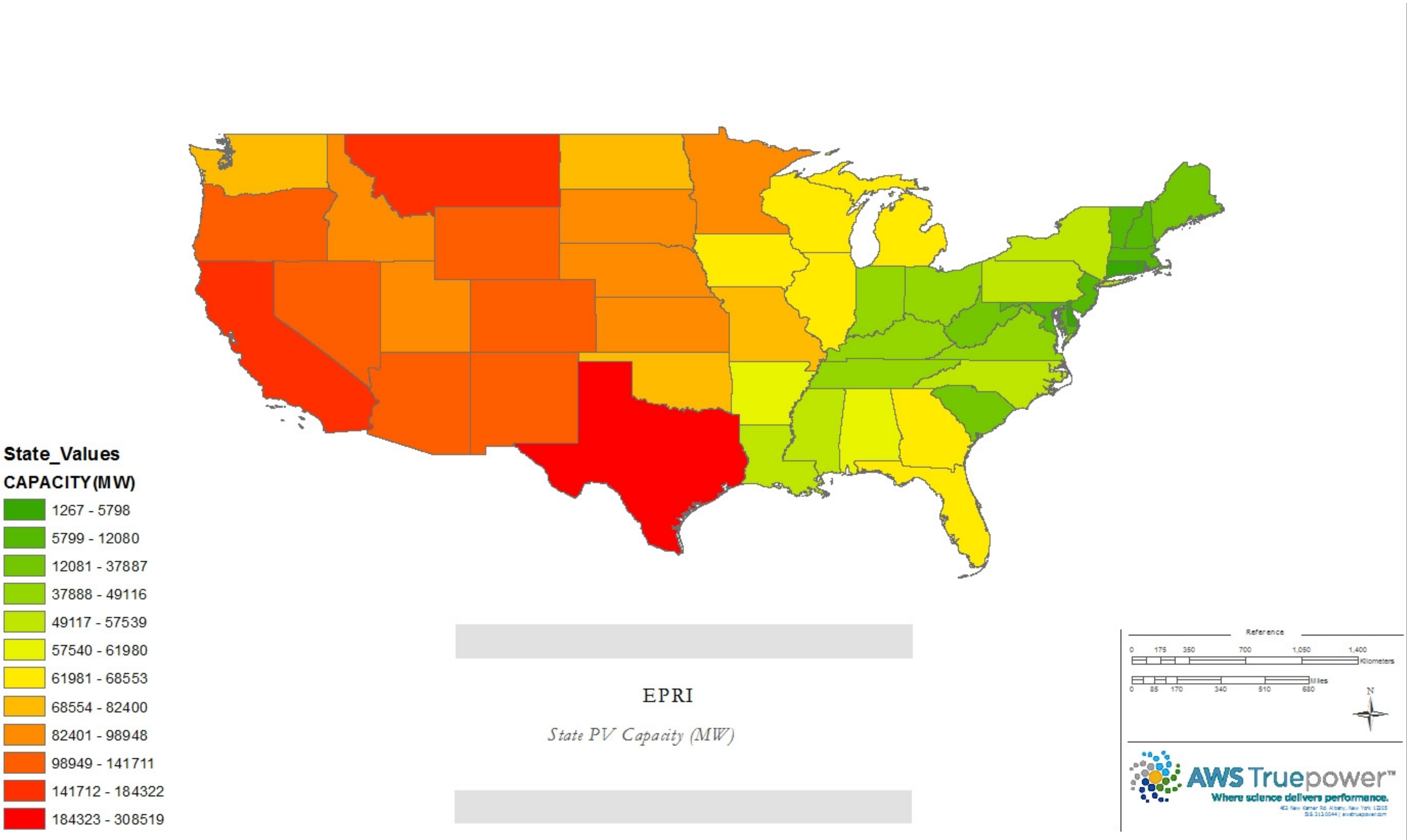


State-Level Wind Resource Base

Less than 400 MW > 40% CF



Location of Central PV Resource by State

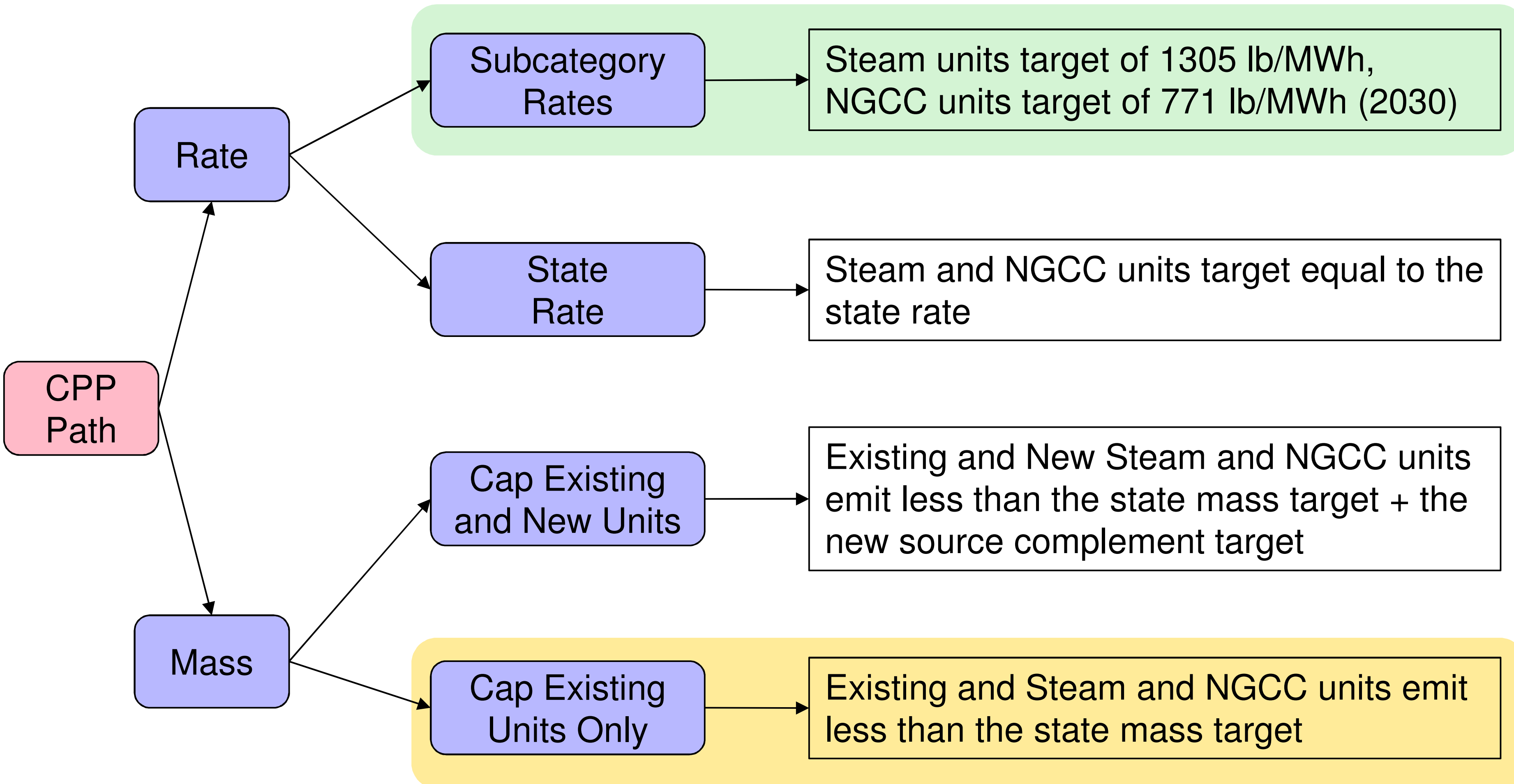


* Assumes the use of up to 1% of each state's available land

US-REGEN vs IPM (used by EPA for CPP design, RIAs)

- US-REGEN and IPM are both based on the same modeling paradigm
  - Full information, inter-temporal optimization
- Compared to IPM, US-REGEN
  - Uses 48 state-based regions vs IPM's 60+ regions across state lines
  - Aggregates units more, but uses ~ 6 times as many representative hours to capture renewable intermittency better
  - Uses model years 2015, 2018, 2021, 2024, 2027, 2030, 2035, 2040, 2045, 2050; IPM uses 2016, 2018, 2020, 2025, 2030, 2040, 2050
- All models of this type have the same computational limitations; modelers must make tradeoffs as to what elements are important to represent the policy at hand

US-REGEN Models Four Main Compliance Pathways



Specific Features for Modeling the Clean Power Plan

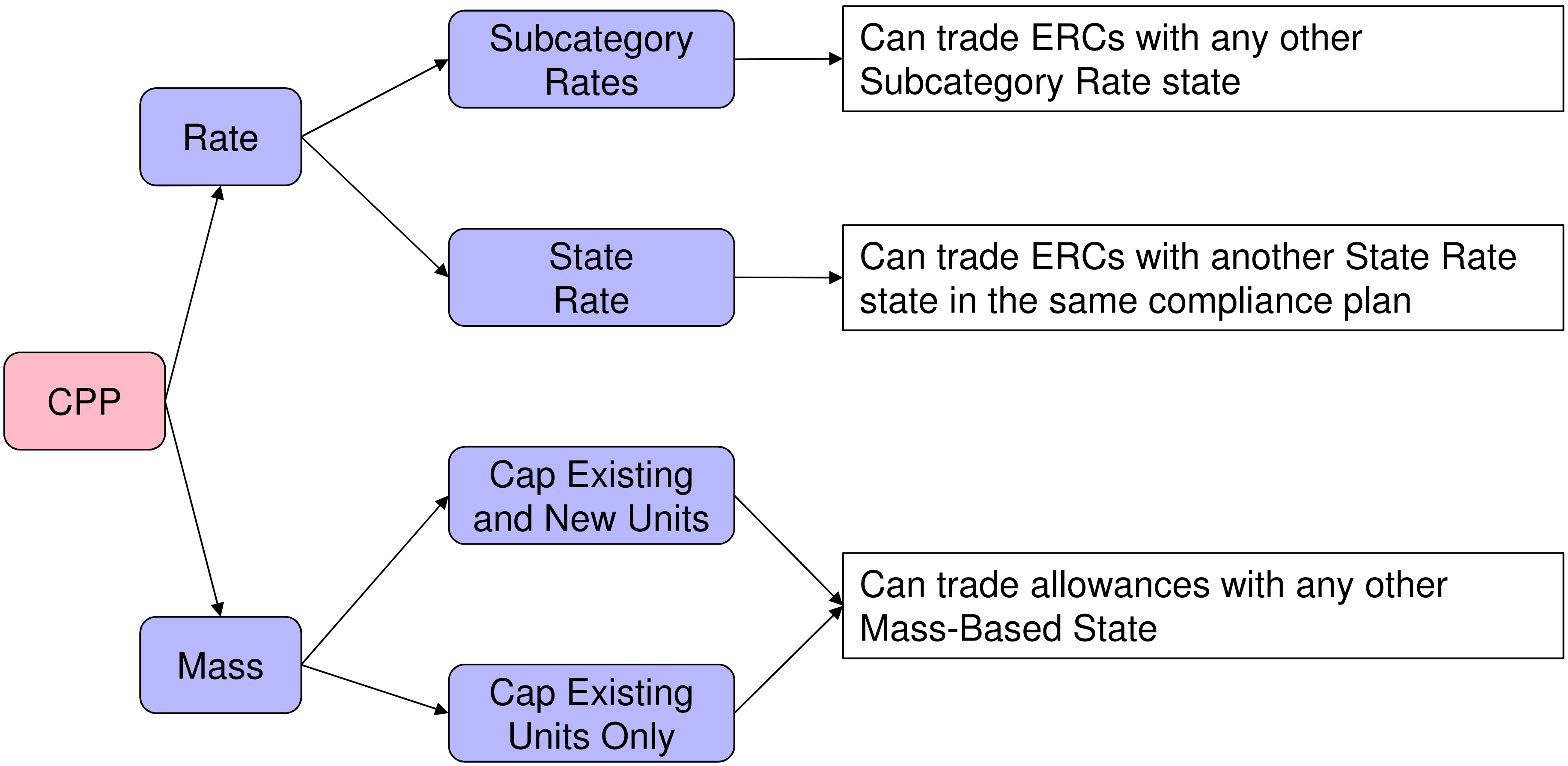
- Detailed representation of ERC sources by type
  - Zero, Fossil, Gas-Shift
- Inclusion of output-based set-asides for Existing Mass path
- Endogenous energy efficiency
  - US-REGEN can endogenously build energy efficiency (that counts towards CPP compliance)
  - Currently using EPA CPP proposal costs, could revisit
- Detailed renewable representation
  - US-REGEN was built from scratch to give a very detailed representation of wind and solar, and their intermittency
- Other options for coal
  - Co-firing, conversion to biomass or gas, CCS retrofits

