Introduction to US-REGEN

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NYSERDA Workshop
16th May 2017

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- Overview and scope of US-REGEN
  - Use of economic models
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- Selected US-REGEN features and data sources
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- Optional example study – Michigan CPP analysis

Overview and Scope of US-REGEN

Uses and Limitations of Economic Models

- Models like US-REGEN are necessarily numerical abstractions of the complex economic and energy systems they represent. As such, they may contain:

    - Approximation errors
    - Incomplete system dynamics
    - Data quality issues

> "Essentially, all models are wrong, but some are useful."
>   -- George Edward Pelham Box

- When viewing model results, it is important to keep in mind:

    - Analyses are **not intended** to be viewed as a prediction of a particular outcome or cluster of outcomes.
    - Insights come by running a variety of cases, comparing the results, and asking "what if" questions.
    - Actual deployment of a model outcome is dependent on many additional factors, such as policy, permitting and siting.

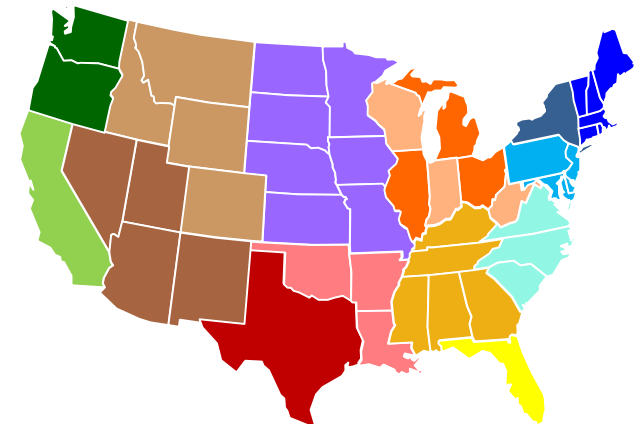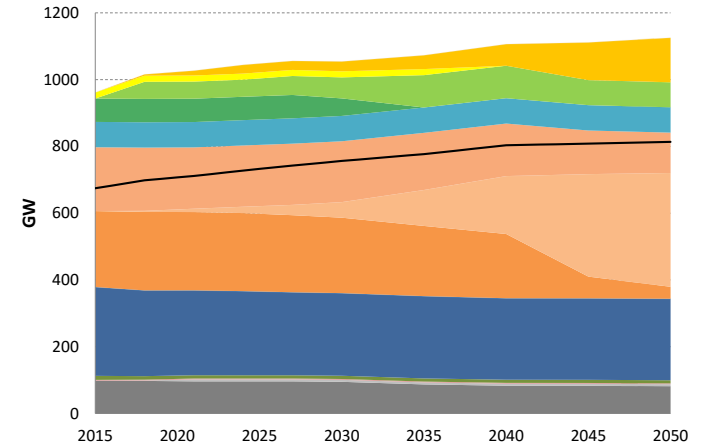EPRI | ELECTRIC POWER RESEARCH INSTITUTE

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

Capacity Expansion Economic
Model, Long Horizon to 2050

Informed by
EPRI Data and
Expertise

State Level Resolution for Policy
and Regulation Analysis

US-REGEN Model Design Features

- State-of-the-art capacity expansion <u>economic</u> model for policy and regulation analysis to 2050

- Endogenous dispatch and investment in generation and transmission capacity

- Regional detail and representative hour approach to capture intra-annual variation of load/wind/solar

- Informed by EPRI data and expertise, used extensively for Clean Power Plan and longer-term decarbonization analysis

The New York Times

Business Day
Energy & Environment

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A New EPRI Computer Model Makes the Case for Regional Climate Solutions
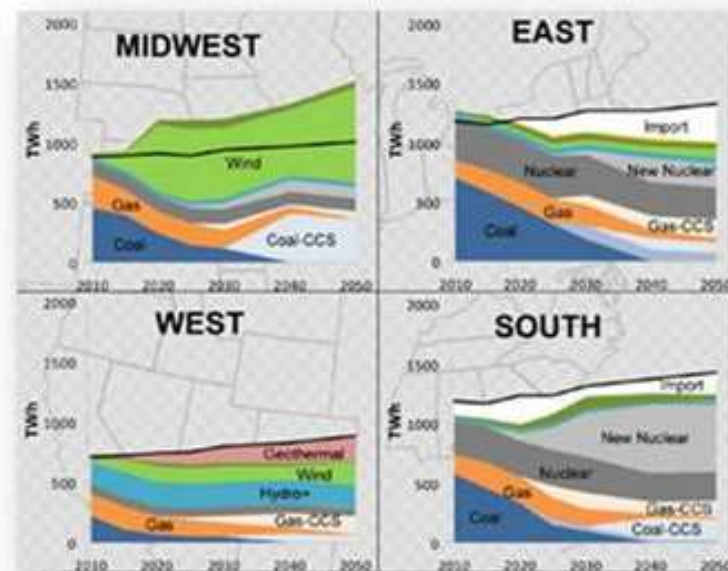
By PETER BEHR of **ClimateWire**
Published: August 19, 2010

The utility industry's top research group is making the case that regional solutions to the nation's climate policy challenges offer the best deal for consumers.
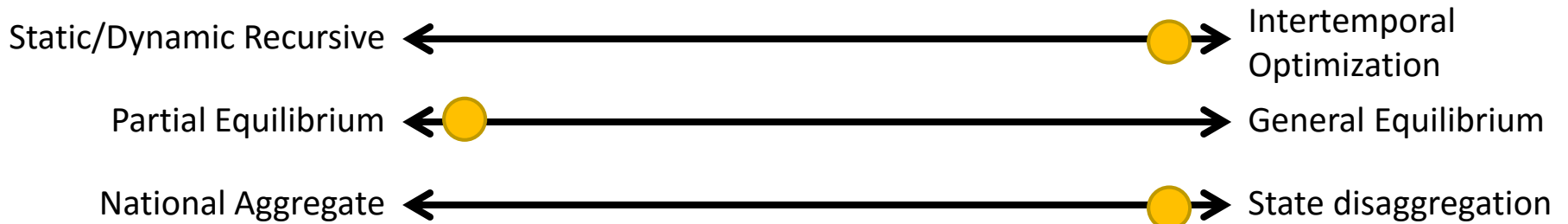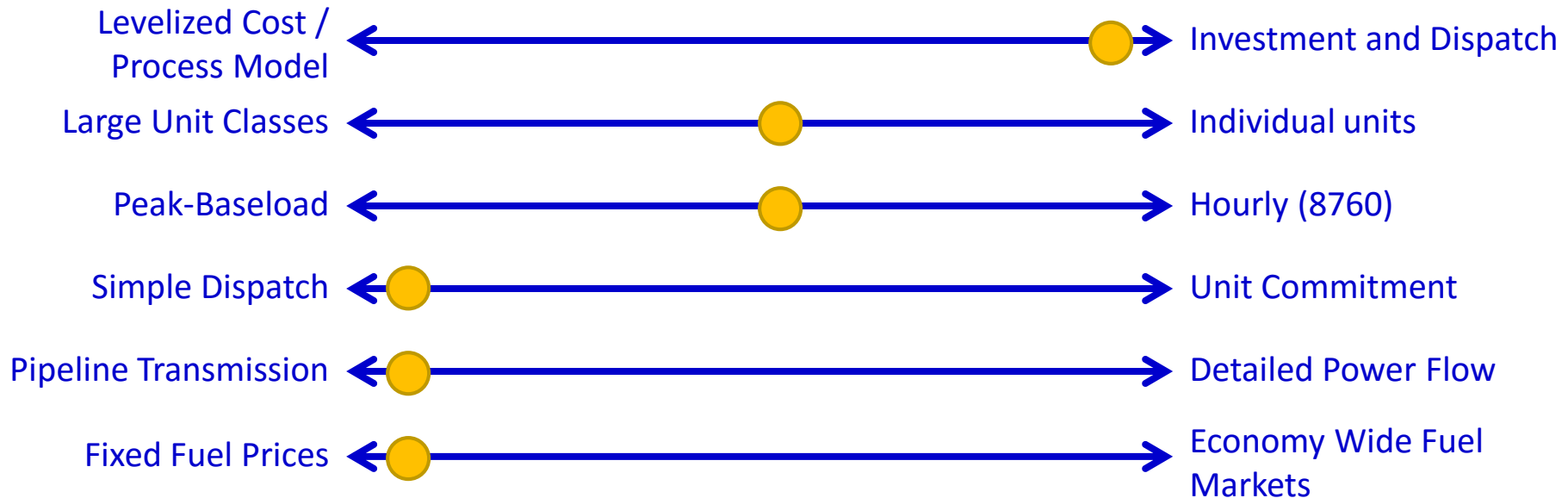
US-REGEN Documentation and Review

