Future Power Markets Forum

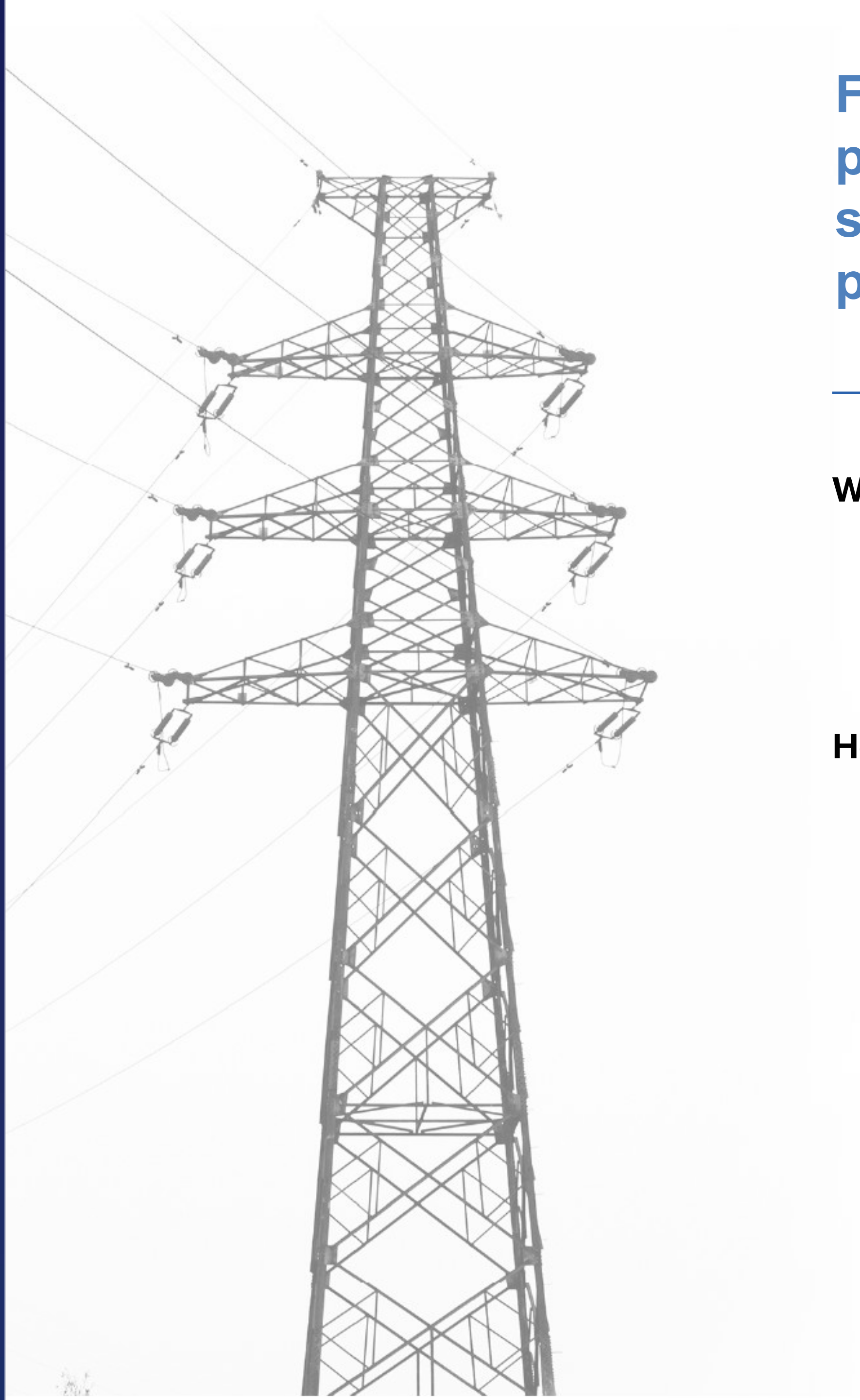
Economics of Resource Adequacy in a Decarbonized Energy System

A PROJECT OF

JOHNS HOPKINS
ENVIRONMENTAL HEALTH
& ENGINEERING

COLUMBIA | SIPA
Center on Global Energy Policy

About Future Power Markets Forum



Future Power Markets Forum investigates proposals for market designs that maintain system efficiency and reliability with a high penetration of variable generation.

What

- Meetings of practitioners, experts and regulators
- Website and digital resource library to share the the research under discussion and the participant perspectives

How

- To encourage participation, there is no explicit or implied value judgment about whether we SHOULD have a high renewable penetration scenario
- To encourage candid discussions, Chatham House Rule will be followed (no attribution to individual speakers outside the meeting)
- To provide a high-quality resource to stakeholders and policy makers, presentations will be posted publicly if authorized by the speaker
- To ensure balance and quality, a diverse advisory committee will provide input on content and speakers

Speakers

Moderator

Dr. Susan Tierney
Analysis Group

Speakers

Dr. Peter Cramton
University of Maryland and University of Cologne

Dr. James Bushnell
University of California Davis

ANALYSIS GROUP

Resource Adequacy:
Future Power Markets Forum
Moderator Comments on the Context for Resource Adequacy Approaches

Sue Tierney

Analysis Group

February 10, 2021

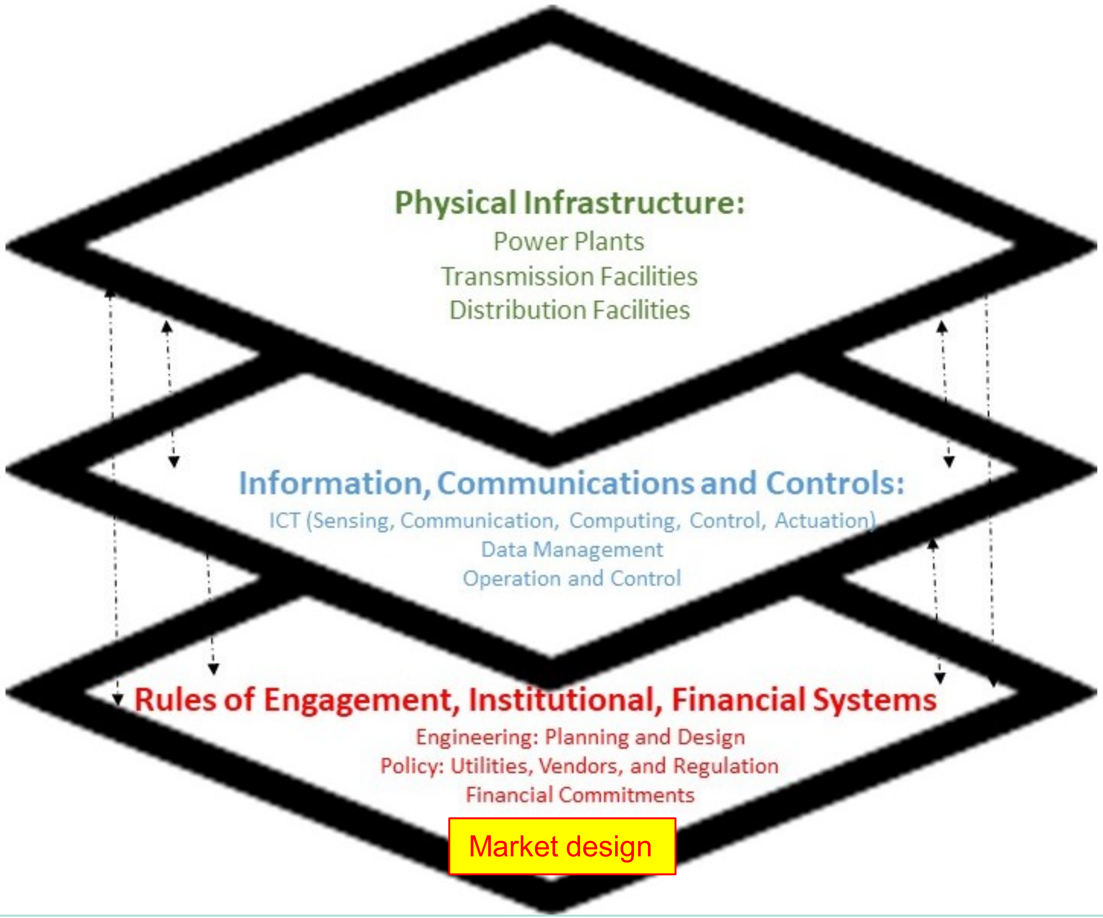
ANALYSIS GROUP

Do we still need a physical requirement for resource adequacy?