Types of ERCs that State X can Create

	Z-ERC	F-ERC	GS-ERC
Description	Created by new zero CO_2 measures such as RE/EE/NUC/T&D. 1 ERC per MWh.	Created by affected EGUs over-complying vs. target rate.	Created by existing NGCCs generating more than their 2012 baseline, per EPA formula
Geographic Restrictions	Can be created by State X for measures taken in **any other rate-based state***	Can be created by State X by over-complying existing EGUs located in State X.	Can be created by State X by existing NGCCs only in State X and ONLY if State X does Subcategory Rate
Usage Restrictions	Can only be used in State X unless inter-state trading allowed	Can only be used in State X unless inter-state trading allowed	Can only be used by steam units in State X [unless inter-state trading allowed???]

* May also be created by *new renewable generation* in mass-based states, Canada, or Mexico, <u>provided the power from the units is sold to any rate-based state</u>.

Compliance Pathway Determines Trading Partners



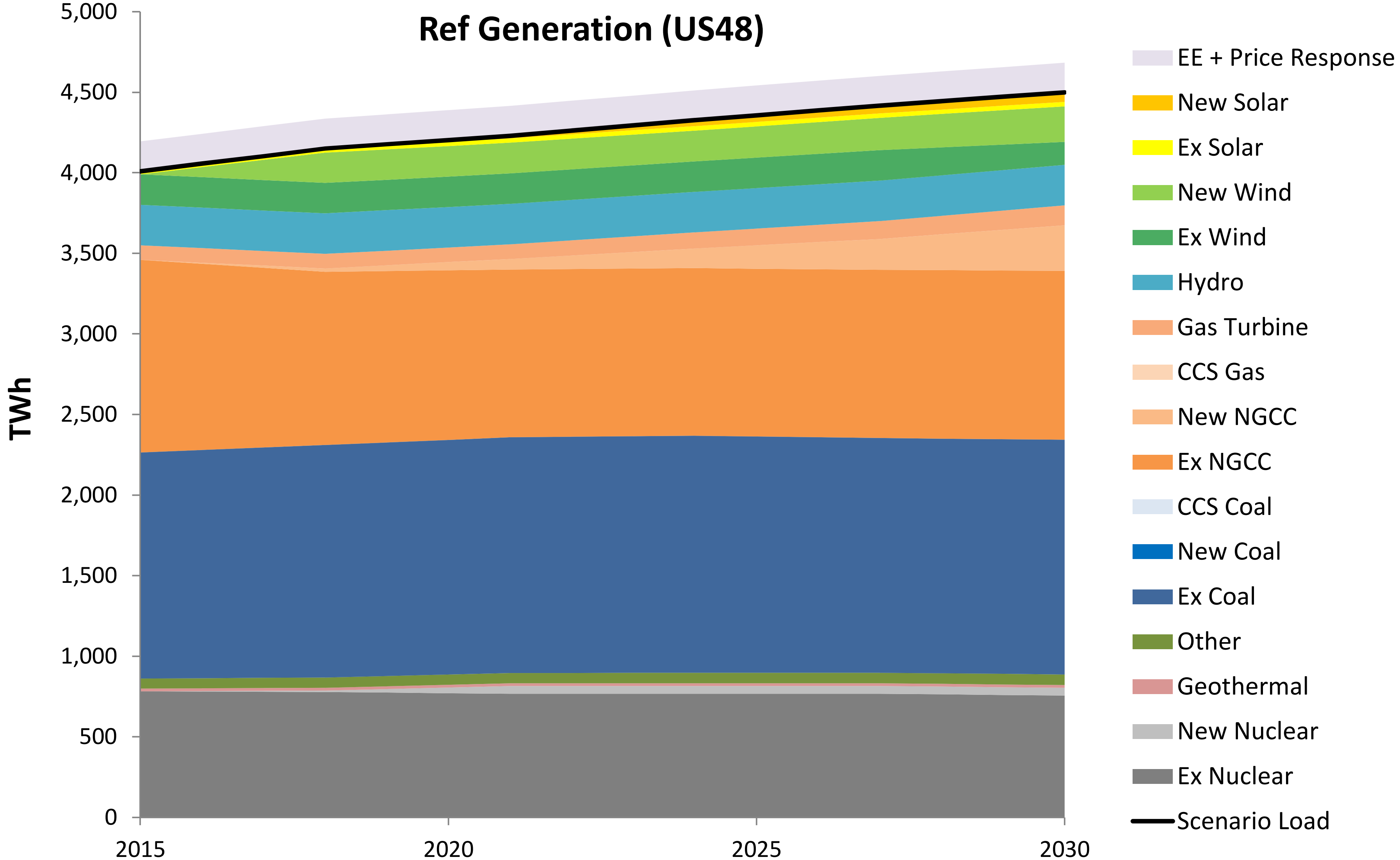
Caveats for Following Model Results

- All analyses preliminary
  - CPP highly complex, still testing our modeling
- Models are highly aggregated simulations but not reality
- No constraints on gas delivery
- Not forecasting
- Choices for states intended to show consequences of alternative pathways in a heterogeneous world, not speaking to what pathways states may choose
- Many uncertainties not explored here
  - Cost of EE and RE
  - Possible future additional CO_2 policy/regulation
  - Ability to deploy added transmission

“Essentially, all models are wrong, but some are useful”.

-- George Edward Pelham Box

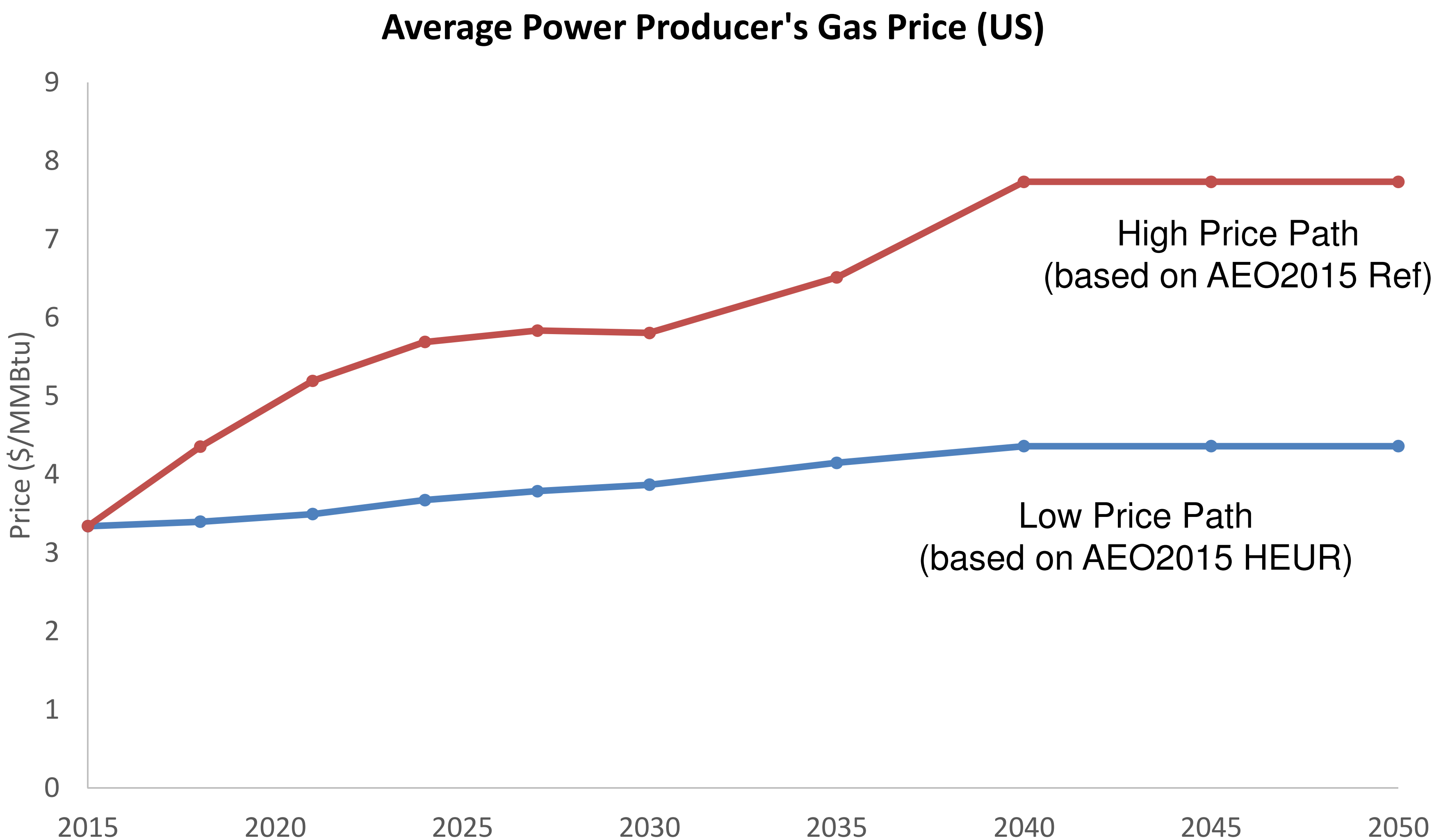
Reference Scenario Provides Point of Reference but is Not a Forecast