- US REGEN was funded by EPRI and 13 U.S. electric companies as part of a 3-year project that cost more than $9 million. Version 1 was completed in 2012.

- US-REGEN has been extensively tested by EPRI staff, the results are routinely vetted by participating electric utility modeling staff, and the model documentation has been reviewed by an outside panel of experts.

- EPRI participates in multiple modeling comparison forums such as the *Energy Modeling Forum* to ensure US-REGEN incorporates the latest advances.

- Full model documentation, journal articles, and EPRI reports are available online via http://eea.epri.com/usregen

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US-REGEN: Key Modeling Choices ⬤

Framework

Static/Dynamic Recursive ←——————————⬤→ Intertemporal Optimization

Partial Equilibrium ←⬤————————————→ General Equilibrium

National Aggregate ←——————————⬤→ State disaggregation

Electric Model

Levelized Cost / Process Model ←——————————⬤→ Investment and Dispatch

Large Unit Classes ←————⬤————→ Individual units

Peak-Baseload ←————⬤————→ Hourly (8760)

Simple Dispatch ←⬤————————→ Unit Commitment

Pipeline Transmission ←⬤————————→ Detailed Power Flow

Fixed Fuel Prices ←⬤————————→ Economy Wide Fuel Markets

US-REGEN: Selected Inputs and Outputs*

INPUTS

Load Growth

Load Shape

Fuel Price Paths

Generation Costs

Environmental Policy Constraints

Resource Constraints (Wind, Solar, Geothermal)

Build Limits (Nuclear)

OUTPUTS

Capacity & Generation Mix

New Inter-State Transmission Investments

Emissions (CO_2, SO_2, NOx)

Water & Fuel Use

Wholesale Electricity Prices

Marginal Costs of Policy Constraints
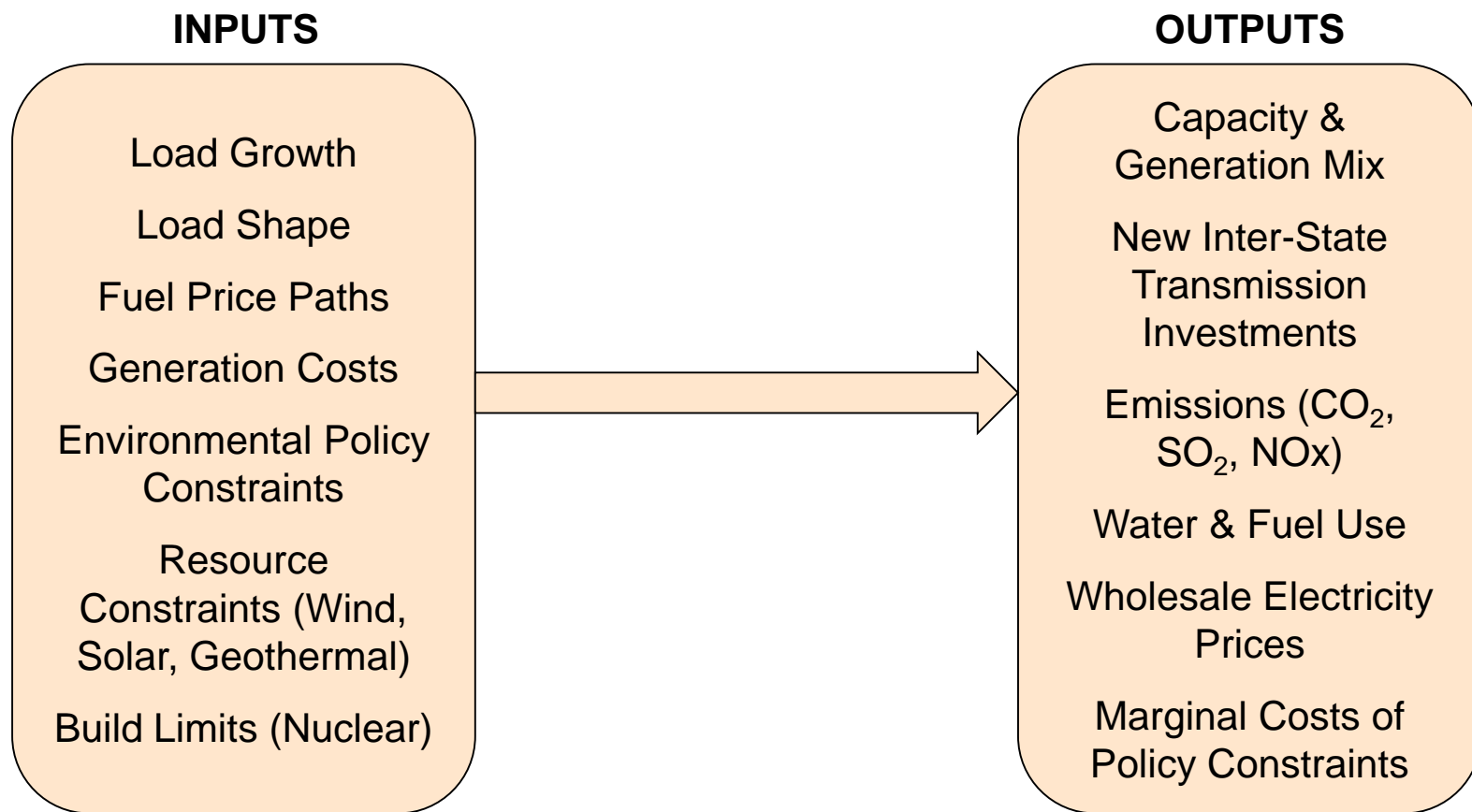
* We have considerable flexibility to customize US-REGEN for a given project, within the structural constraints, because all of the code is in-house, and most of the data is from public sources.