Context matters: Electric system "architecture"

Architecture:

Complex set physical, communications and institutional systems ("layers") that have to interact with each other to keep the lights on

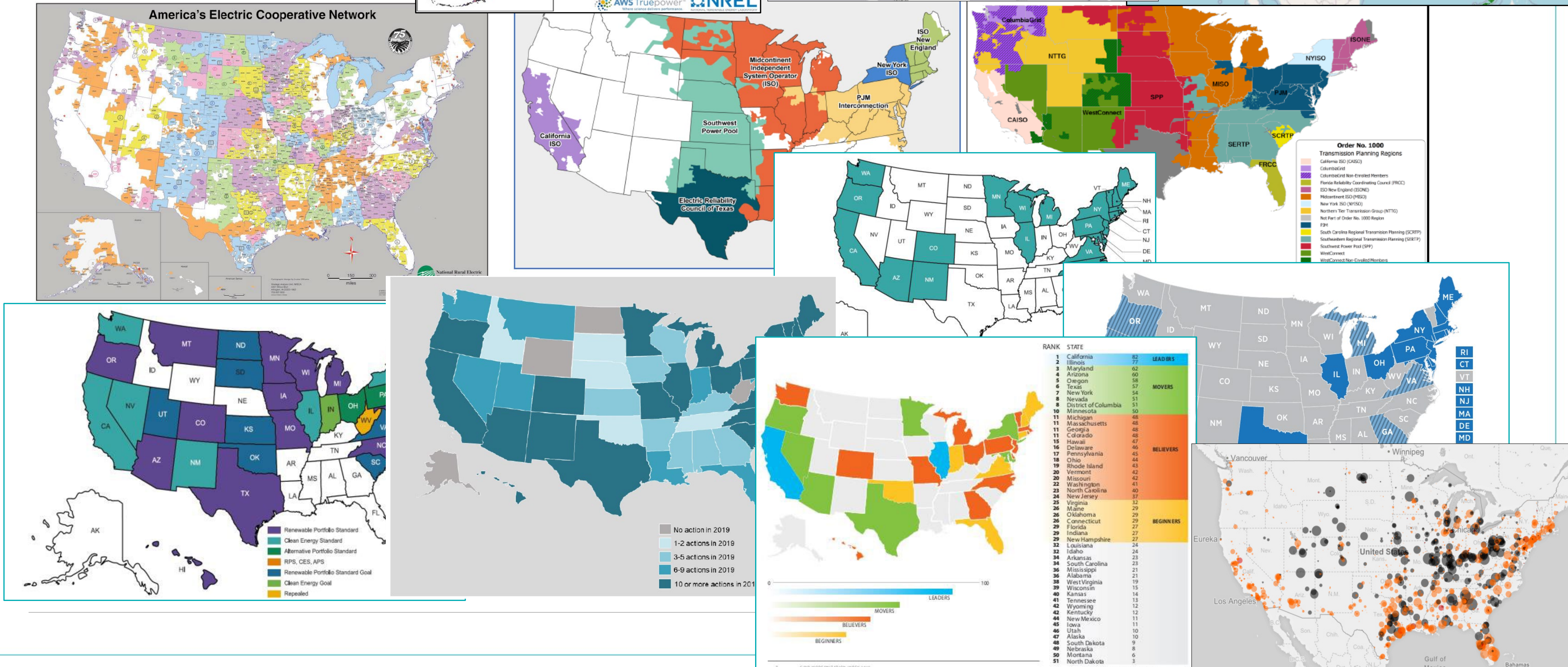


Market design matters, but so do other aspects of the electric system architecture, including the physical infrastructure, policy conditions, etc.

ANALYSIS GROUP

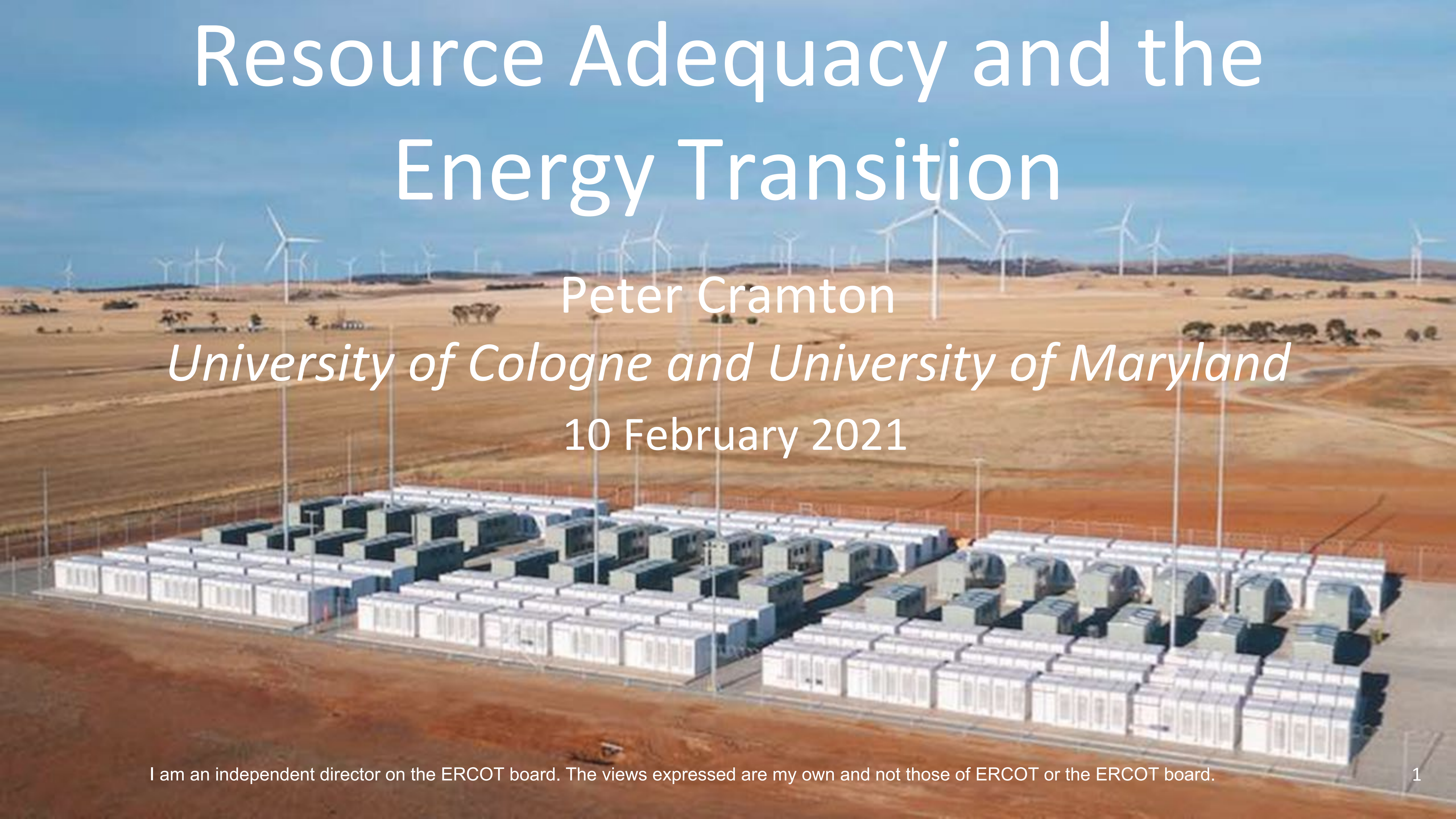
Do we still need a physical requirement for resource adequacy?