Island Results

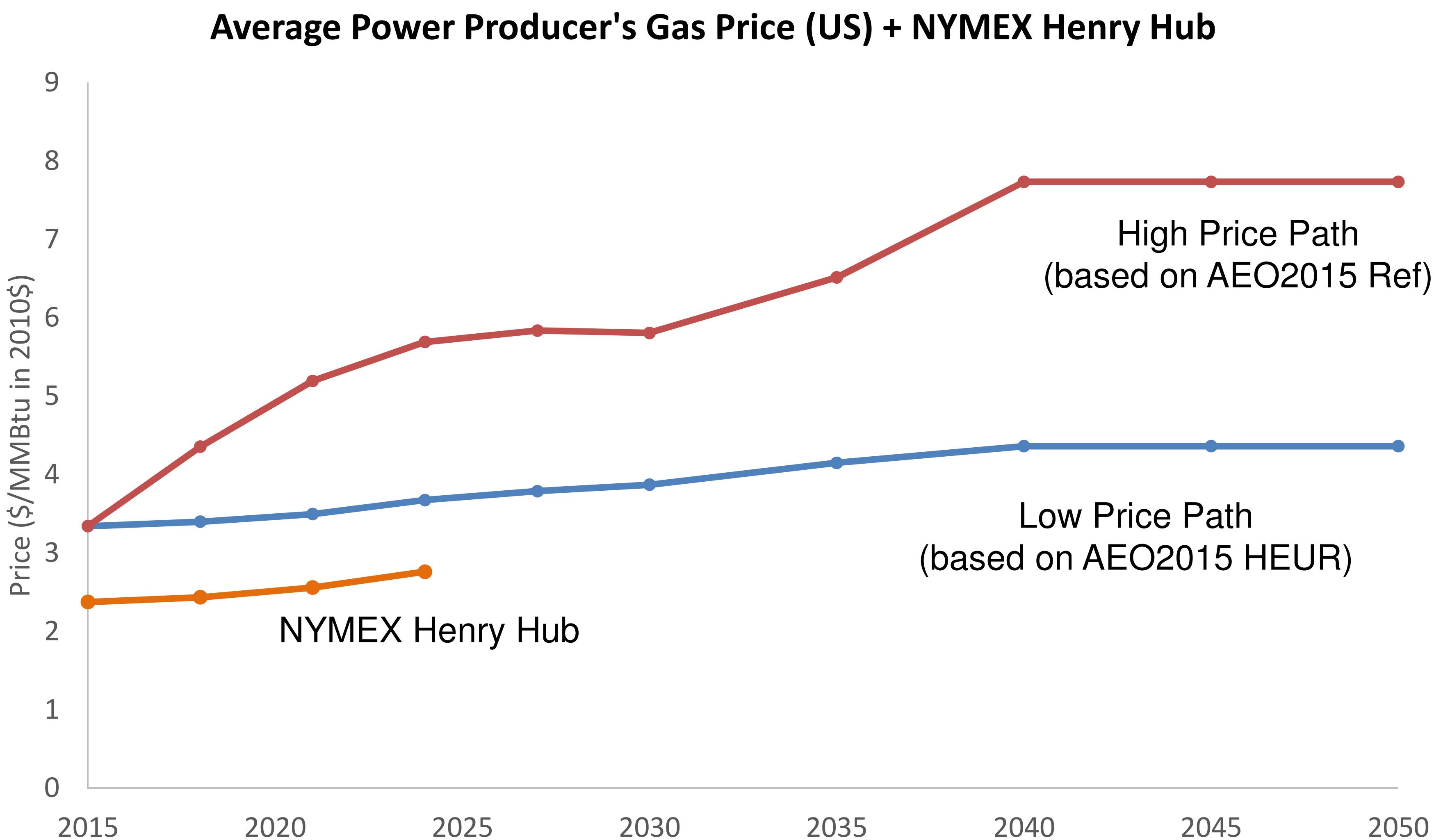
Each state must comply relying solely on resources within its own boundary; power flows limited to levels in reference case

Natural Gas Price Uncertainty Represented with EIA's Annual Energy Outlook 2015 "High" and "Low" Paths



Source: U.S. Energy Information Administration's Annual Energy Outlook for 2015

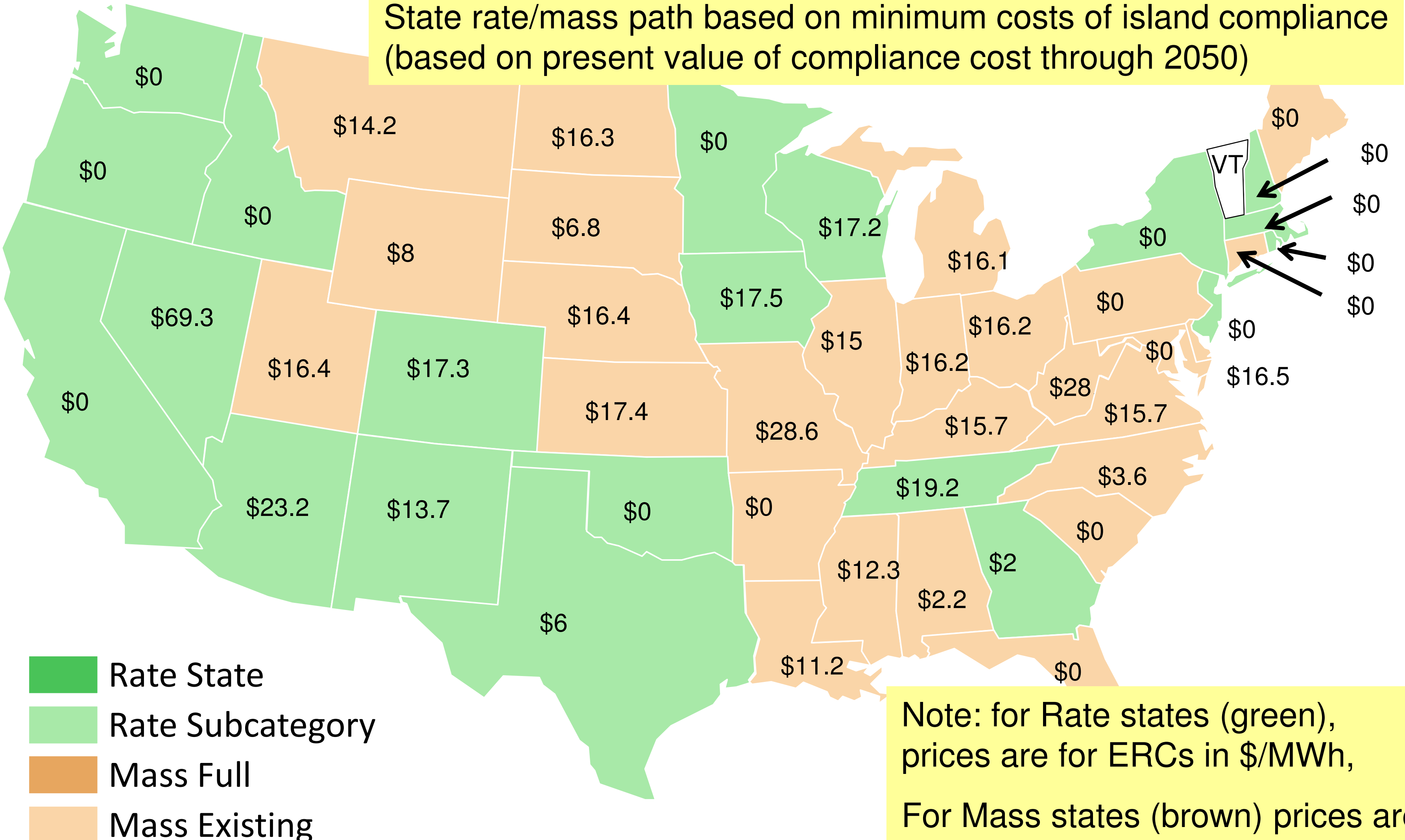
Natural Gas Price Uncertainty Represented with EIA's Annual Energy Outlook 2015 "High" and "Low" Paths



Source: U.S. Energy Information Administration's Annual Energy Outlook for 2015

Emission Rate Credit (ERC)/Allowance Prices for 2030 with Full Island Compliance (Low gas price path)

State rate/mass path based on minimum costs of island compliance (based on present value of compliance cost through 2050)



Note: for Rate states (green), prices are for ERCs in $/MWh,

For Mass states (brown) prices are for Allowances in $/metric ton

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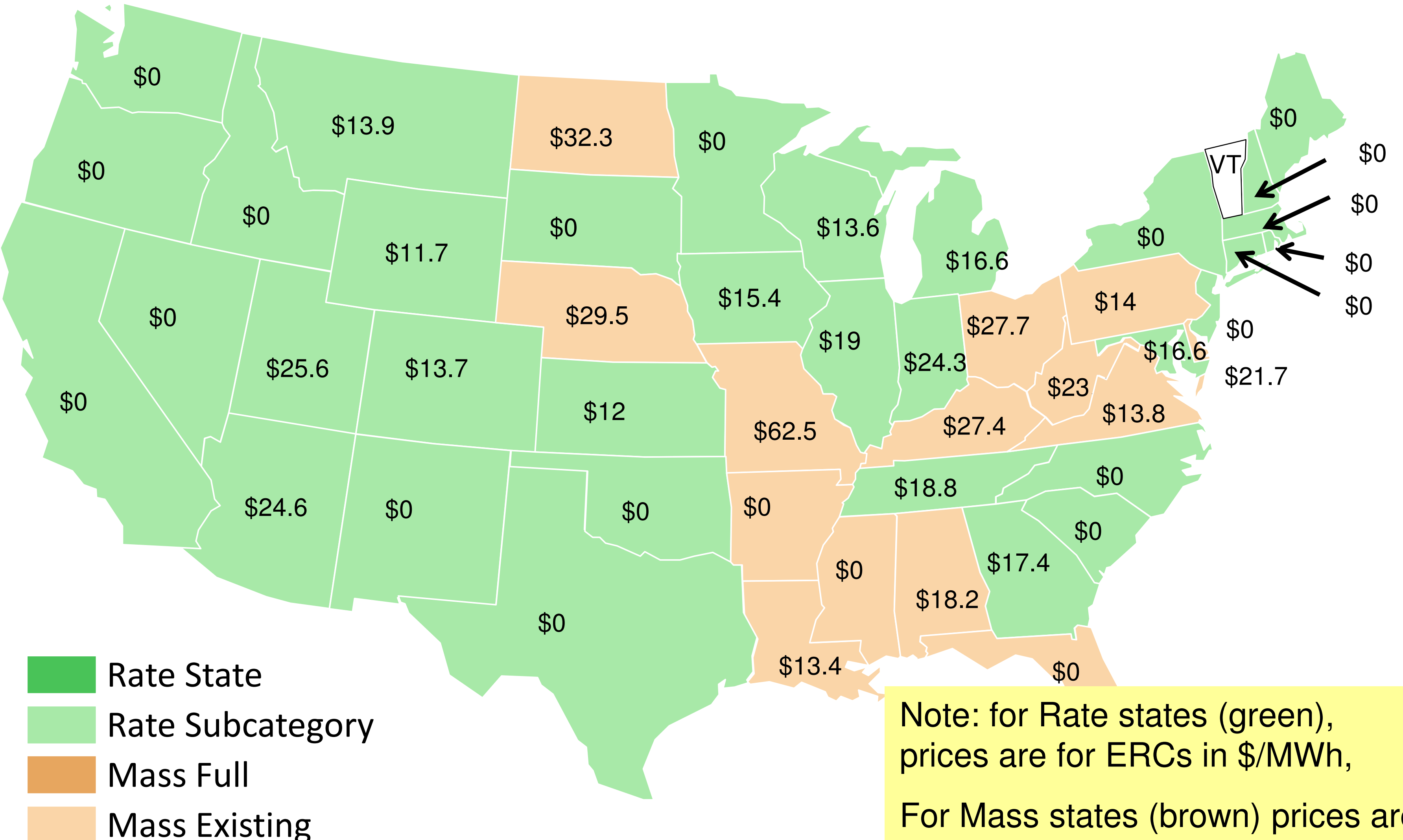
ERC/Allowance Prices for 2030 with Full Island Compliance (<u>High gas price path</u>)