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Selected US-REGEN Features and Data Sources

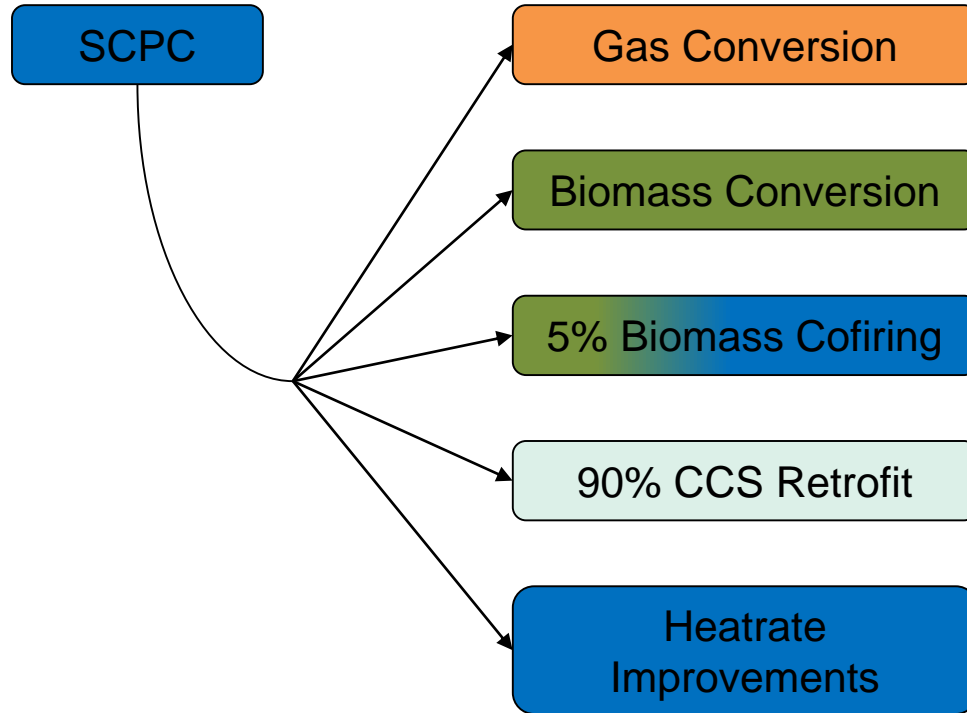EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Broad Coverage of New and Retrofit Technologies

US-REGEN models over 100 technologies, including multiple conversion and retrofit options for existing coal. We work closely with EPRI's Technology Assessment Guide to make sure we have the latest costs and technologies included.
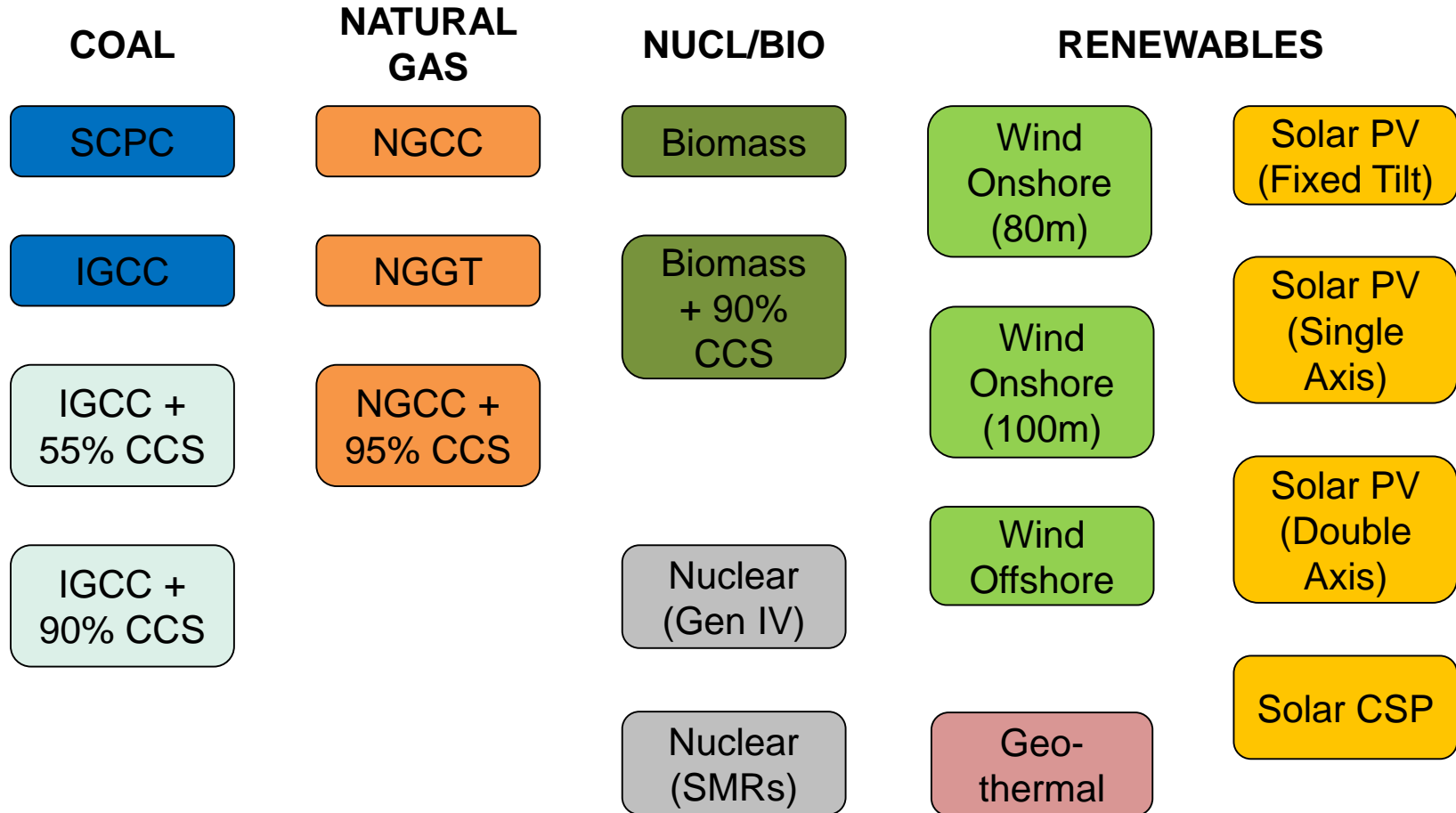
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Key Coal Retrofit Technologies Included

EXISTING SUPERCRITICAL PULVERIZED COAL

SCPC

Gas Conversion

Biomass Conversion

5% Biomass Cofiring

90% CCS Retrofit

Heatrate Improvements

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Key New Generation Technologies Included

COAL	NATURAL GAS	NUCL/BIO	RENEWABLES	
SCPC	NGCC	Biomass	Wind Onshore (80m)	Solar PV (Fixed Tilt)
IGCC	NGGT	Biomass + 90% CCS	Wind Onshore (100m)	Solar PV (Single Axis)
IGCC + 55% CCS	NGCC + 95% CCS		Wind Offshore	Solar PV (Double Axis)
IGCC + 90% CCS		Nuclear (Gen IV)		
		Nuclear (SMRs)	Geo-thermal	Solar CSP

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Treatment of Intermittent Generation

Solar Resource Duration Curve for NW-Central

Legend:
- 8760 Hourly Data
- 103 Segment Data (US-REGEN)
- 9 Segment Data (Seasonal Average Method)