Context matters: So much variation (in resources, the grid, policies, etc.)



Do we still need a physical requirement for resource adequacy?

Context matters: Critical services depend on assured power supply



Resource Adequacy and the Energy Transition

Peter Cramton

University of Cologne and University of Maryland

10 February 2021

I am an independent director on the ERCOT board. The views expressed are my own and not those of ERCOT or the ERCOT board.

Buy enough in advance

- Buy: capacity is bought on behalf of load
  - Capacity = energy and reserves during shortage [vs anytime]
  - Capacity is a derivative of the real time market = *pay for performance* [vs exceptions, missing money]
- Enough:
  - Capacity demand curve to guarantee physical capability [vs vertical]
  - Capacity value = ability to provide energy during shortage [vs nameplate, EFORd]
- In advance:
  - Three years ahead for price formation [vs spot]

Learning to ride a bike: does a capacity market help or hurt?

$125

$55

$13,000


S-WORKS
SPECIALIZED
SPECIALIZED
DURA-ACE
RAPIDE
CLX
RAPIDE
CLX
roval
roval
roval
roval

First fix your spot market

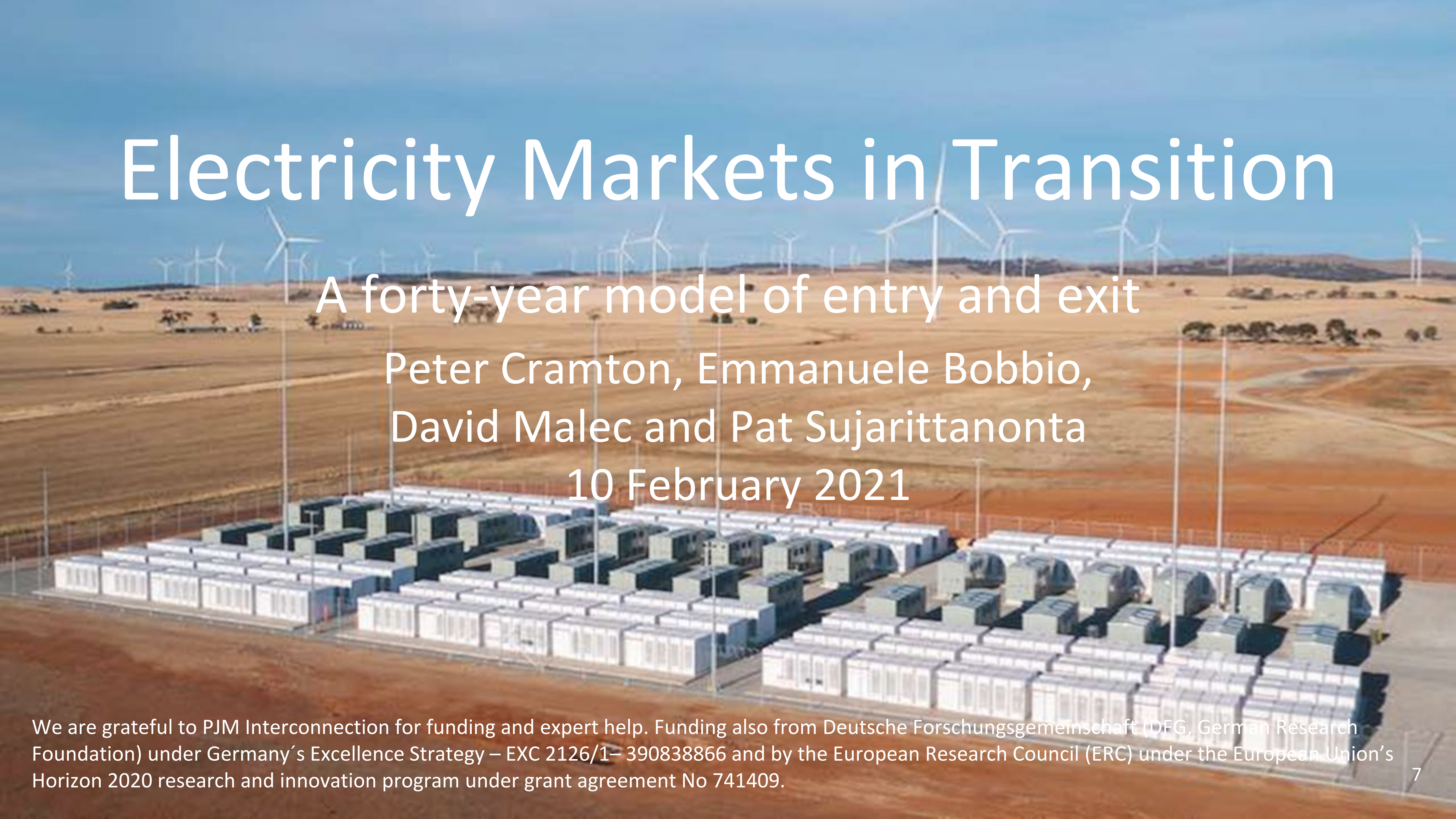
- Financial day ahead market for scheduling
  - Co-optimize energy and reserves to maximize as-bid social welfare subject to constraints
  - Allow simple expression of unit characteristics and economics (3-part bids for fossil)
  - Allow virtual bids and offers to arbitrage between day ahead and real time markets
  - Automatically mitigate market power if it appears due to local constraints
- Physical real time market for dispatch and settlement
  - Co-optimize energy and reserves to maximize as-bid social welfare subject to constraints
  - Automatically mitigate market power if it appears due to local constraints

Result: Day-ahead and real-time prices that induce efficient behavior!

Is reliability a public good?

- Absent demand response, yes.
- But an effective market encourages demand response with
  - Demand curves for reserves that reflect the value of avoiding shortage ($9000 shortage price)
  - Rate plans that let the consumer see and feel the real-time price on the margin
    (it is fine if most consumers select a flat rate plan!)
  - Emergency demand response that pays customers to reduce in emergency
    - ERCOT has 2 GW
    - Pay-for-performance is key (e.g ERCOT Aug 2019 vs CA Aug 2020)

Result: reliability is no longer a problem (and is not a public good)