Note: for Rate states (green), prices are for ERCs in $/MWh,

For Mass states (brown) prices are for Allowances in $/metric ton

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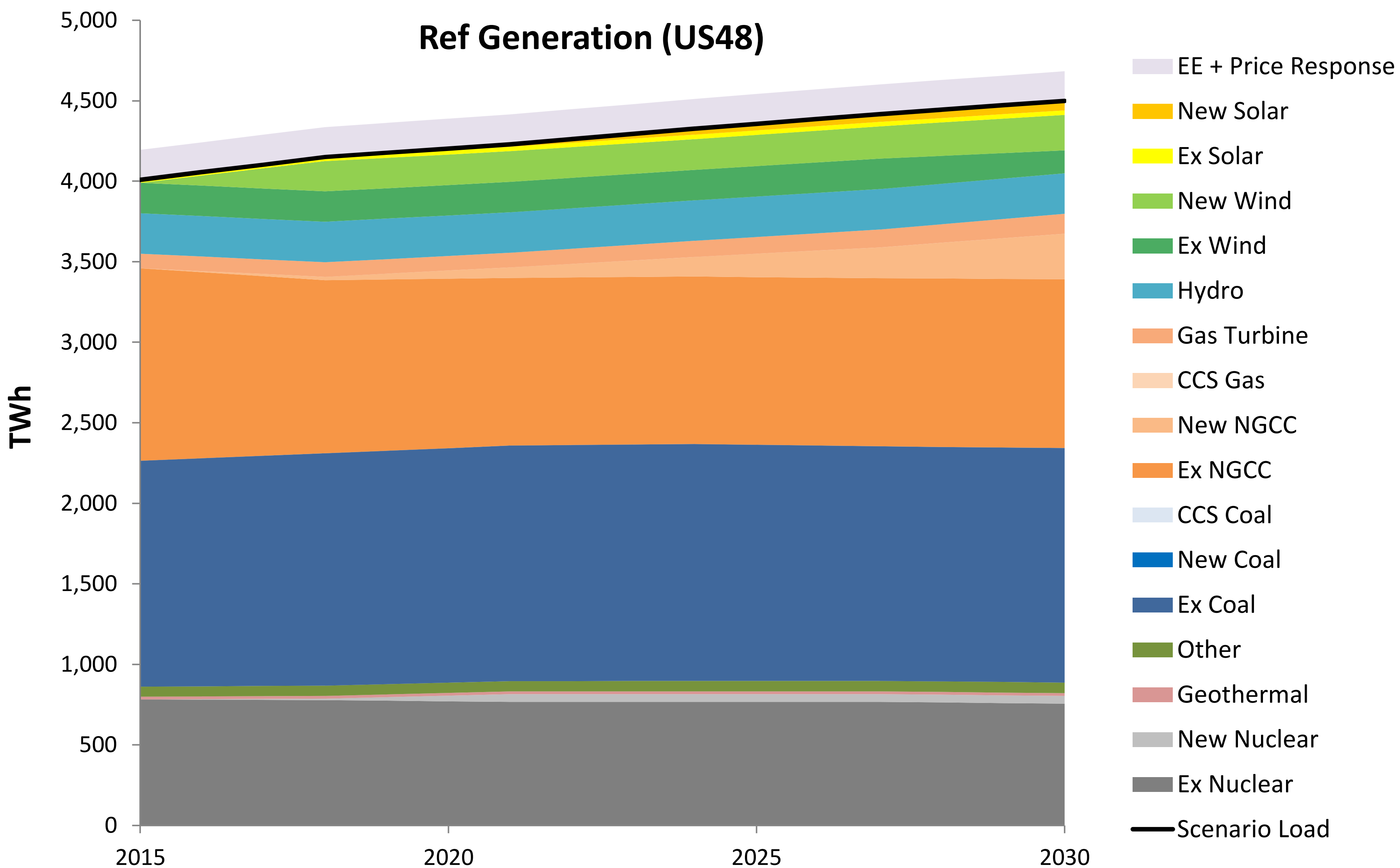
Observations

- Simple economics of rate vs mass:
  - rate compliance achieved with investment in renewables (wind) and energy efficiency, gas redispatch
  - mass compliance achieved with more gas generation
- Zero prices imply states are in compliance in 2030 (though possible need some effort to comply in other time periods)
- Low prices driven by ease of compliance, in turn driven by
  - Low price of natural gas
  - Low incremental cost of wind (in high-wind states)
  - Energy efficiency credits from existing EE programs
  - Announced/expected post 2012 coal retirements
- Many states at/near compliance for both Rate and Mass paths

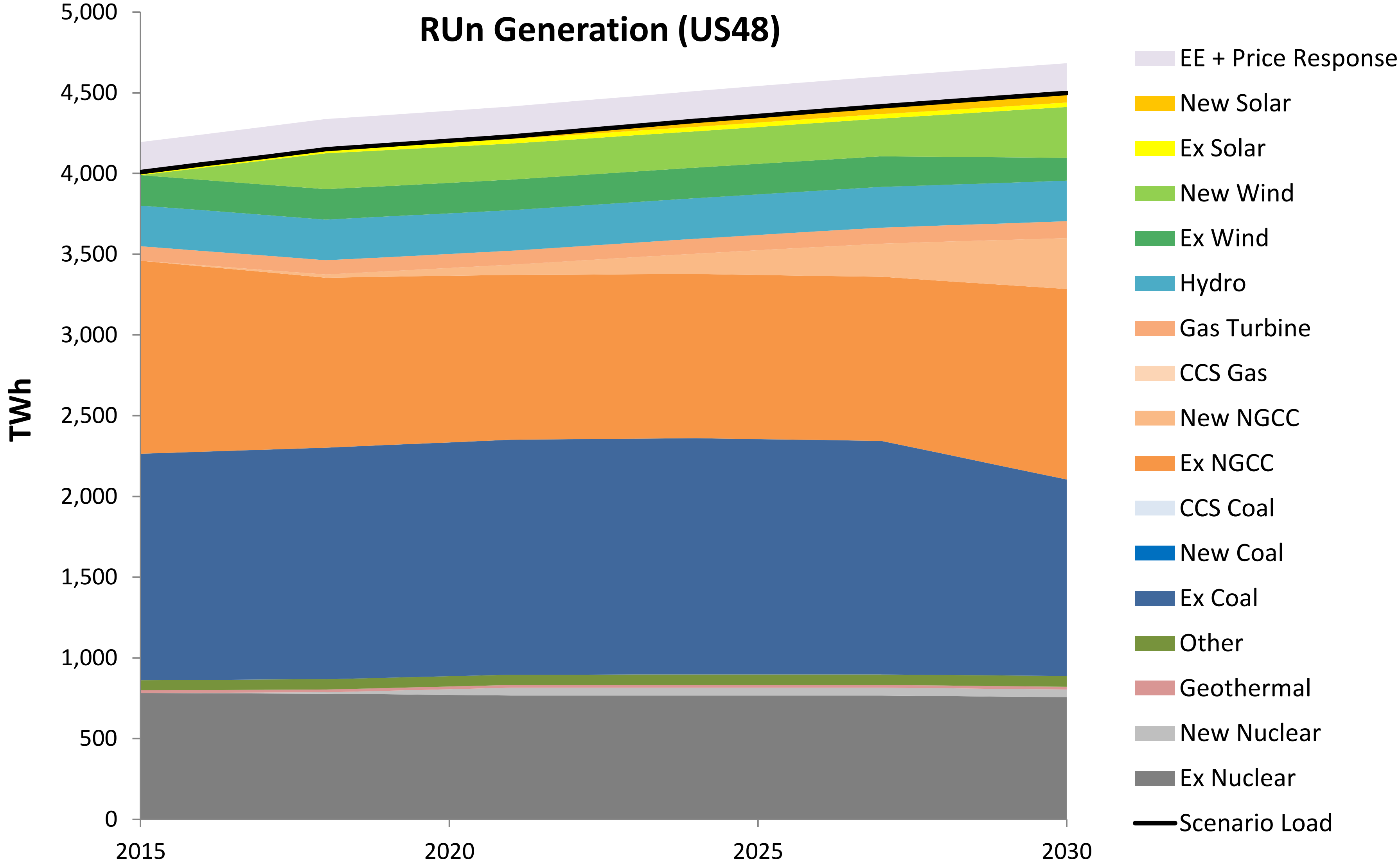
National Uniform-Pathway Results

All states choose the same compliance pathway and trade ERCs and Allowances per Rate and Mass Model Rules
(also trade power)