Y-axis: Solar (% of Maximum)
X-axis: Hours of Year (Sorted)
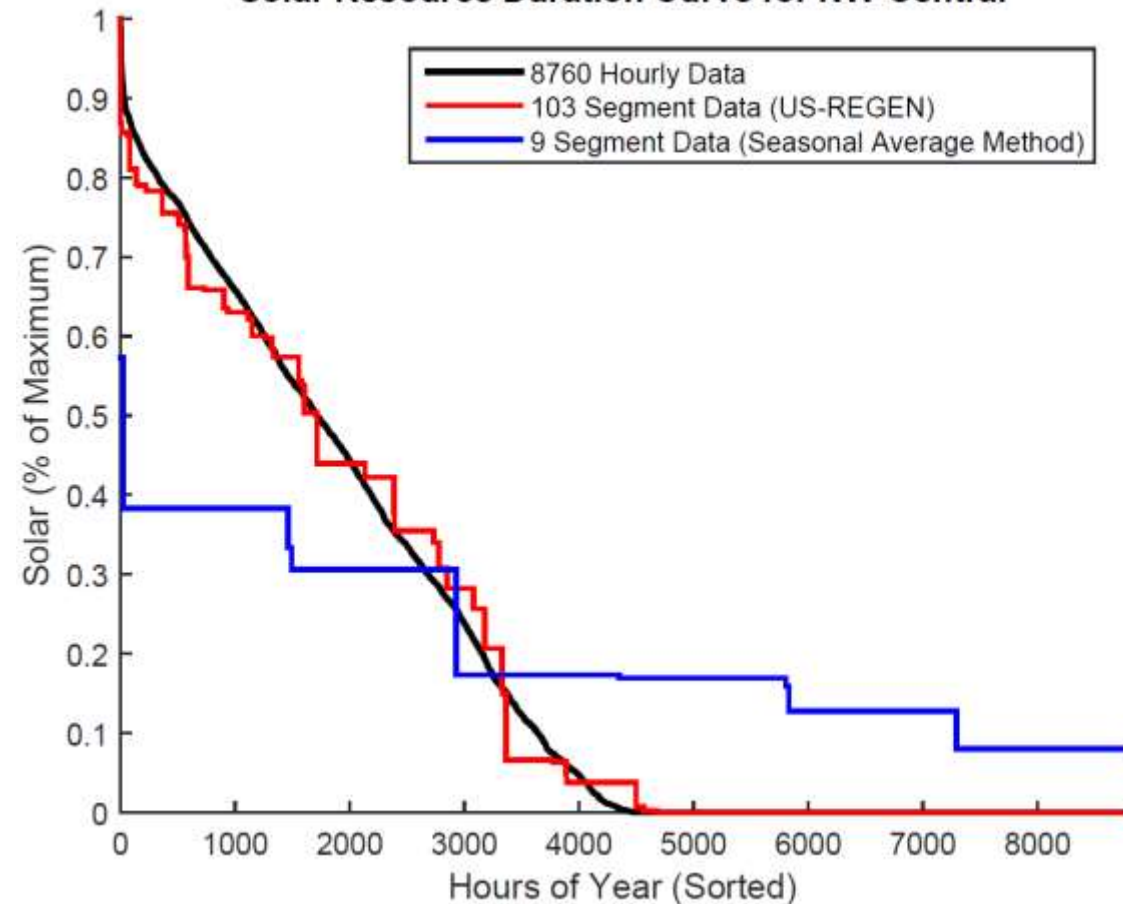
US-REGEN employs an innovative algorithm to capture wind, load, and solar shapes in a long time horizon model, with much improved match to actual shapes compared to other approaches such as the Seasonal Average Method

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17 wind quality classes from AWS (including off-shore)

Wind Speed m/s

	> 10.0
	10.0
	9.5
	9.0
	8.5
	8.0
	7.5
	7.0
	6.5
	6.0
	5.5
	5.0
	4.5
	4.0
	< 4.0

Source: Wind resource estimates developed by AWS Truewind, LLC for windNavigator®. Web: http://navigator.awstruewind.com | www.awstruewind.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

AWS Truewind

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

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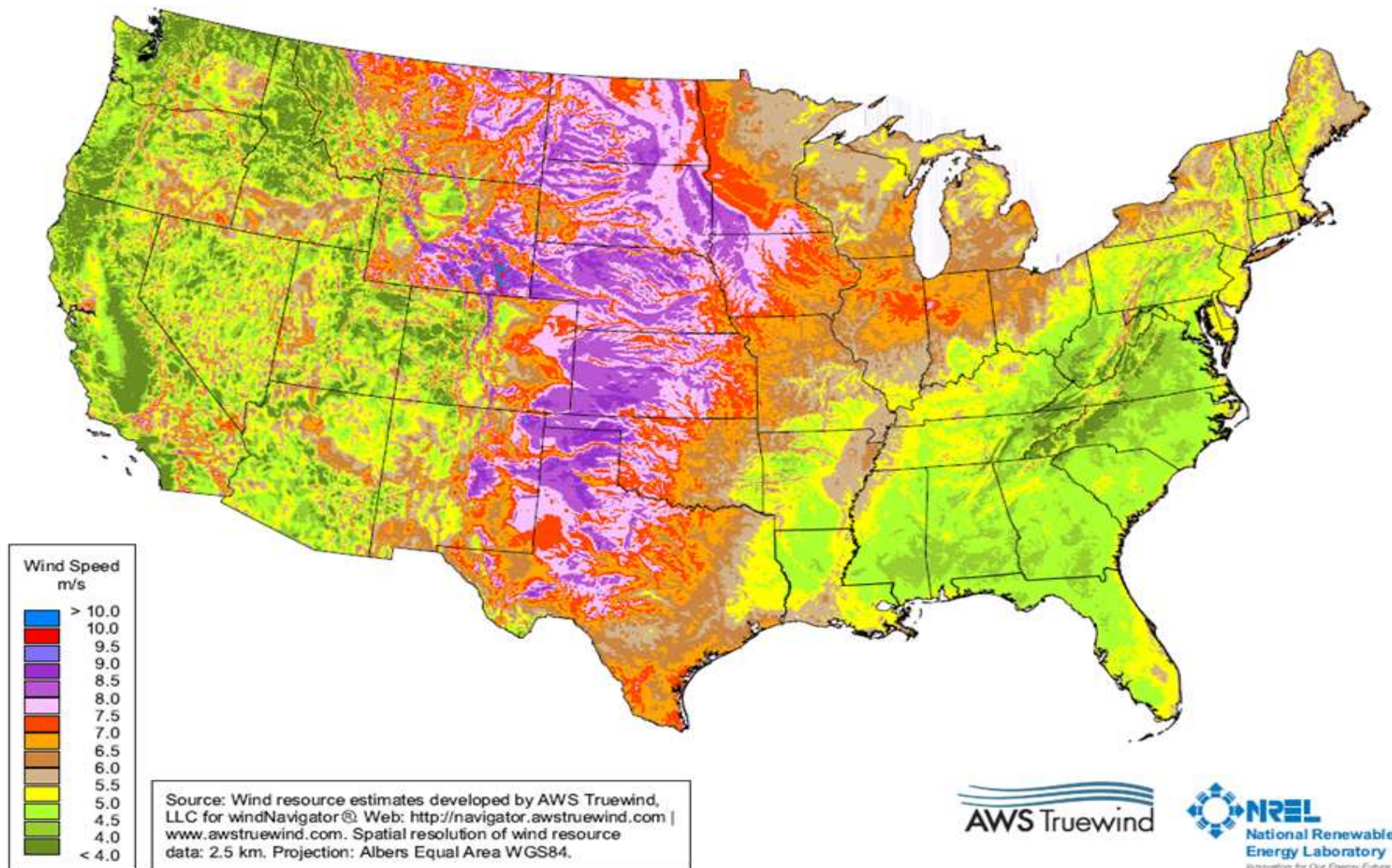
17 wind quality classes from AWS (including off-shore)

AWS Truepower wind data

- Based on actual 1997-2012 meteorology
- Provides simulated hourly output for typical turbine (80m or 100m heights, 1.5 MW)