Electricity Markets in Transition

A forty-year model of entry and exit

Peter Cramton, Emmanuele Bobbio,
David Malec and Pat Sujarittanonta

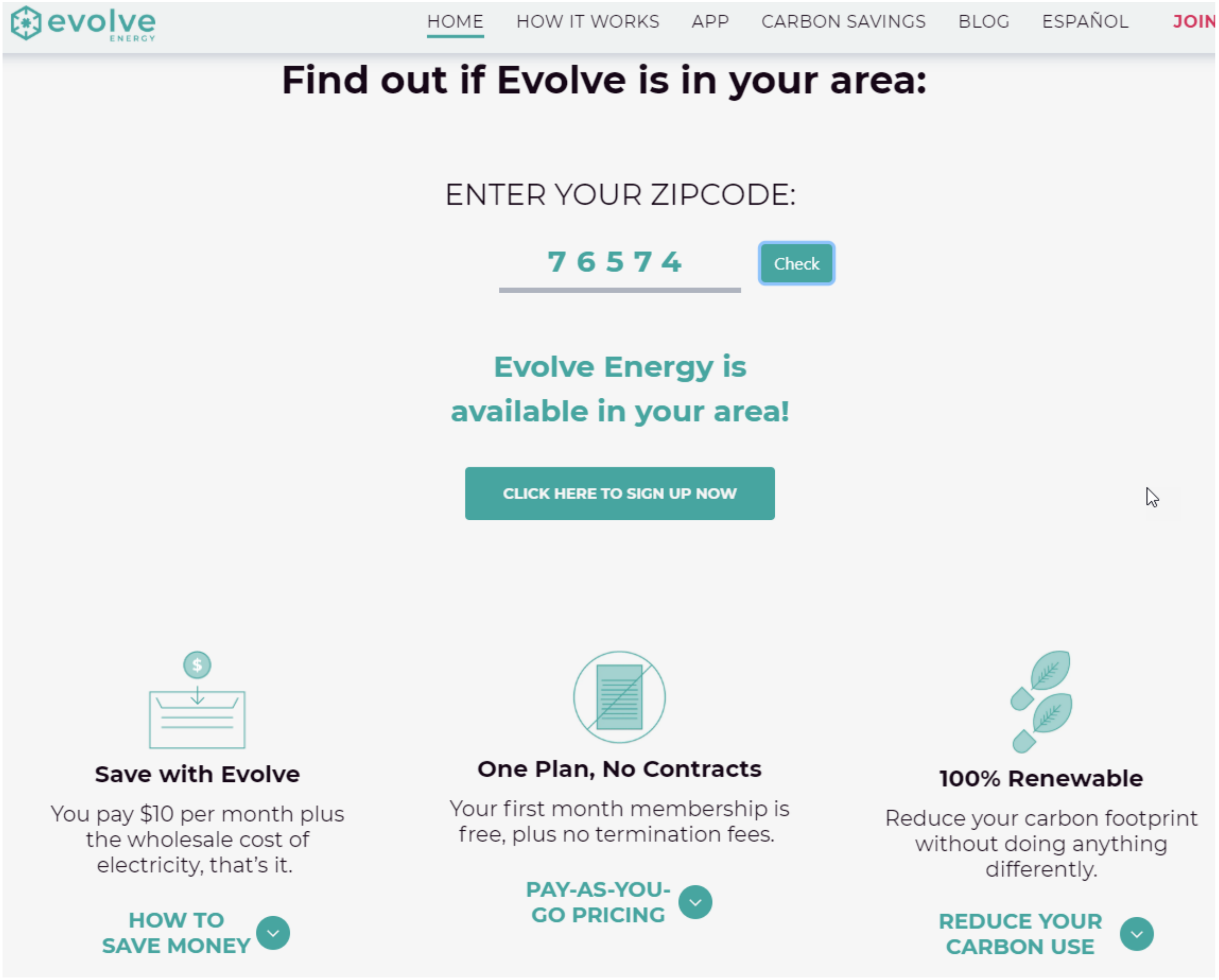
10 February 2021

We are grateful to PJM Interconnection for funding and expert help. Funding also from Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany´s Excellence Strategy – EXC 2126/1– 390838866 and by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program under grant agreement No 741409.


Welcome
THE FUTURE
IS NOW


DUAL MOTOR

Electricity market design matters



Texas (ERCOT): $10/month plus wholesale cost of 9 cents/kWh

	cents
real time price	3.8
delivery	3.7
taxes & fees	1.4
wholesale cost	8.9

California ISO:
$16/month + about 36 cents/kWh

400% more than Texas!

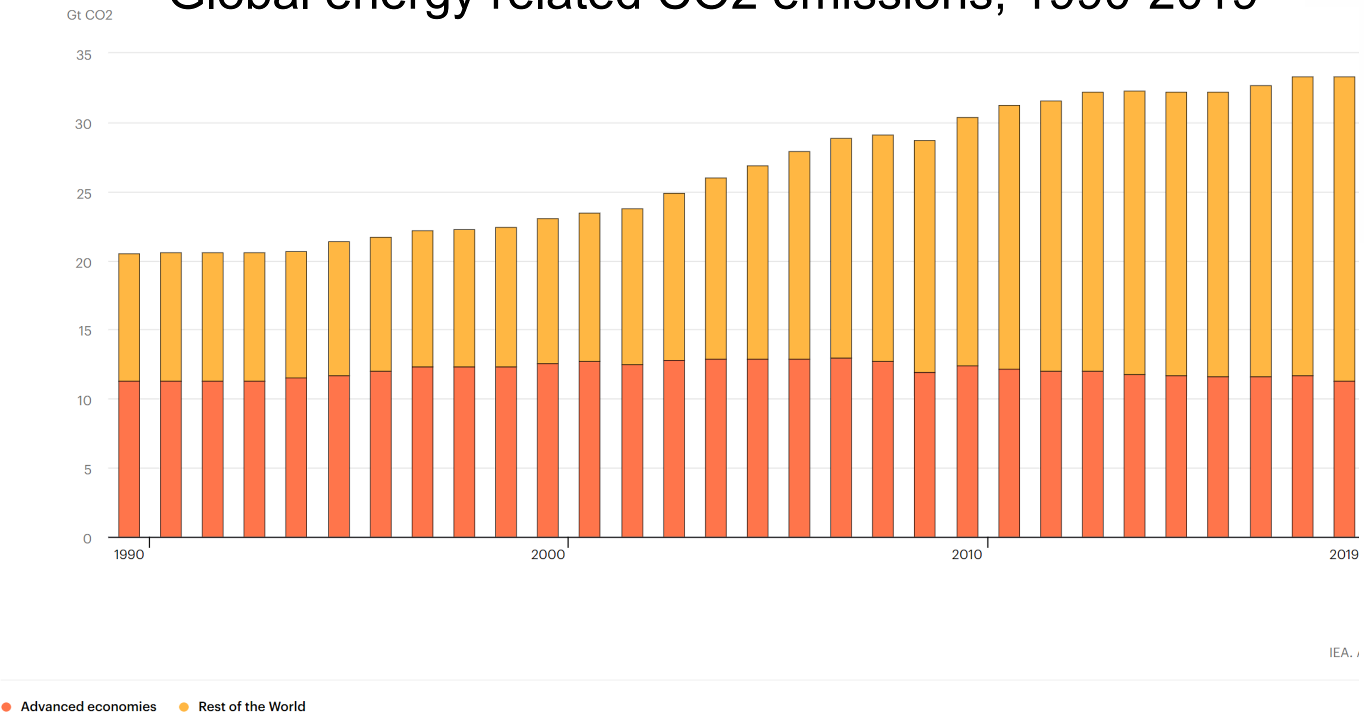
EV-TOU-5, a plan for your home and electric vehicle: This new plan is similar to EV-TOU-2 but the On-Peak and Off-Peak pricing is reduced by one cent kW/h and the Super Off-Peak rate is reduced to **just 9¢** kW/h when you pay a Basic Monthly Service Fee of $16. Super Off-Peak hours are midnight to 6 am weekdays, and midnight to 2 pm on weekends and holidays.