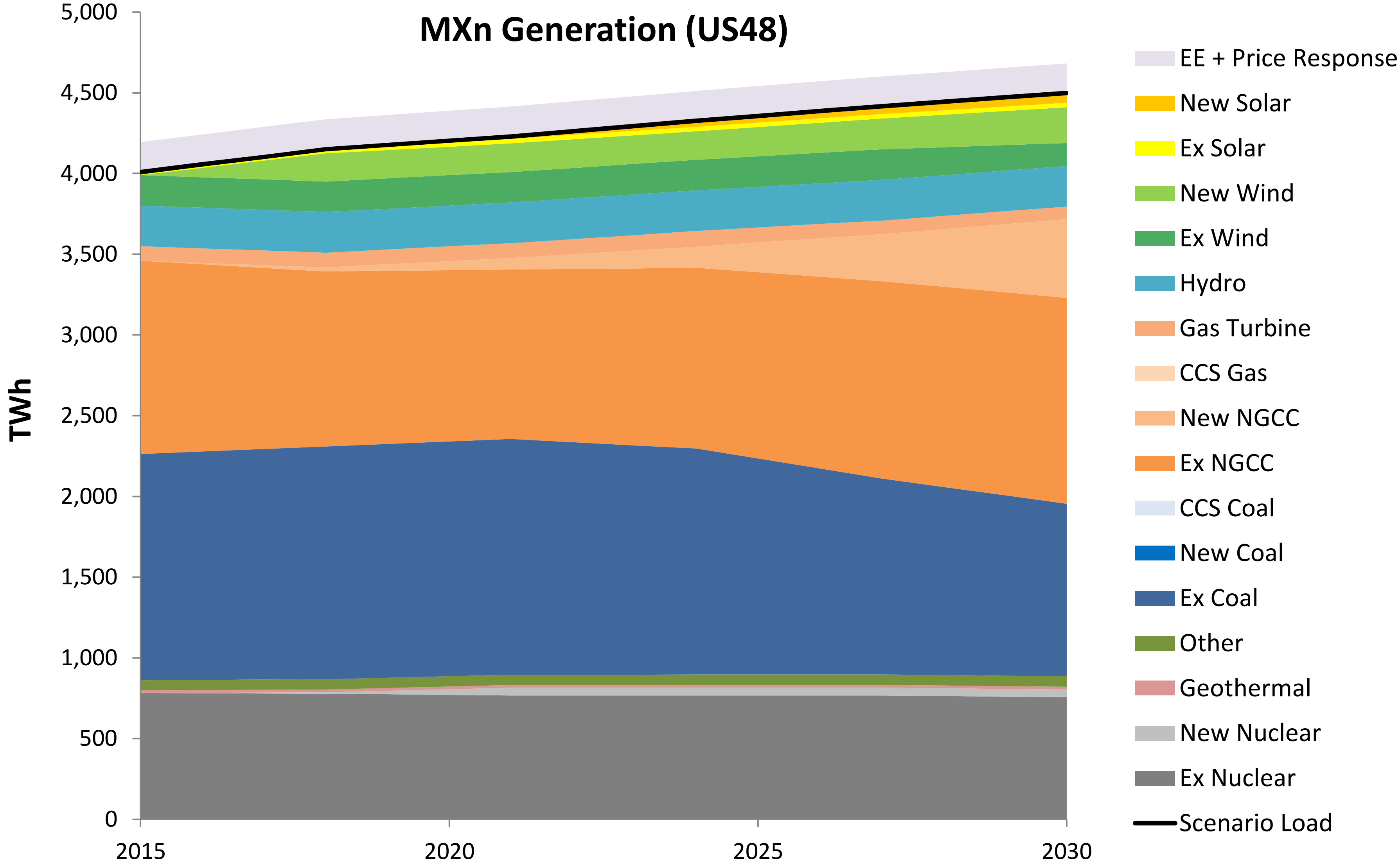
Reference Scenario



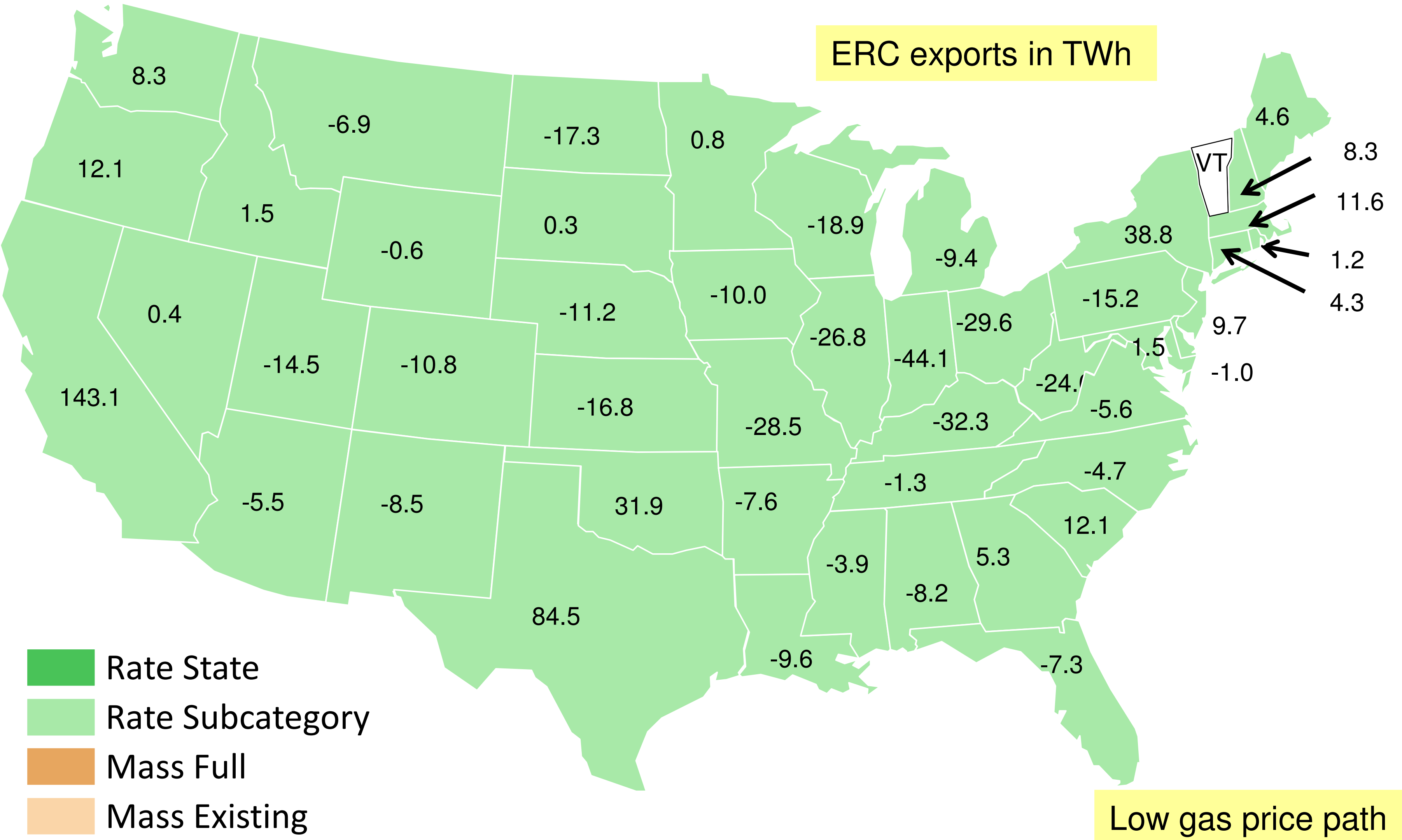
Generation Mix with Uniform Compliance Under Subcategory Rate Path (with ERC trading)



Generation Mix with Uniform Compliance Under Exististing Mass Path (with Allowance trading)



2030 Net ERC Exports if All States Choose Sub Category Rate Path and Trade ERCs (ERC price = $10.6/MWh)



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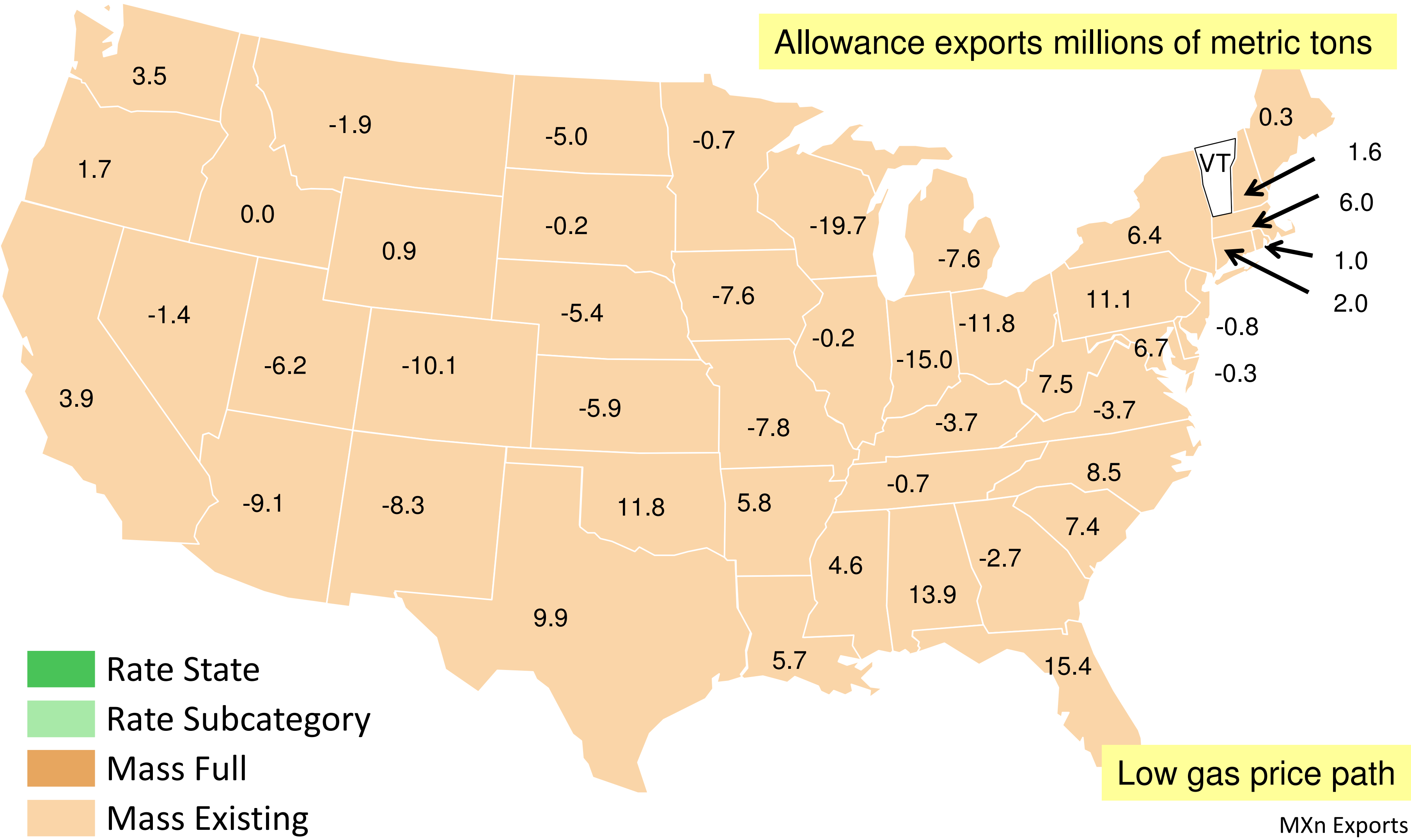
2030 Net Emission Allowance Exports if All States Choose Existing Mass Path (EA price = $11.9/metric ton)