Identified 5300+ "utility-scale" sites

- Exclusion areas
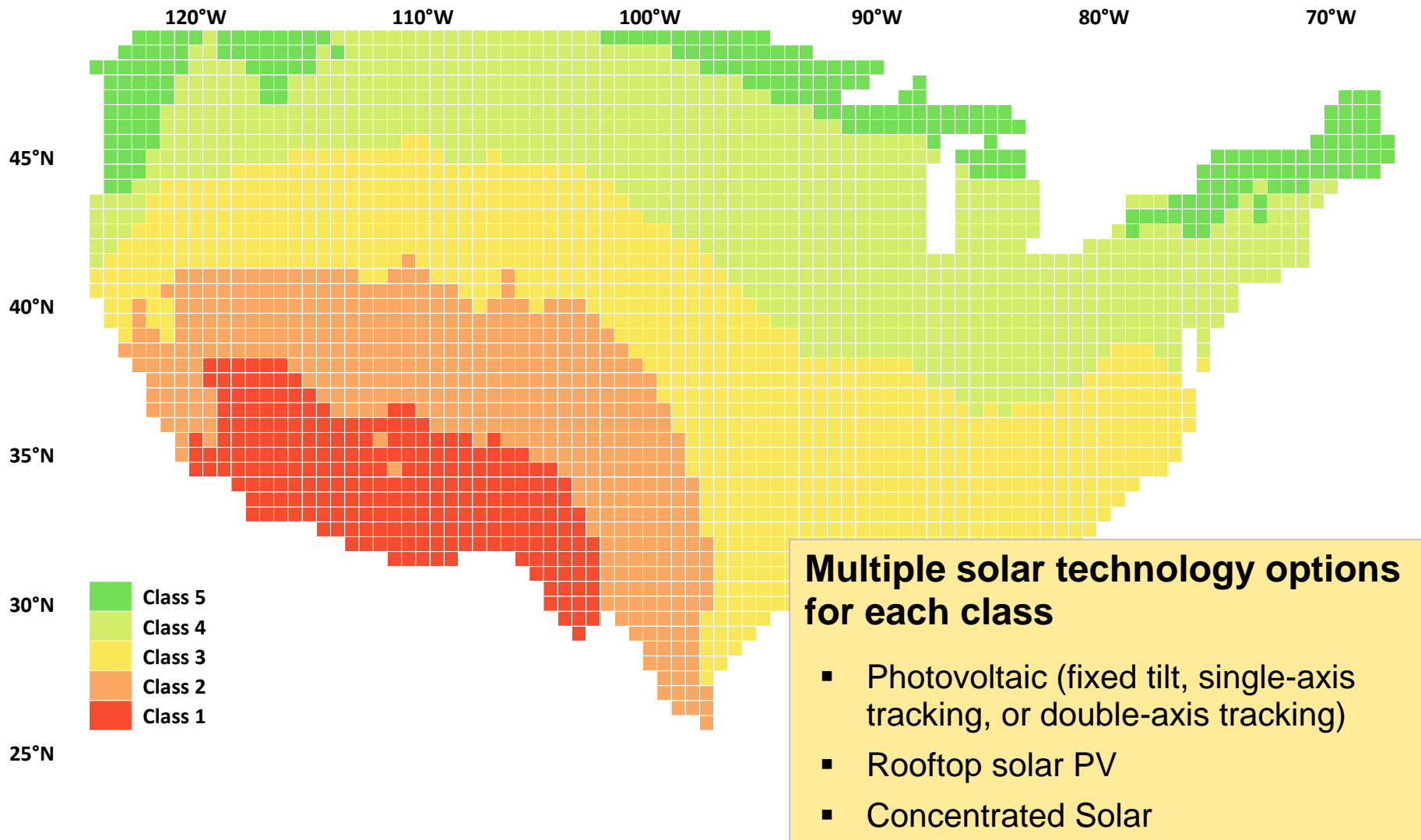- 100 MW site minimum
- Distance to grid
- Terrain/wake effects
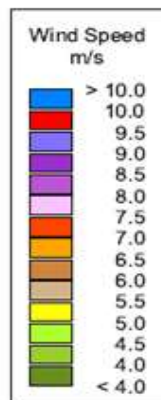
Wind Speed m/s

> 10.0	
10.0	
9.5	
9.0	
8.5	
8.0	
7.5	
7.0	
6.5	
6.0	
5.5	
5.0	
4.5	
4.0	
< 4.0	

Source: Wind resource estimates developed by AWS Truewind, LLC for windNavigator®. Web: http://navigator.awstruewind.com | www.awstruewind.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.
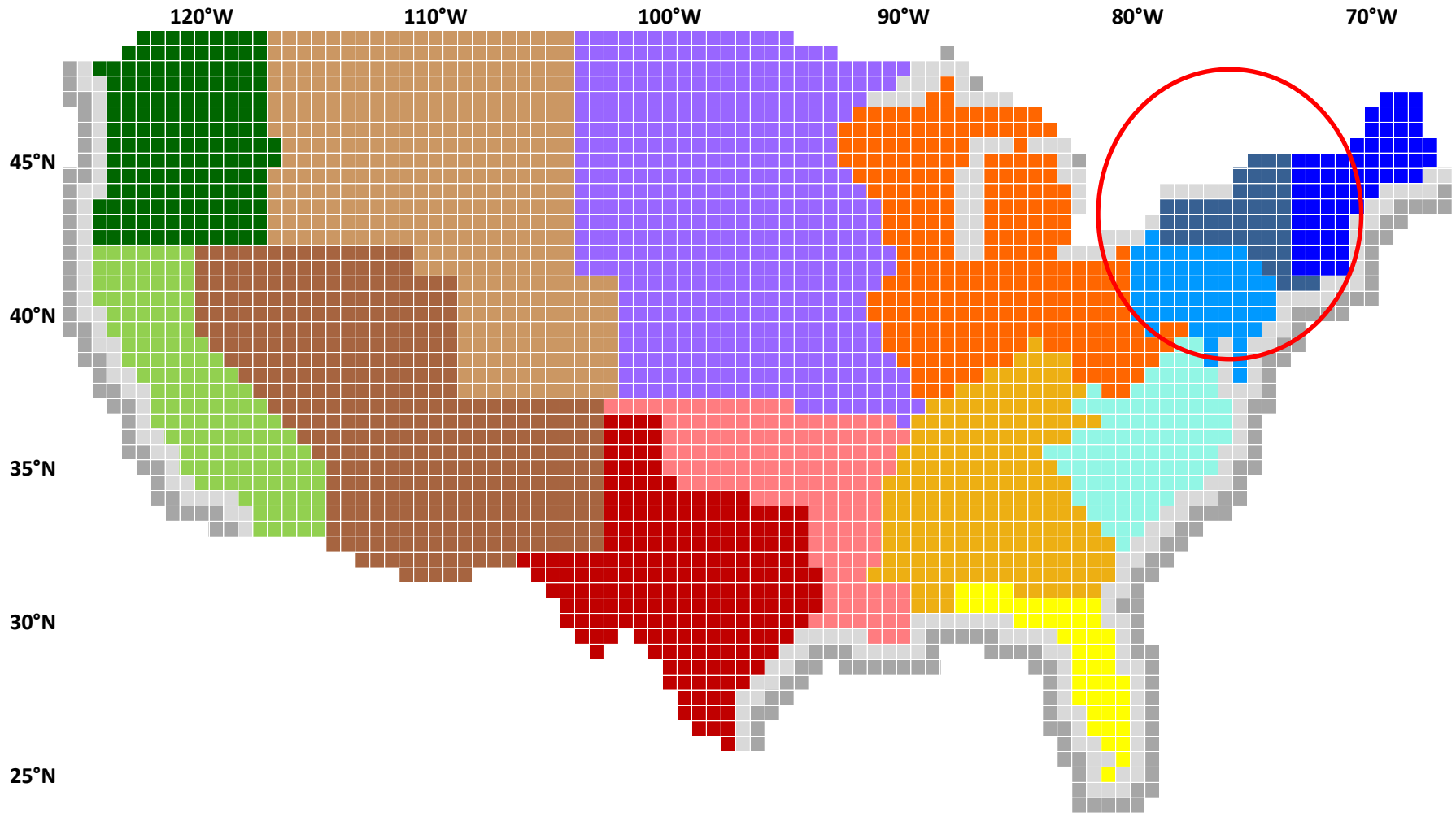
AWS Truewind