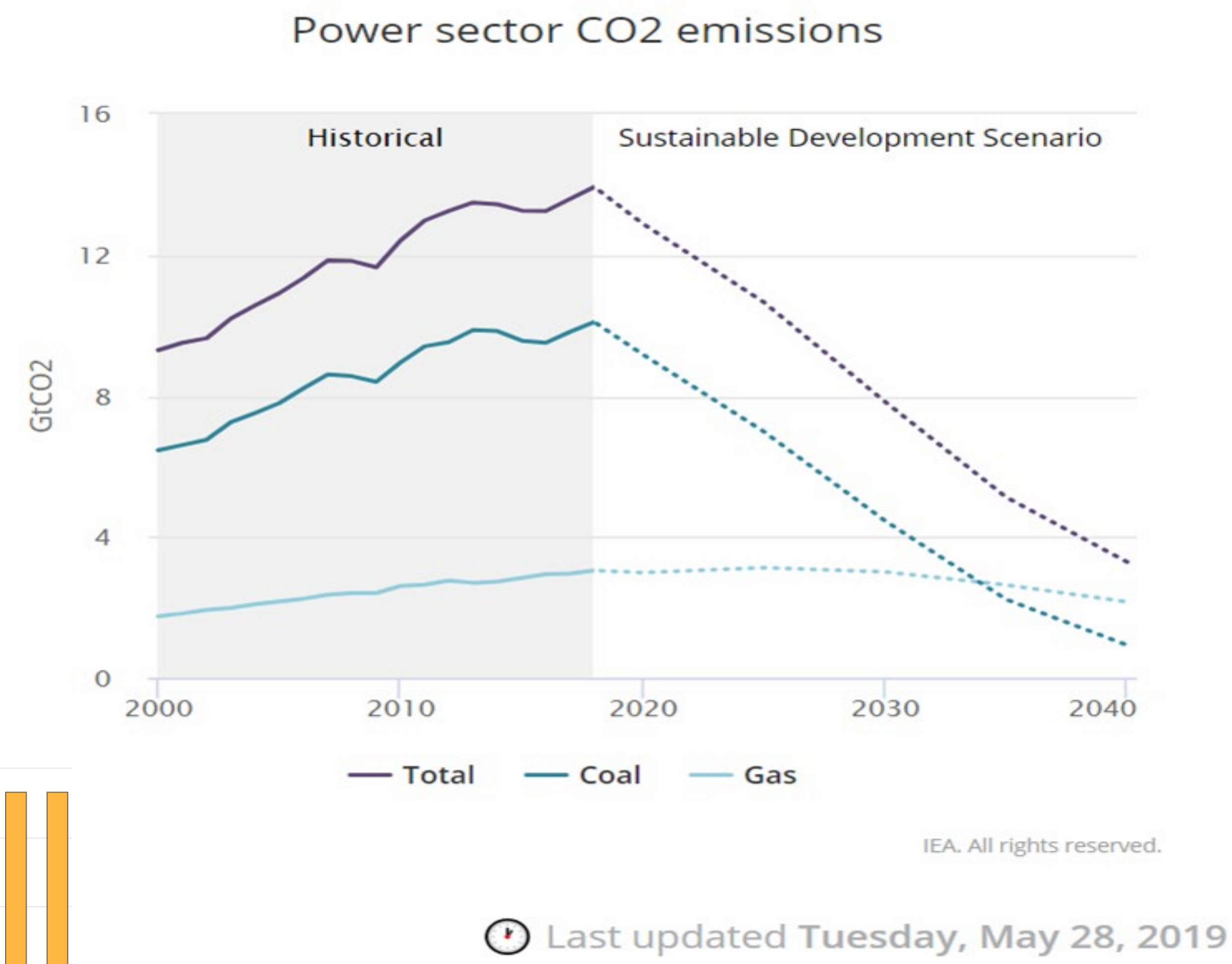
SDGE EV Time of Use Plans (cents/kWh)

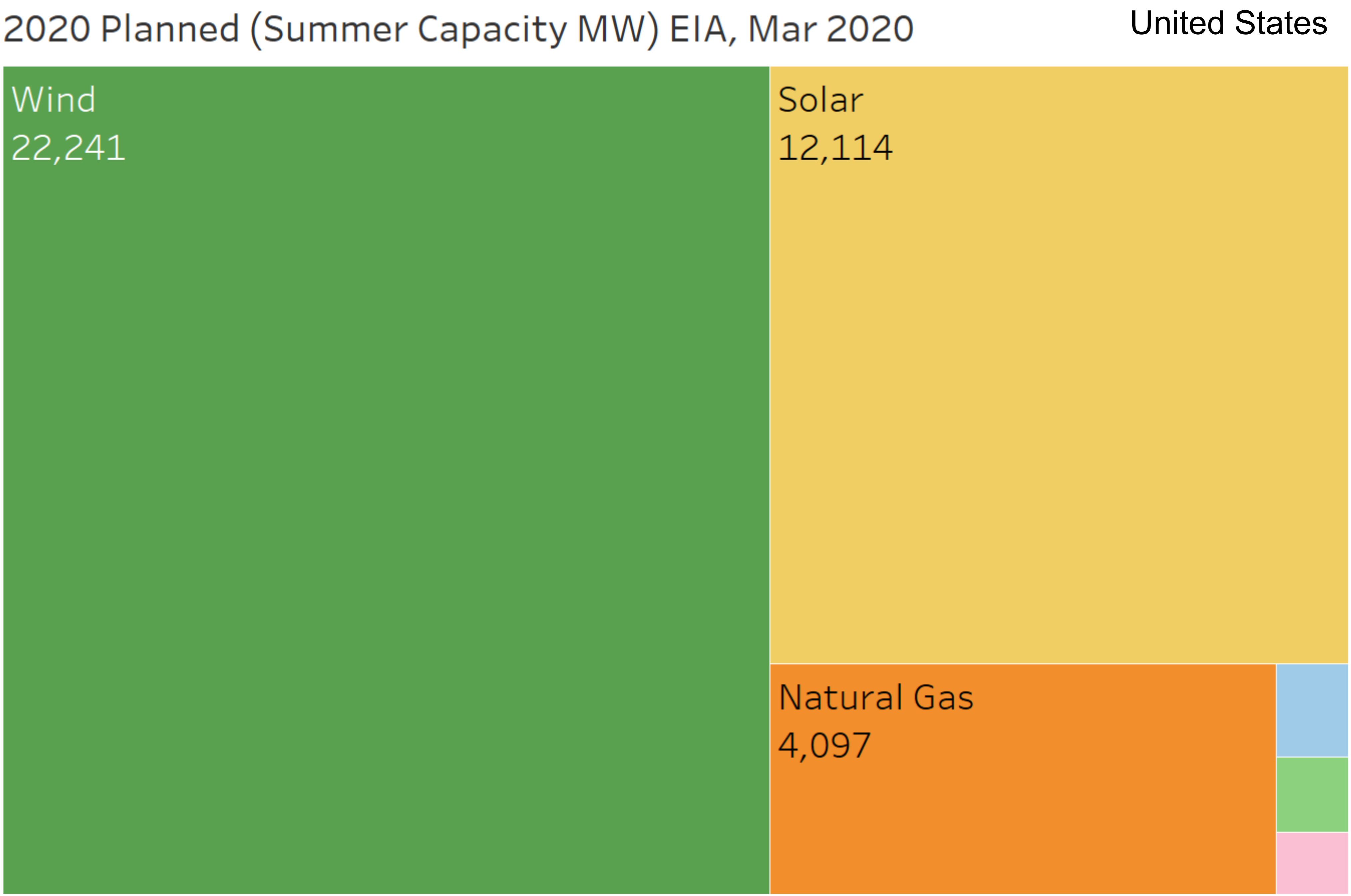
	Peak	Off peak	Super off peak
Hours	16-21	6-15, 22-23	0-5
Winter	26	25	9
Summer	50	29	9