MXn Exports

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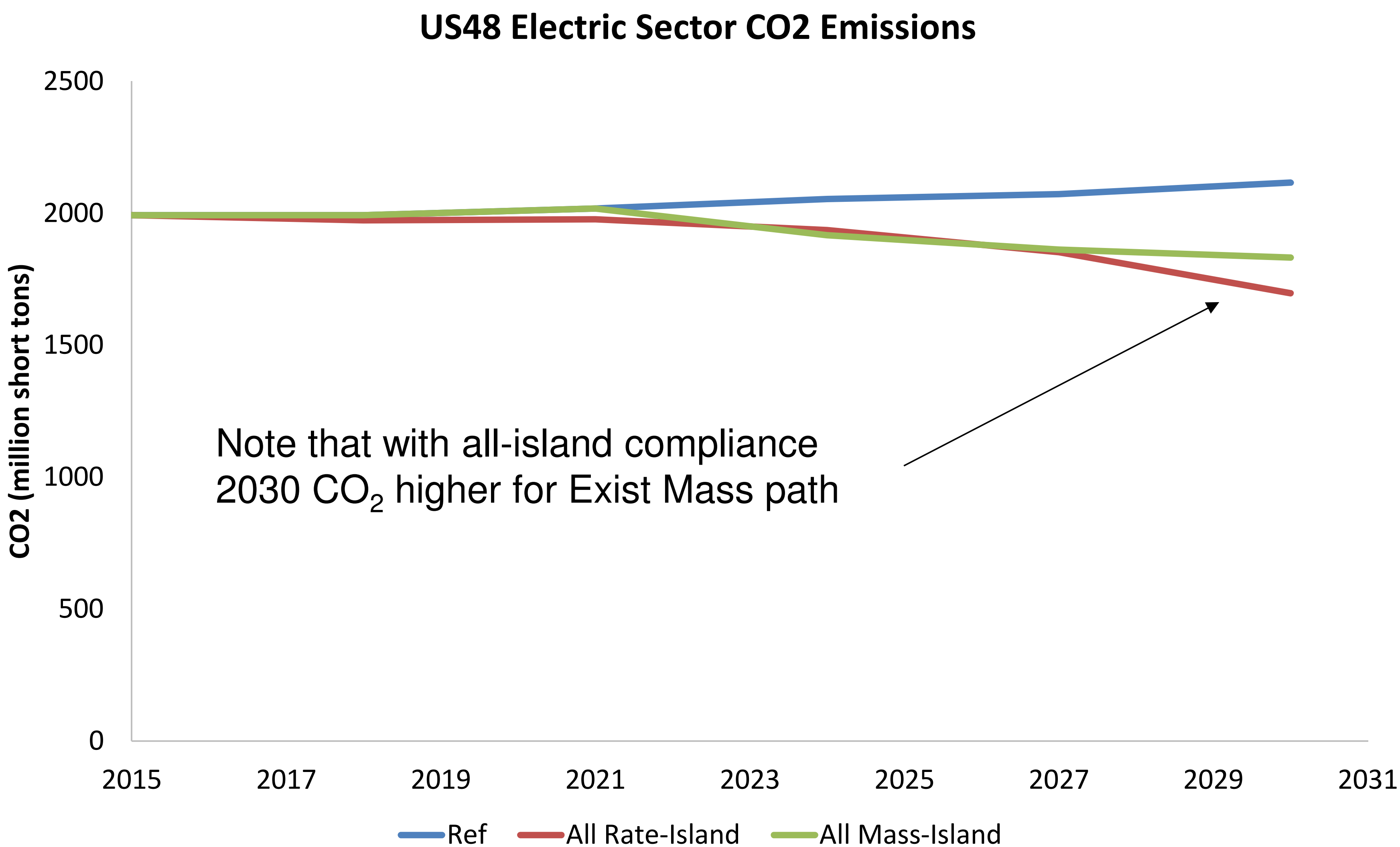
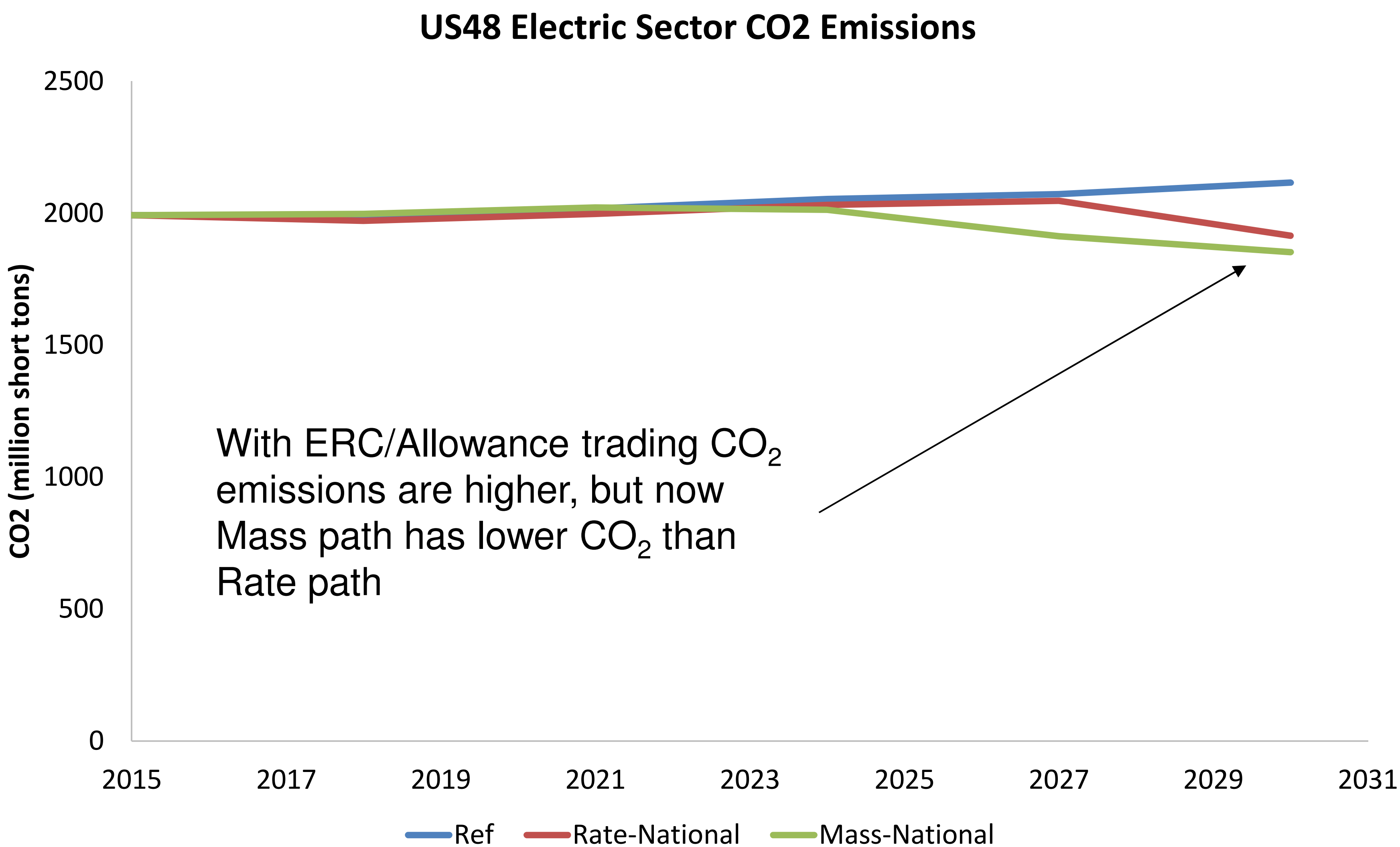
CO_2 Emissions

All Island w Uniform Choice of Paths (Sub. Rate vs. Exist. Mass) with no CPP Trading, no Incremental Power Flows



Nationally Uniform Choice of Paths (Sub. Rate vs. Exist. Mass) with ERC/Allowance Trading (per Model Rule)



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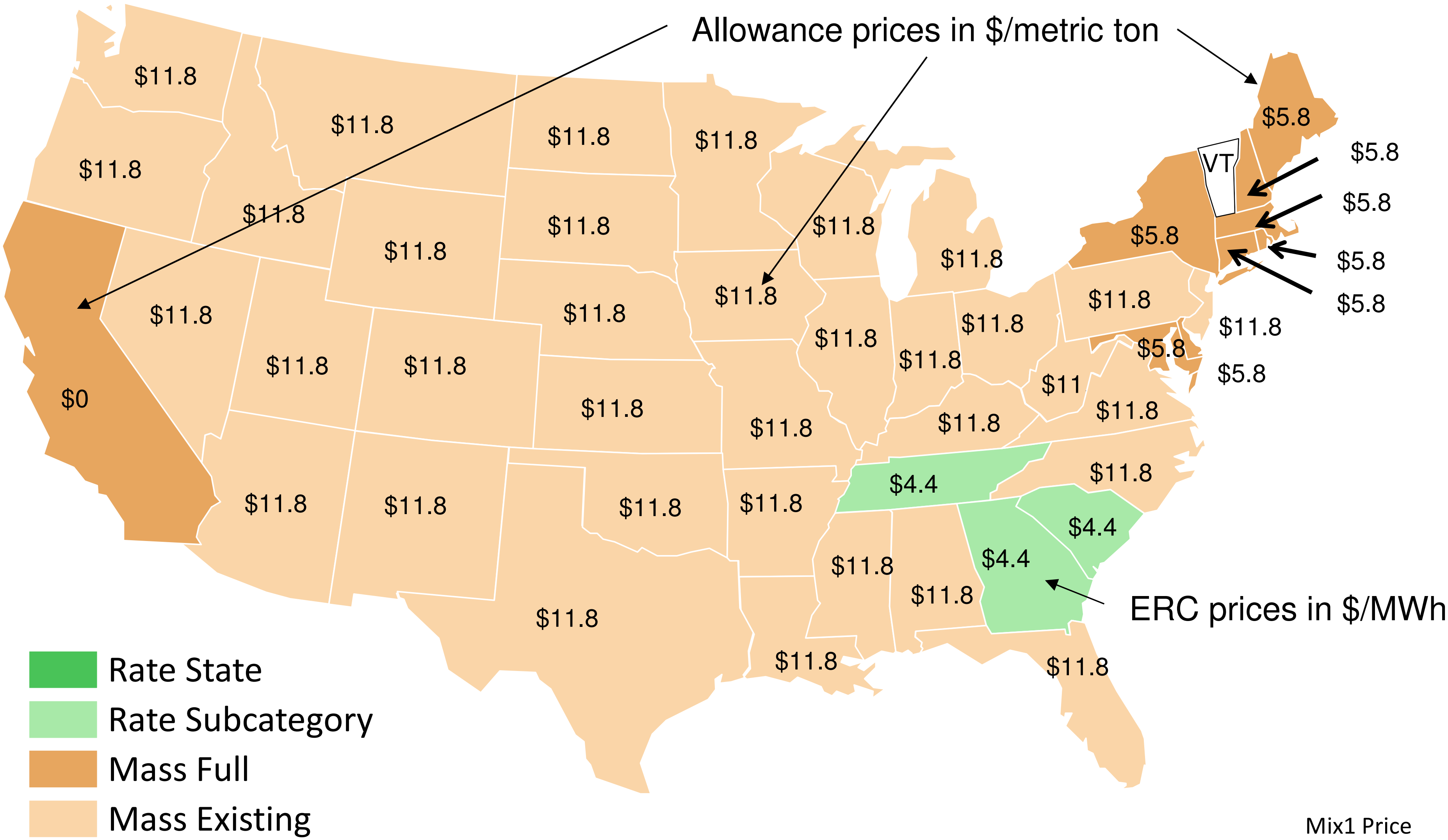
Trading Results Sensitive to National Mix of Pathways