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Five solar PV quality classes based on long-run average GHI (MERRA dataset)

Class 5
Class 4
Class 3
Class 2
Class 1

Multiple solar technology options for each class

- Photovoltaic (fixed tilt, single-axis tracking, or double-axis tracking)
- Rooftop solar PV
- Concentrated Solar

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Grid includes 46 NY cells (excluding off-shore)

Planned Model Development: Customizing US-REGEN for NYS and Climate Impact Assessment
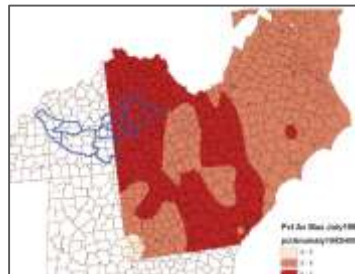
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Summary of New Features to Better Characterize NYS Electric System in REGEN

- Break NY into 5 superzones based on NY transmission zones
- Select representative hours to capture intra-annual variability of water availability and temperature
- Track water use (consumption, withdrawals) and cooling technology of generation units in order to apply future water constraints
- Add efficiency penalties on thermal generation and transmission lines based on air temperature response functions
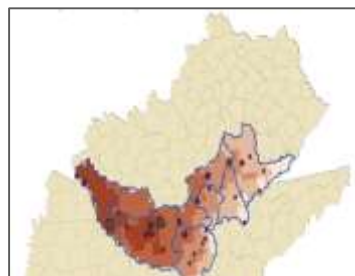- Introduce climate-adjusted load curves with increased cooling / decreased heating demand

Source: Federal Energy Regulatory Commission
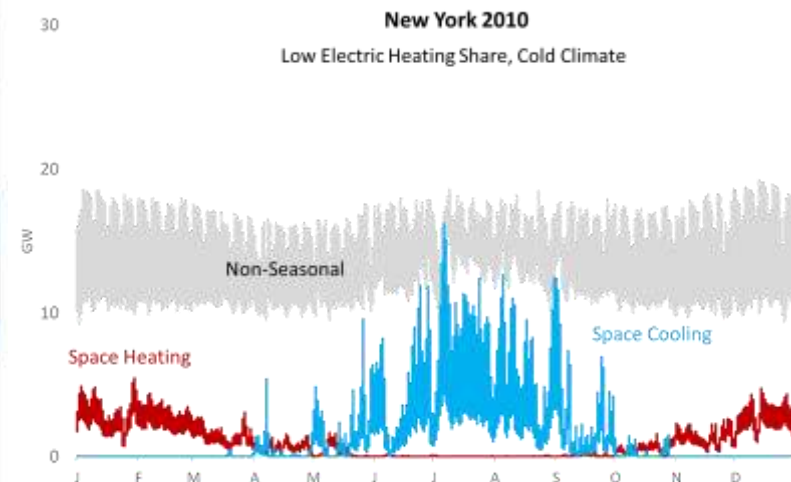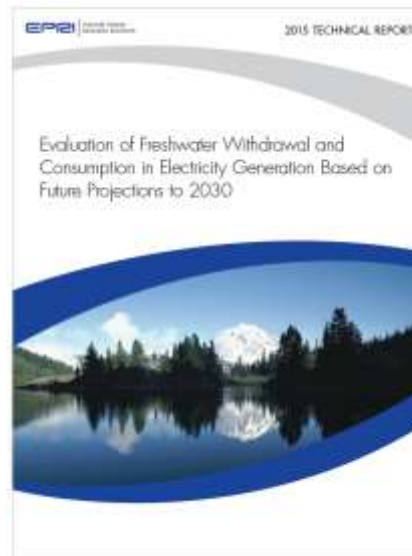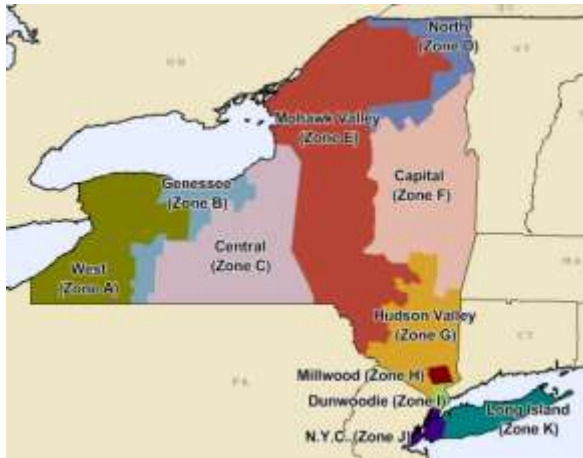
Impact pathways under development in US-REGEN for this study

Changes in:

Other policy, resource, customer drivers
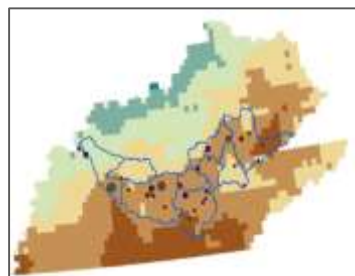

Air temperature

Water temperature

Water availability

Cooling technology choice

Increased cooling / decreased heating → End-use technology choice

Transmission impacts → Add inter-region transmission capacity

Decreased thermal efficiency / increased cooling cost (EPRI SOAPP model)

Changes in availability of hydro generators

Generation capacity addition and dispatch decisions

Illustrative climate drivers from Cumberland Basin study (ORNL 2016)