Climate policy matters

Global energy related CO2 emissions, 1990-2019

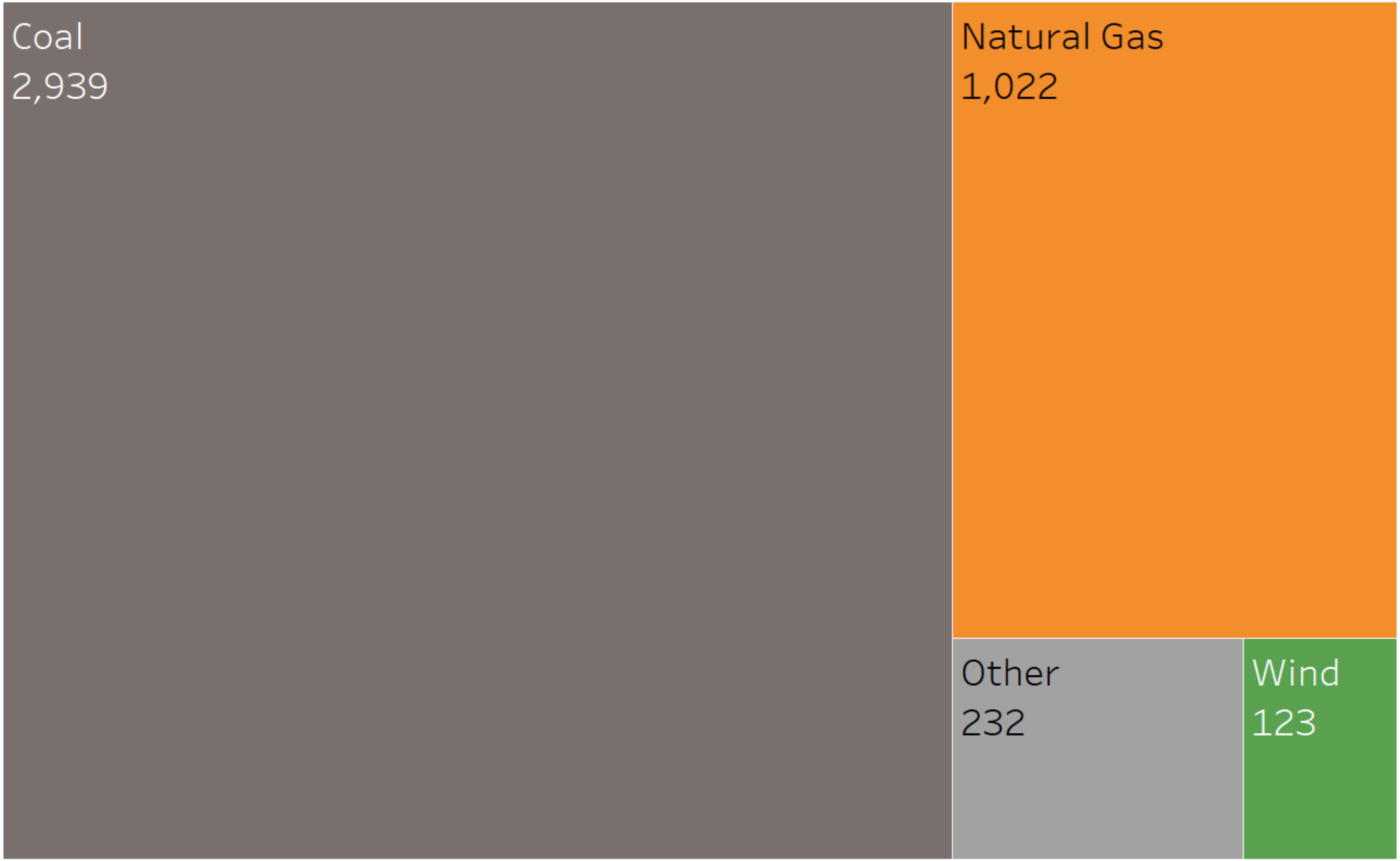





2020 Planned (Summer Capacity MW) EIA, Mar 2020
United States
Wind
22,241
Solar
12,114
Natural Gas
4,097

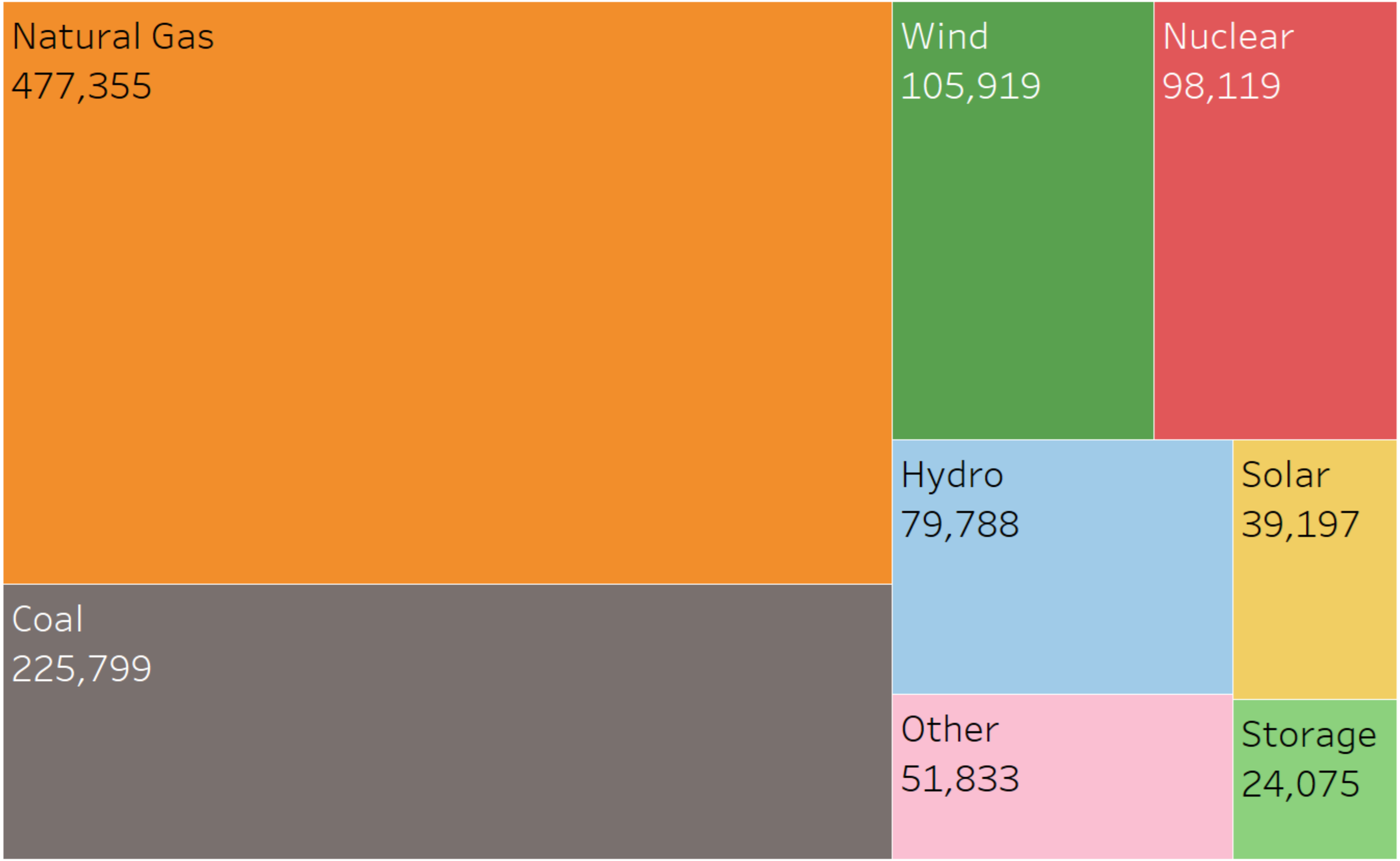
2020 Retiring (Summer Capacity MW) EIA, Mar 2020