2030 Mix1 ERC/Allowance Pricing (Low Gas Prices)



Mix1 Price

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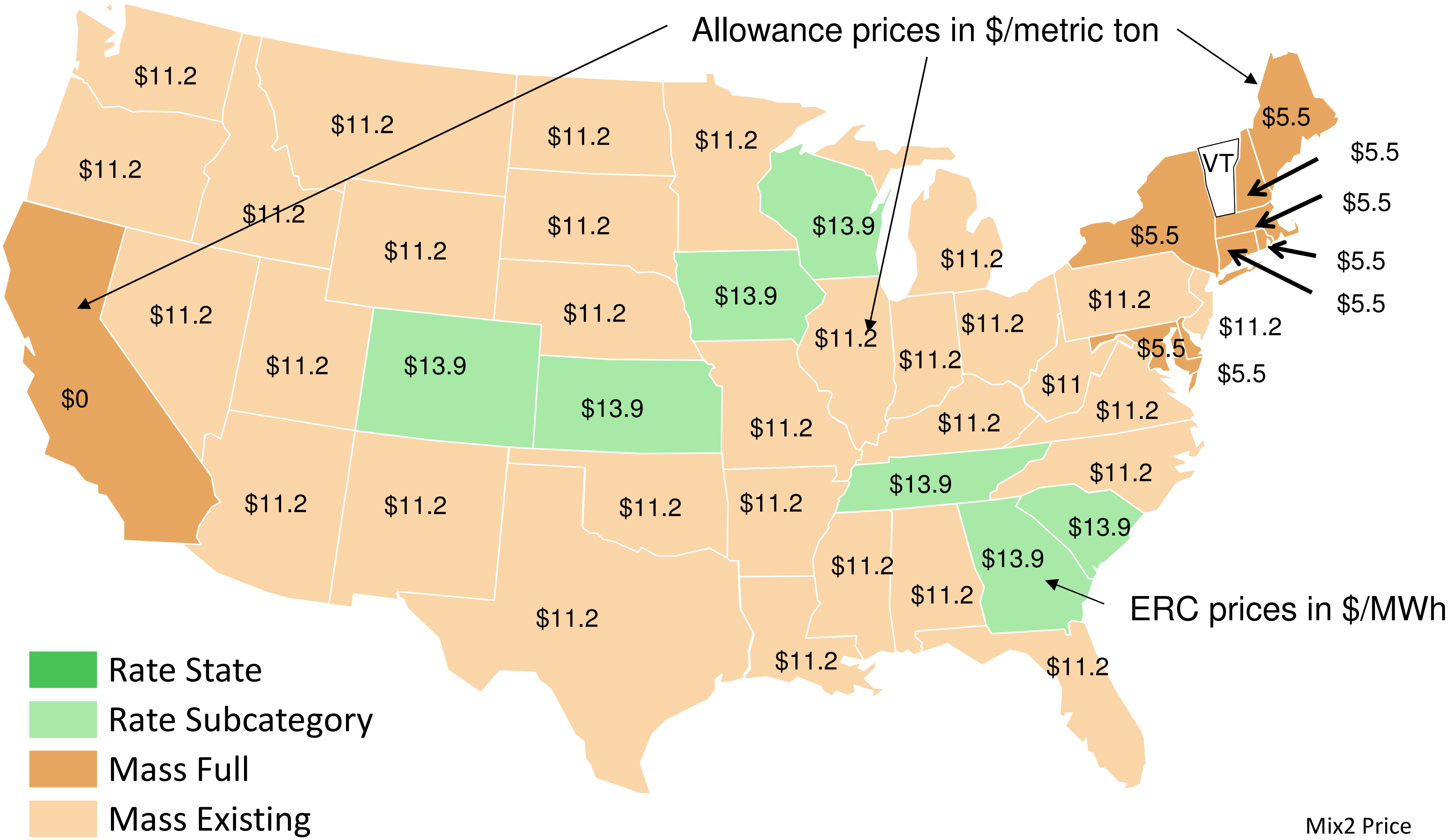
2030 Mix2 ERC/Allowance Pricing (Low Gas Prices)



Mix2 Price

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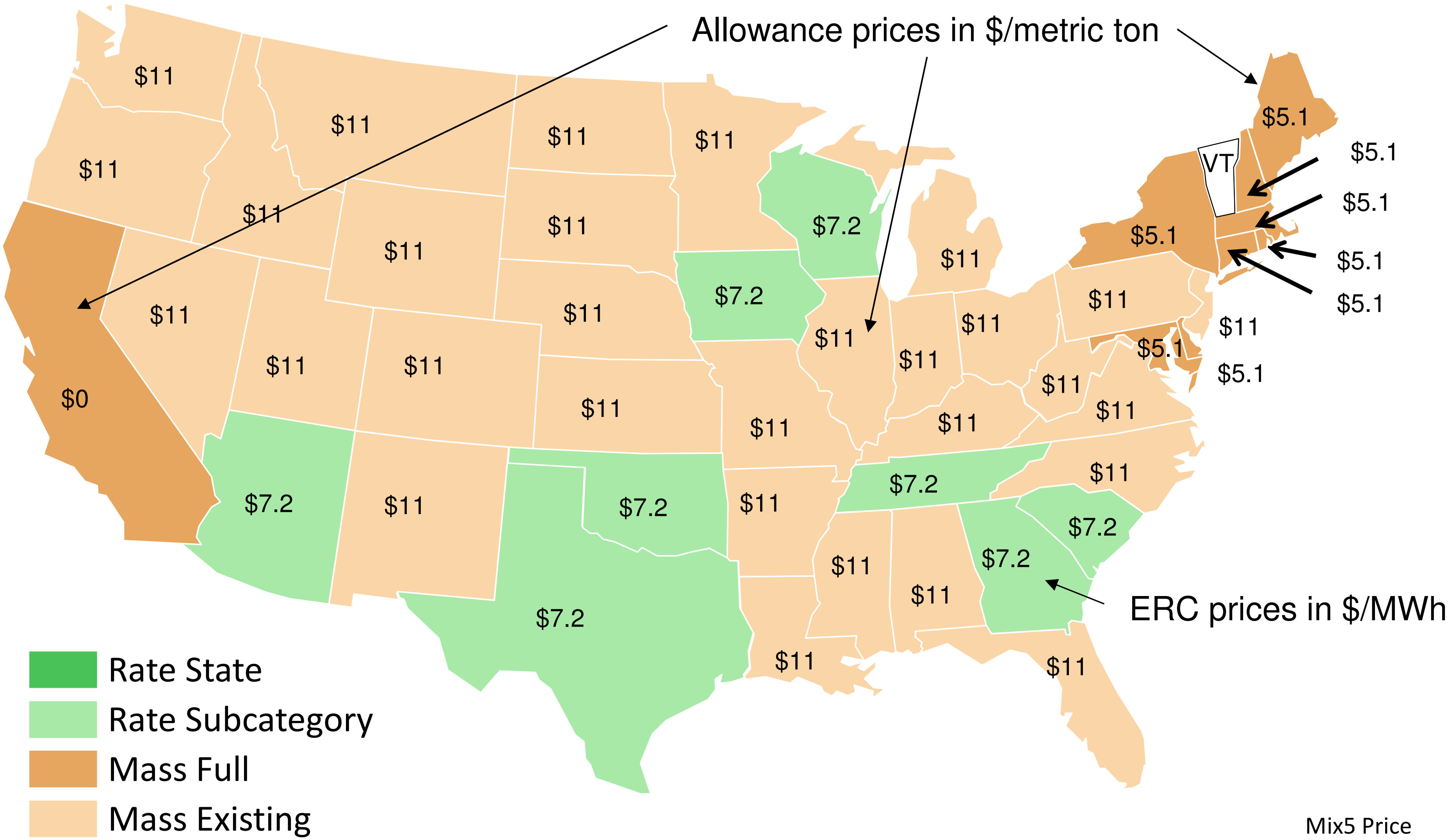
2030 Mix5 ERC/Allowance Pricing (Low Gas Prices)



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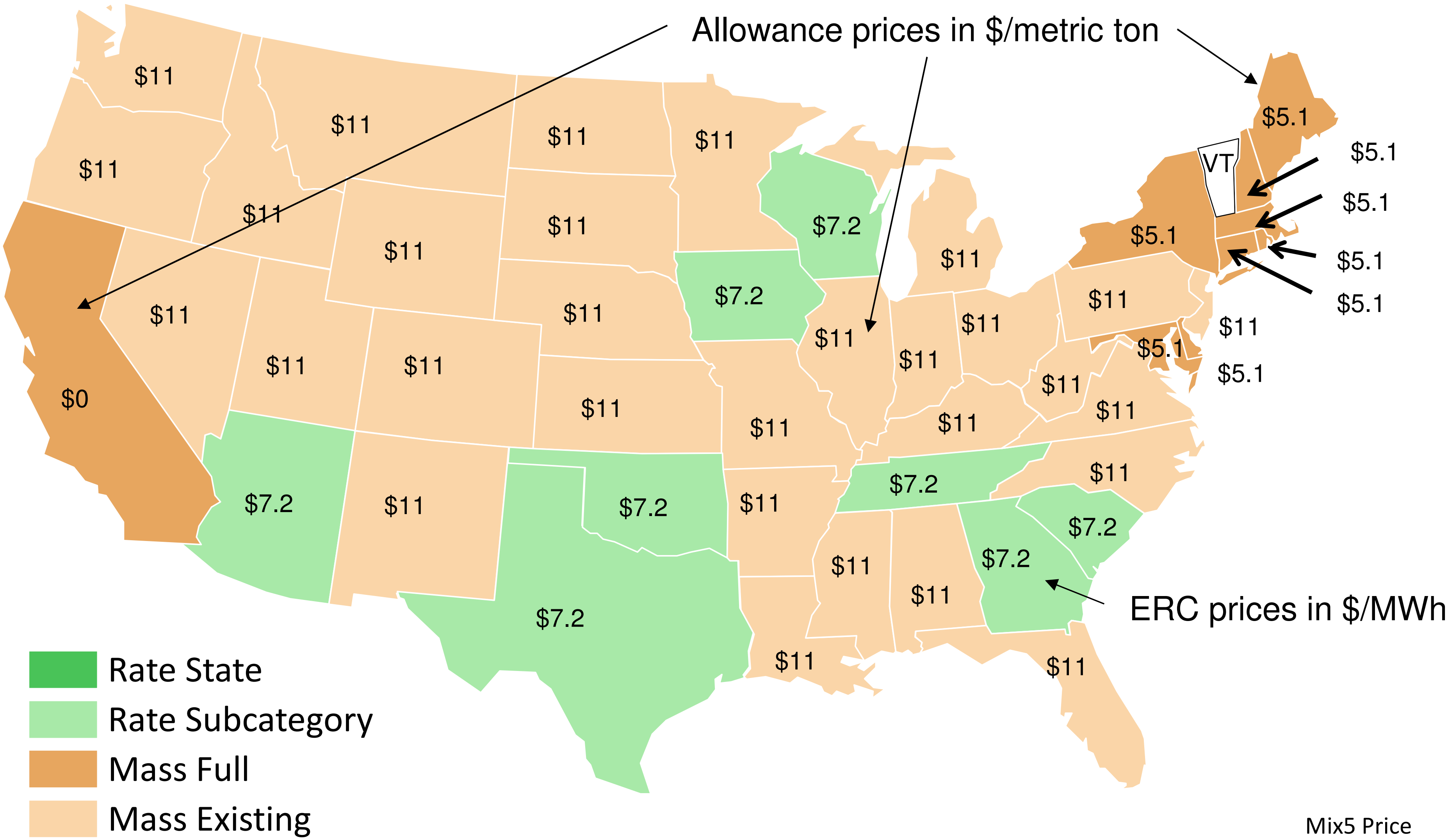
Implications of NSC (Full) Mass Pathway as Choice for an Individual State (StateX)