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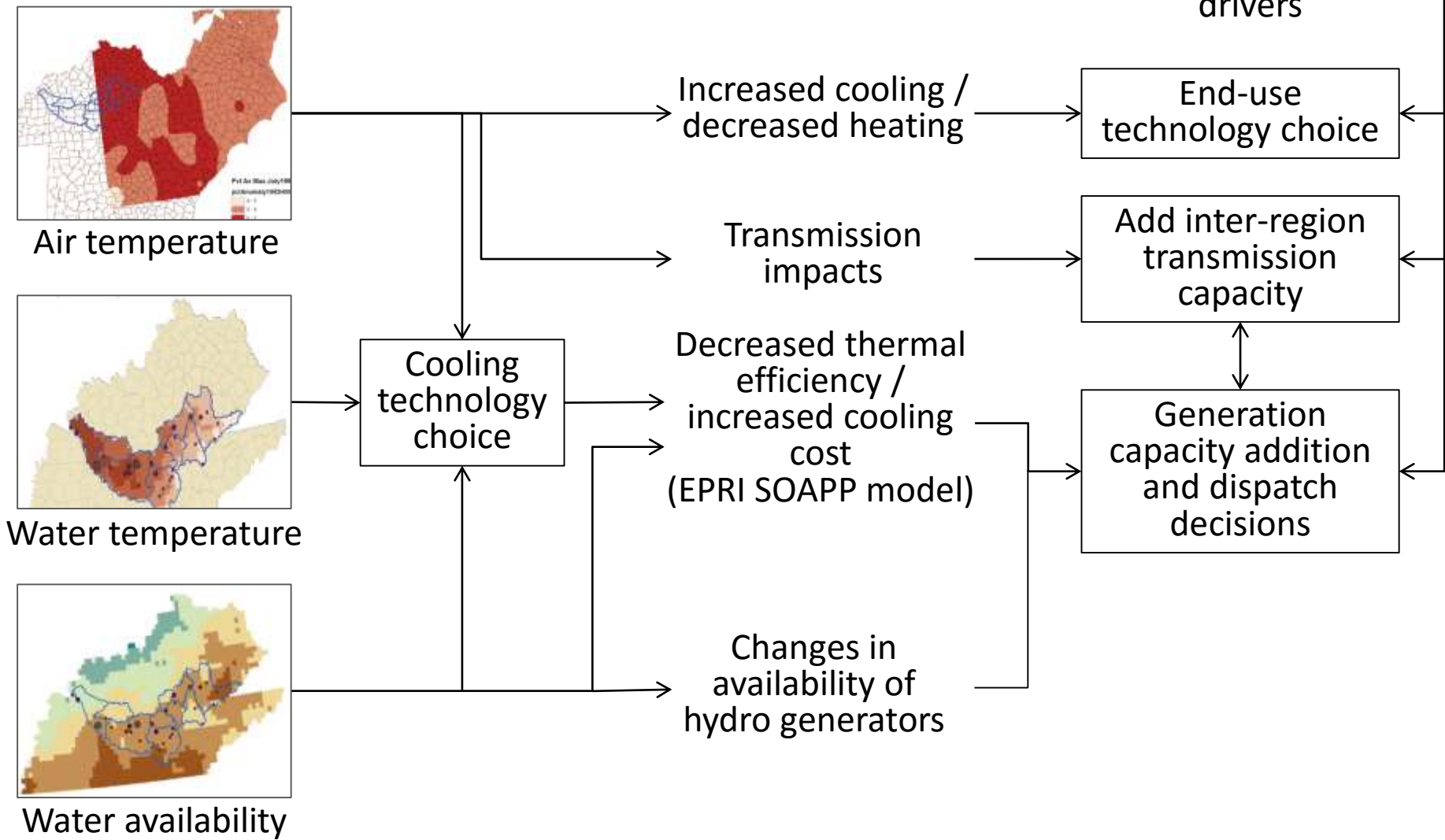
References

US-REGEN Model Documentation (2016 version)

http://eea.epri.com/usregen

**Recent Publicly Available Research using US-REGEN**

Technical and Economic Challenges of Flexible
Operations: Case Studies of California and Texas

Understanding Clean Power Plan Choices in Michigan:
Options and Uncertainties

Potential Cross-State Power Flow Impacts of the CPP
around Minnesota

http://eea.epri.com/research.html

http://eea.epri.com/cpp

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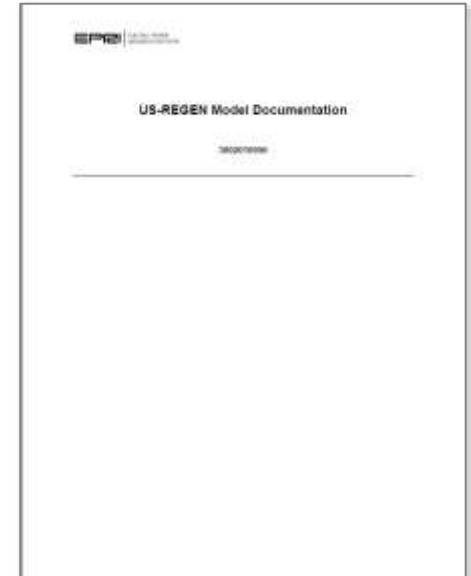
Together…Shaping the Future of Electricity

David Young
650 855 8927
dyoung@epri.com

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New York Transmission Zones

Source: Federal Energy Regulatory Commission

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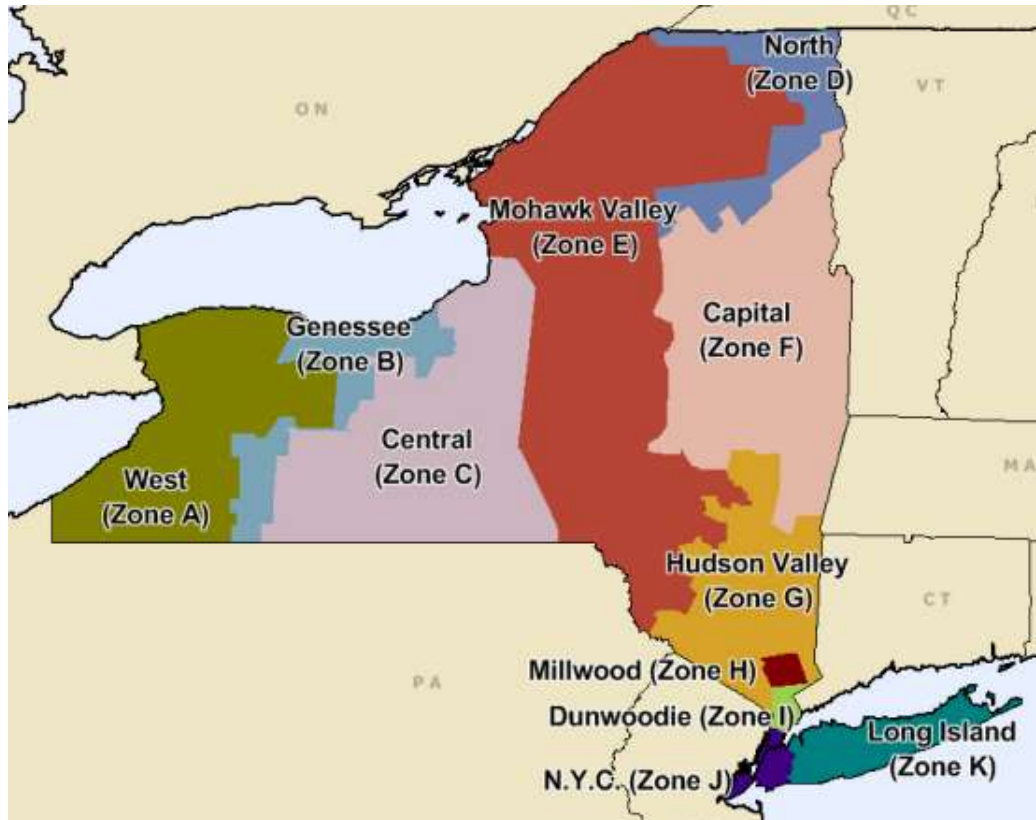
Example: Michigan CPP Study

Question: What are the impacts to Michigan of choosing a mass- vs. rate-based compliance pathway for the Clean Power Plan?

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Rest of U.S. Compliance Sensitivity: MixA

Legend:
- **Rate State** (blue)
- **Rate Performance** (light blue)
- **Mass Full** (orange)
- **Mass Existing** (tan)

Assume all existing mass states trade together (tons CO_2); all rate states trade together (ERCs); CA doesn't trade, and RGGI only trades within RGGI

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Rest of U.S. Compliance Sensitivity: MixB

Assume all existing mass states trade together (tons CO_2); all rate states trade together (ERCs); CA doesn't trade, and RGGI only trades within RGGI