United States



Summer Capacity MW, EIA, Mar 2020

United States



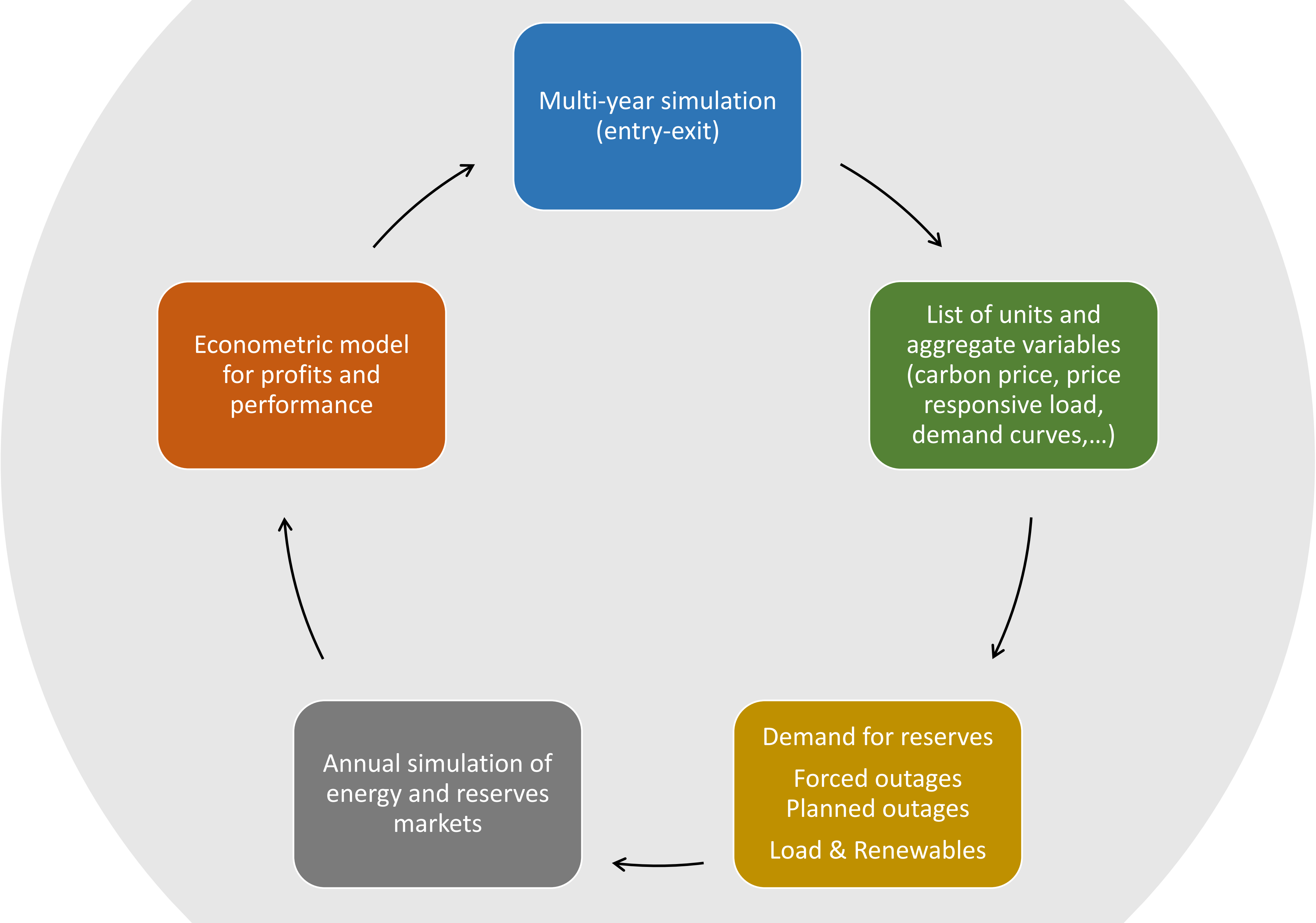
Mar 2020	MW
Total	1,102,084
Planned	39,034
Retiring	4,316
Change	43,350 3.9%

How does transition depend on market rules and policy?

Long run model

Not steady state

Must model energy market


Multi-year simulation
(entry-exit)
List of units and
aggregate variables
(carbon price, price
responsive load,
demand curves,…)
Demand for reserves
Forced outages
Planned outages
Load & Renewables
Annual simulation of
energy and reserves
markets
Econometric model
for profits and
performance

Storage

Batteries are fundamentally different

Marginal cost (benefit) is opportunity cost (benefit)

Opportunity cost depends on price expectations and capabilities

Approach

Day ahead: directly model battery characteristics and schedule optimally

Real time: optimally dispatch based on linear program

Price responsive demand

Portion of load is traditional

Portion of load is price responsive

- Constant elasticity (a 1% increase in price, decreases quantity by 0.1%)

Demand curve for price responsive demand explicitly modeled

Energy market model

Three main processes:

- Unit Commitment/Scheduling is mixed integer program that runs every hour on the half hour.
  - First run at 14:30 prior day; fixes day ahead price/quantity
  - Updated once an hour until end of day in question
- Dispatch is linear program that runs every 5 minutes
  - Fixes real time price
- Settlement models how units handle dispatch instructions and runs every 5 minutes
  - Fixes real time quantity

Examples

10:05 Timepoint:
Settle 10:05-10:10
Dispatch 10:15-10:25

11:30 Timepoint:
Settle 11:30-11:35
Dispatch 11:40-11:50
Schedule 12:00-24:00

17:30 Timepoint:
Settle 17:30-17:35
Dispatch 17:40-17:50
Schedule 18:00-24:00
Schedule Next Day

Unit commitment optimization (simplified)

Maximize:

$$\sum_t \mathrm{Benefit}_t(PriceResponse_t) + \sum_t \mathrm{ORDC}_t(Reserve_t) - \sum_t \sum_i \left(\mathrm{Cost}_i(generation_{i,t}) + \mathrm{StartCost}_i \cdot start_i\right)$$

Subject to:

- Market clearing: $NetLoad_t + PriceResponse_t = \sum_i generation_{i,t} + \sum_j \left(discharge_{j,t} - charge_{j,t}\right) \ \forall t$
- Aggregate reserves: $Reserve_t = \sum_i reserve_{i,t} + \sum_j reserve_{j,t} \quad \forall t$
- Generation operating constraints
- Storage operating constraints

Unit commitment optimization (simplified)

Generation unit constraints:

Storage unit constraints:

feasible output ranges

$$generation_{i,t} \geq \mathrm{MinGeneration}_i \cdot on_{i,t} \qquad \forall t, \forall i$$
$$generation_{i,t} \leq \mathrm{MaxGeneration}_i \cdot on_{i,t} \qquad \forall t, \forall i$$
$$generation_{i,t} \geq generation_{i,t-1} - 60 \cdot \mathrm{Ramp}_i \qquad \forall t, \forall i$$
$$generation_{i,t} \leq generation_{i,t-1} + 60 \cdot \mathrm{Ramp}_i \qquad \forall t, \forall i$$

$$charge_{j,t} \leq \mathrm{MaxCharge}_j \qquad \forall t, \forall j$$
$$discharge_{j,t} \leq \mathrm{MaxDischarge}_j \qquad \forall t, \forall j$$

unit state consistency

$$start_{i,t} \geq on_{i,t} - on_{i,t-1} \qquad \forall t, \forall i$$
$$on_{i,t} \geq \sum_{s=0}^{\mathrm{MinOnline}_i} start_{i,t-s} \qquad \forall t, \forall i$$
$$on_{i,t} \leq \sum_{s=0}^{\mathrm{MinOffline}_i} \left(1 - start_{i,t+s}\right) \qquad \forall t, \forall i$$

$$stored_{j,t} - stored_{j,t-1} = \mathrm{Efficiency}_i \cdot charge_{j,t} - discharge_{j,t} \qquad \forall t, \forall j$$
$$stored_{j,t} \leq \mathrm{MaxStored}_j \qquad \forall t, \forall j$$
$$stored_{j,t} \geq 0 \qquad \forall t, \forall j$$

reserve provisioning

$$reserve_{i,t} \leq 10 \cdot \mathrm{Ramp}_i \cdot on_{i,t} \qquad \forall t, \forall i$$
$$reserve_{i,t} + generation_{i,t} \leq \mathrm{MaxGeneration}_i \qquad \forall t, \forall i$$

$$reserve_{j,t} + discharge_{j,t} \leq \mathrm{MaxDischarge}_j + charge_{j,t} \qquad \forall t, \forall j$$
$$reserve_{j,t} \leq stored_{j,t} \qquad \forall t, \forall j$$