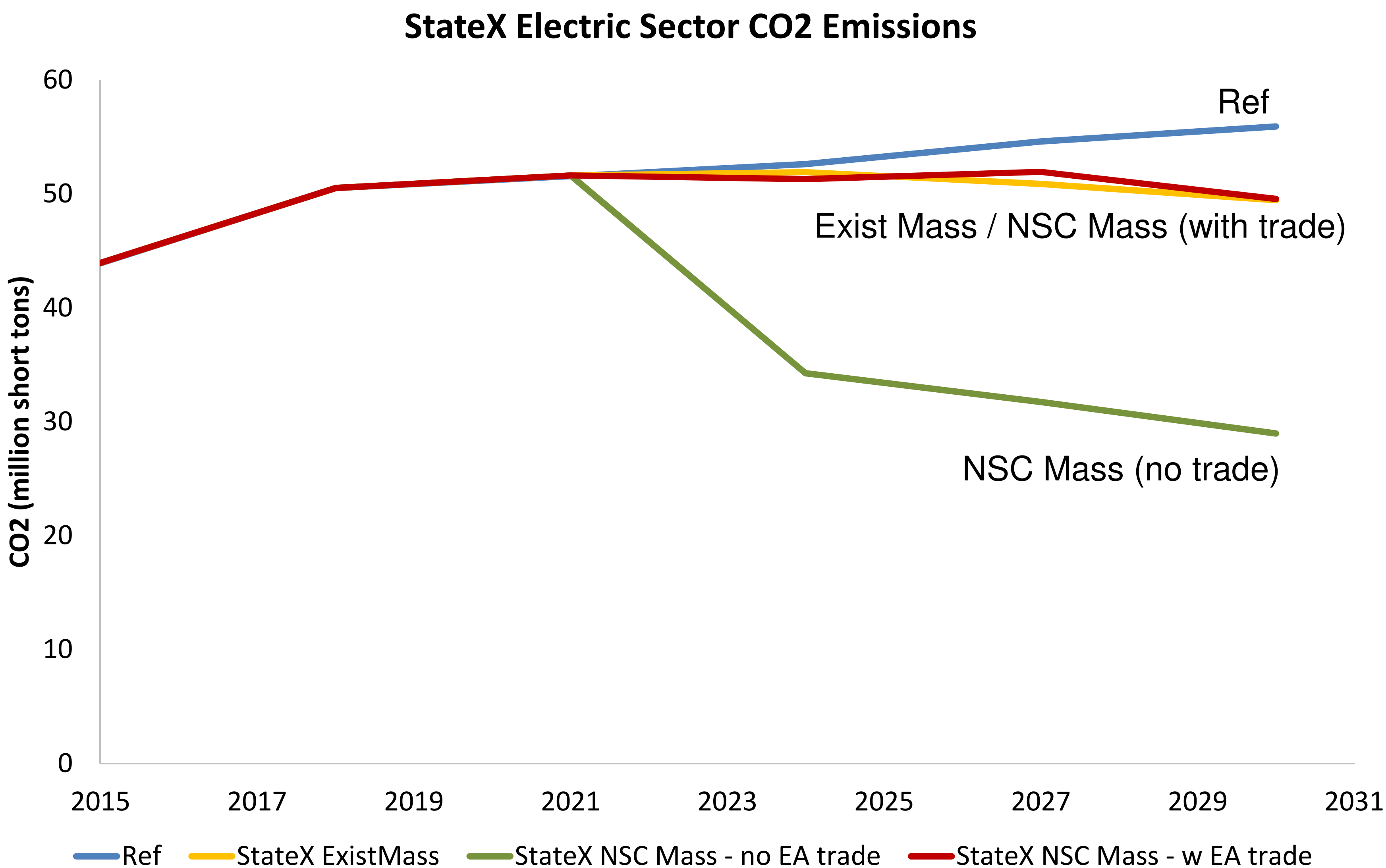
For Mix 5, let one anonymous state vary mass compliance across:

1) Existing Mass with allowance and power trading
2) NSC Mass no-EA trade (no allowance trading, but with power trading)
3) NSC Mass w EA trade (with full allowance and power trading)

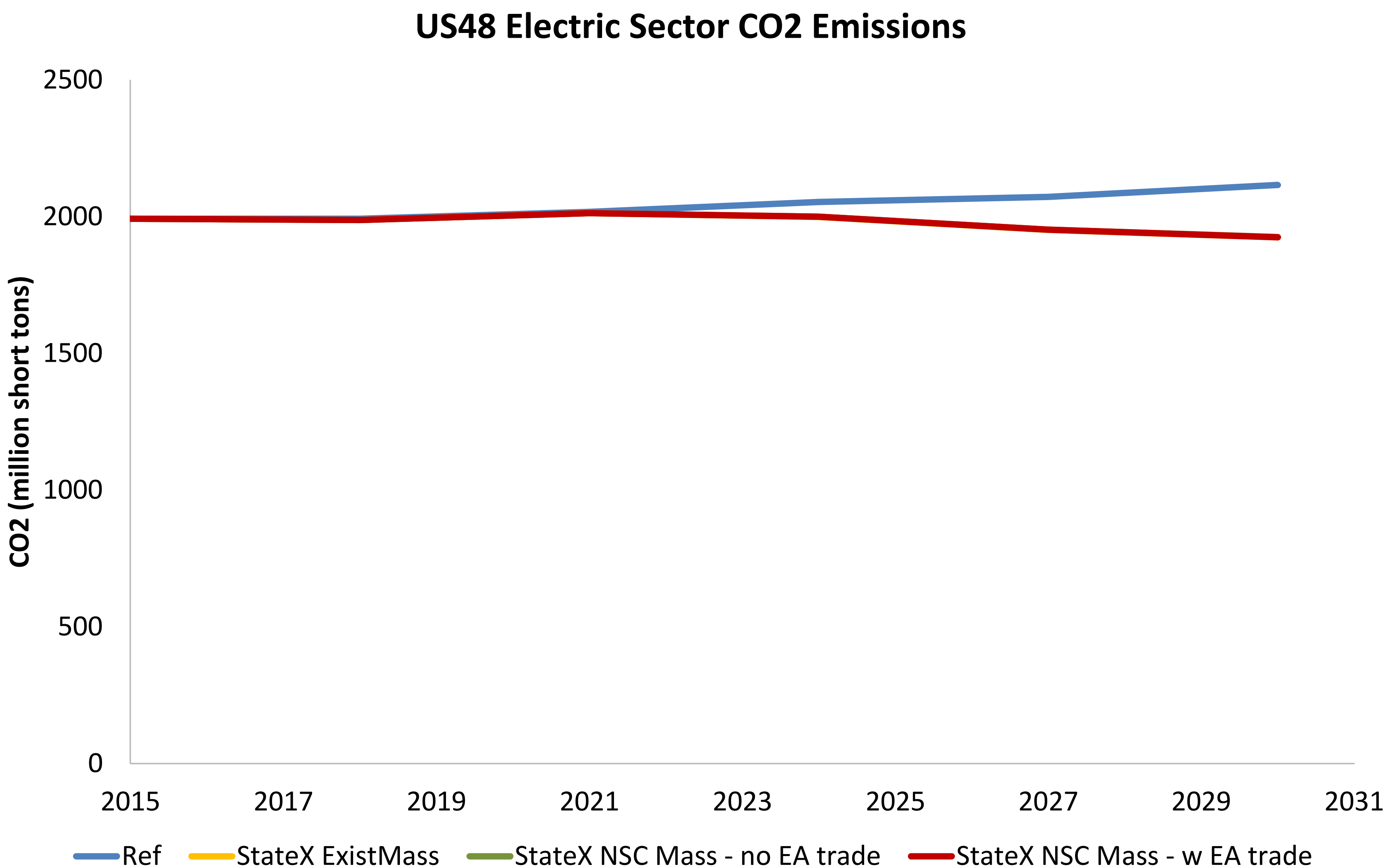
2030 Mix5 ERC/Allowance Pricing (Low Gas Prices)



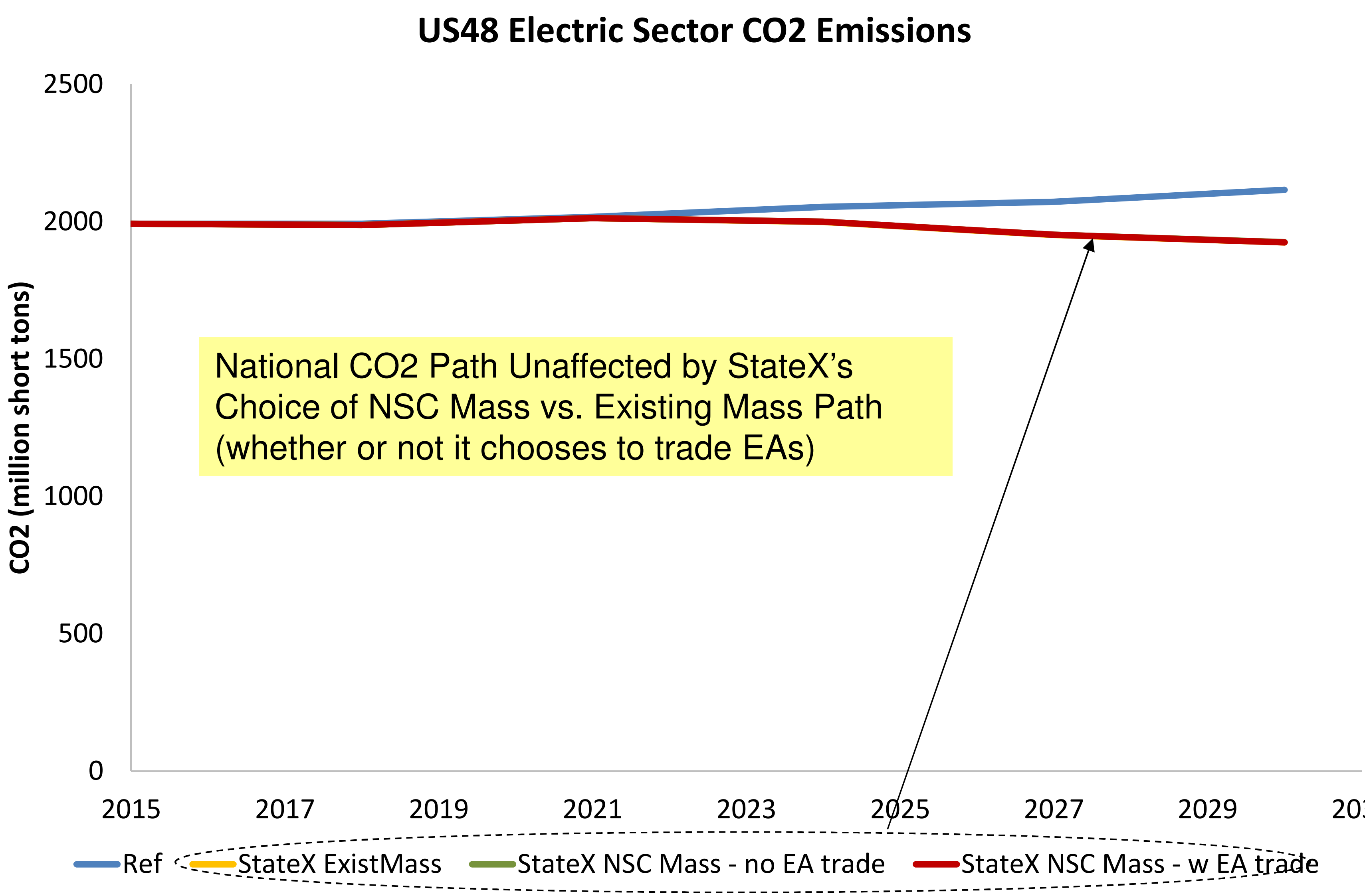
StateX CO_2 Emissions Under Alternative Mass Paths



National CO_2 Emissions Across StateX Mass Paths



National CO_2 Emissions Across StateX Mass Paths



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Observations

- Mix scenarios are illustrative samples of many possibilities
- Assume national markets for ERCs and Allowances
- ERC price if only new-nuclear states choose Rate is low, but that price may invite other state to “go rate”
- Mix2 and Mix5 probably more representative
- Many states nominally committed to mass path through existing state polices, e.g., California and RGGI states, would be in compliance with the CPP by choosing rate pathway
- With trade, a state selecting Full Mass has no impact on national CO_2
- Reasonable variation in future natural gas prices has greater impact on costs than the Clean Power Plan

Strategic Insights

- Key decisions for states are Rate vs. Mass, but also reliance on participation in the market
- Some states appear to have lower costs with Rate, some for Mass, no single universal lowest-cost choice
- Some states may be net beneficiaries of the CPP
- Trading creates value on both sides of the transaction
- The future matters
  - Natural gas prices
  - Renewable and EE costs
  - Market scope and depth
    - Supply/demand for ERCs and Allowances depends on individual state choices for Rate vs. Mass

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