Generation Impact of Mass Compliance (No Trading)
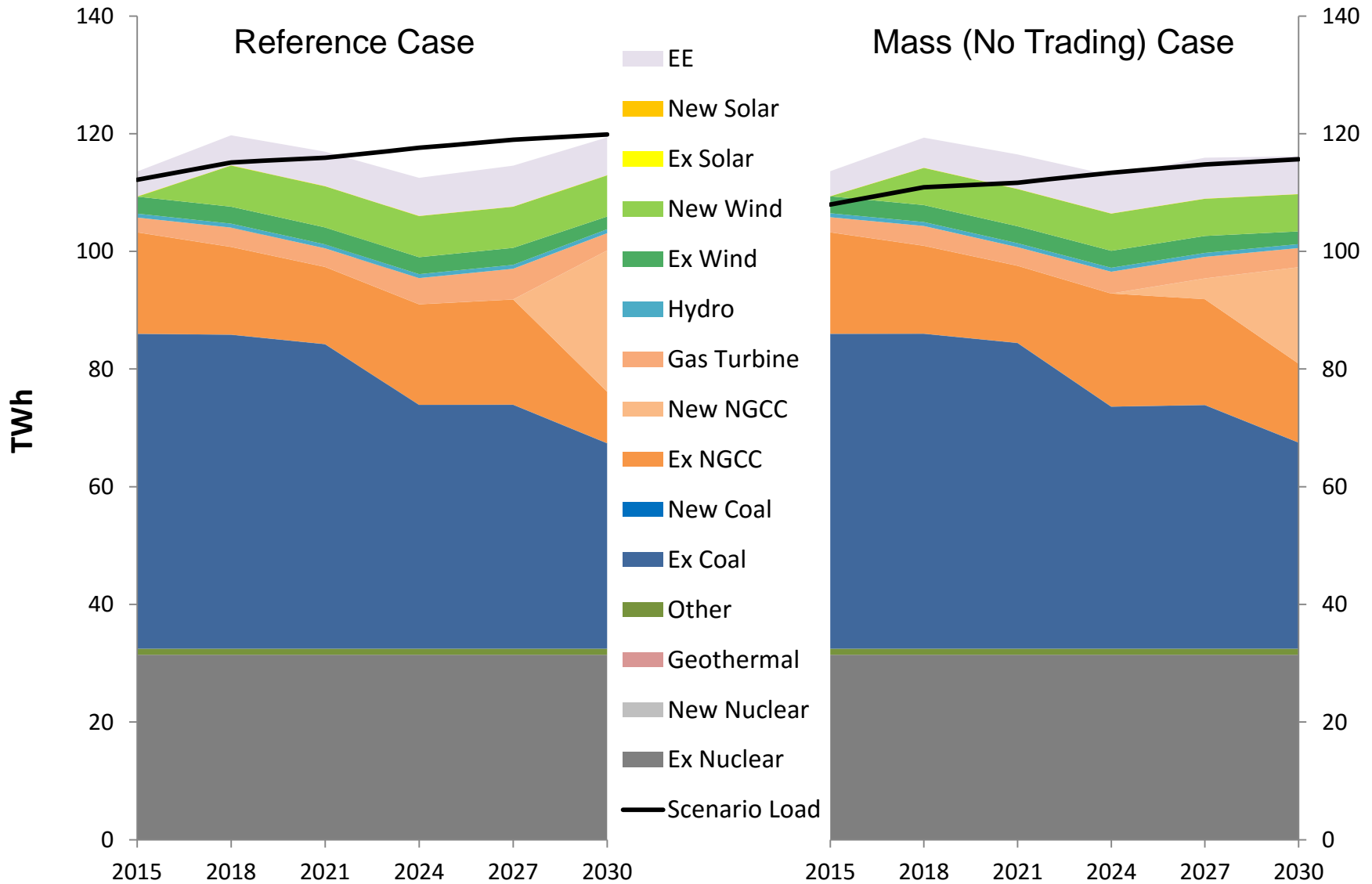
Michigan Likely to Meet Mass Targets if Planned Coal Retirements Take Place

Emissions from Existing Steam & NGCC Units vs. CPP State Target

Legend: Target — Reference — AnnouncedRetire — HighGasPrice

Y-axis: Million Short Tons CO_2 (0–70)
X-axis: 2015, 2018, 2021, 2024, 2027, 2030
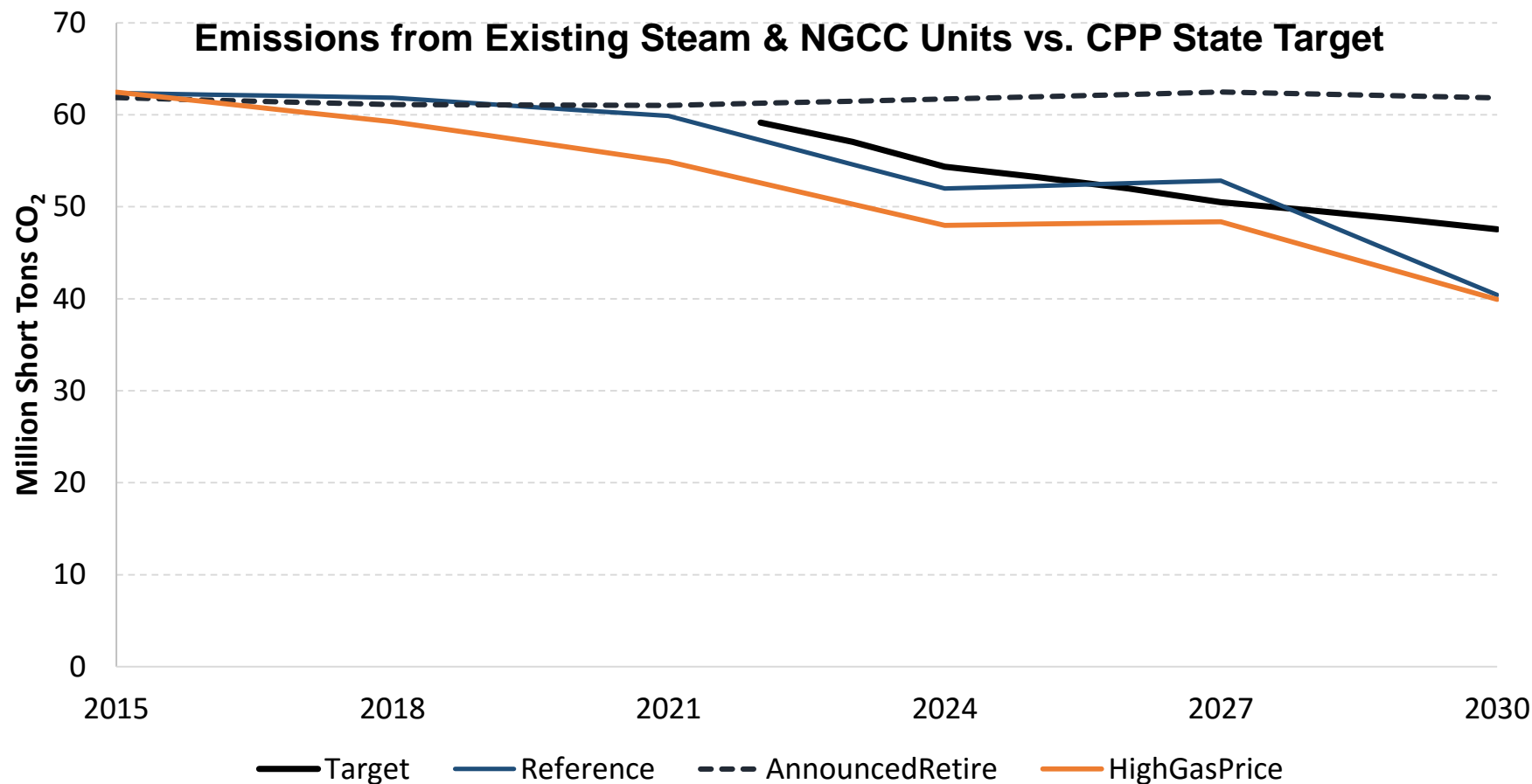
Higher gas prices lower CO_2 emissions from existing NGCC units, which, in addition to likely coal retirements, helps Michigan mass compliance.

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Different Trading Mixes (by Other States) Don't Significantly Change Michigan's Compliance Costs

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