Econometric model for profits & performance

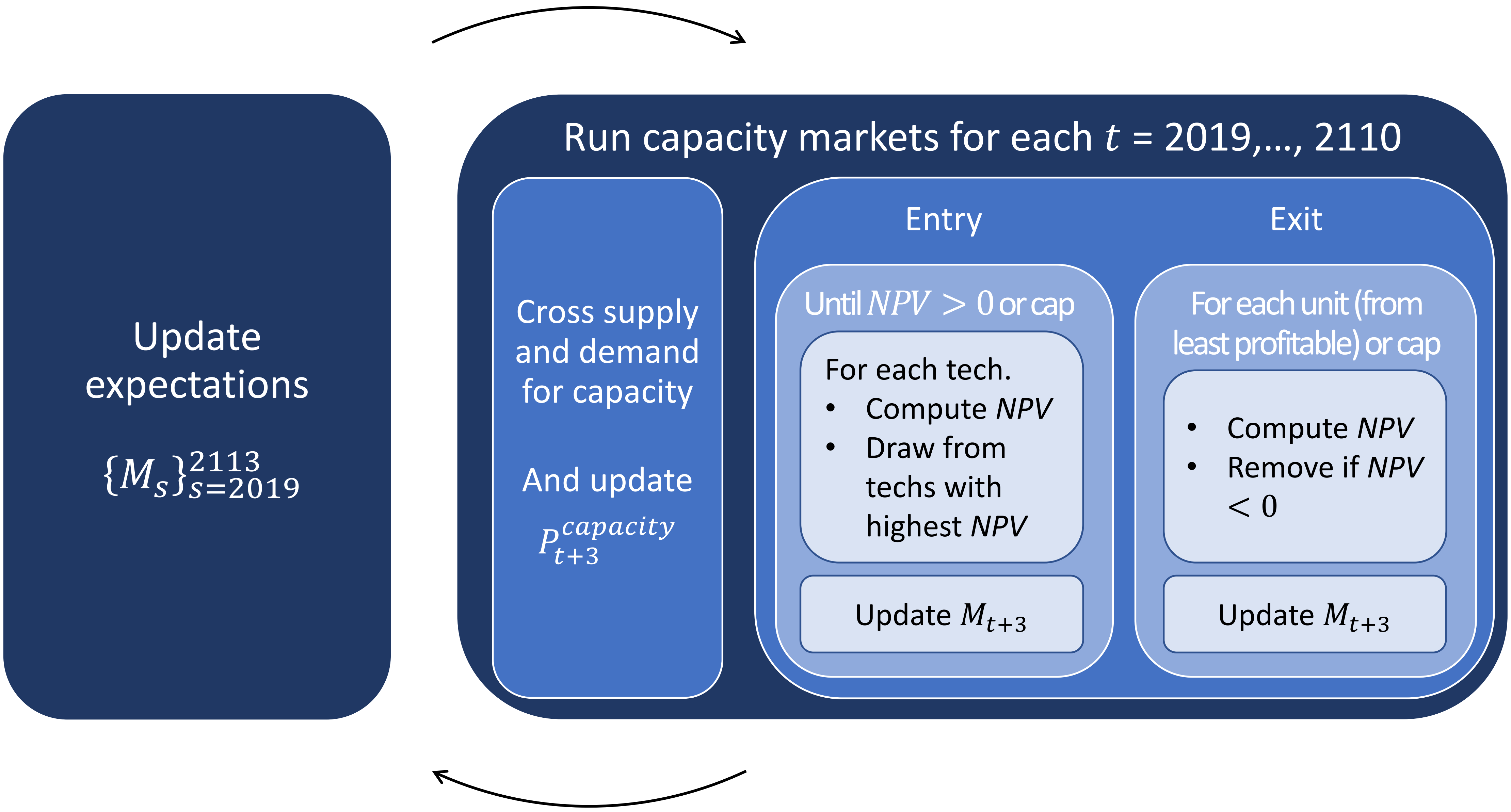
Problem

- Energy market model can do 50 runs per day on high-end server
- Multi-year simulation makes 80 million calls, would take 4000 years

Solution

- Use energy market model to create 20 thousand known instances
- Estimate econometric model for energy profits and performance
- Profits and performance are highly non-linear
  - Carbon price can increase profits for gas units when lots of coal in market
- Use ensemble combining fast predictors
  - Classifier (e.g., tree) to partition data into relatively homogenous regions
  - Apply separate regression model in each sub-region

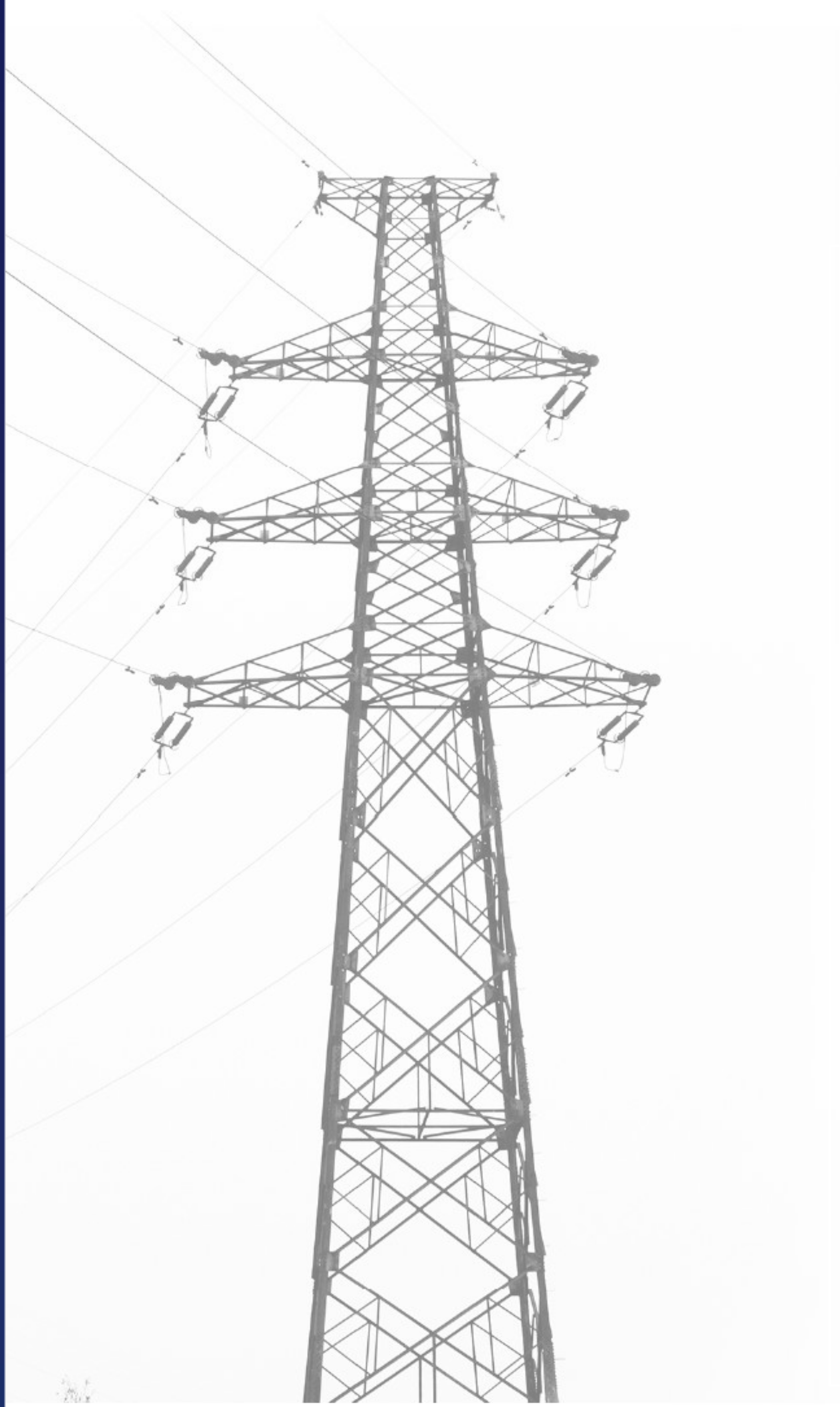
Multi-year simulation, iterate until expectations reasonably accurate



Detailed evidence of impact of market rules and policies on:

- Pace of transition
- Market efficiency
- Cost to load
- Reliability

Future Power Markets Forum
Sponsors



Thank You

Advanced Energy Economy

American Council on Renewable Energy

American Public Power Association

American Wind Energy Association

Calpine

ClearPath

Clearway Energy

Electric Power Supply Association

Electric Power Research Institute

Electricity Consumers Resource Council

Enel Foundation

Energy Foundation

Exelon

Google

Gridlab

ISO New England

Microsoft

Midcontinent Independent System Operator

National Hydropower Association

New York Independent System Operator

NextEra

NRG Energy

National Hydropower Association

Nuclear Energy Institute

PJM Interconnection

Renewable Energy Buyers Alliance

Sustainable FERC

Tenaska

Vistra

Connect

Submit comments for the Future Power Markets Forum website

Website powermarkets.org

Contact team@powermarkets.org