

# Electricity Markets in Transition

A forty-year model of entry and exit

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A green road sign with a white border and a smaller 'Welcome' sign above it, set against a space background. The main sign is tilted and features the text 'THE FUTURE IS NOW' in white, bold, sans-serif capital letters. The background is a dark space scene with a green nebula on the left and a blue nebula on the right, with numerous stars scattered throughout.

Welcome

**THE FUTURE  
IS NOW**









# Electricity market design matters

## Find out if Evolve is in your area:

ENTER YOUR ZIPCODE:

7 6 5 7 4

Check

Evolve Energy is  
available in your area!

CLICK HERE TO SIGN UP NOW



### Save with Evolve

You pay \$10 per month plus the wholesale cost of electricity, that's it.

HOW TO  
SAVE MONEY 



### One Plan, No Contracts

Your first month membership is free, plus no termination fees.

PAY-AS-YOU-  
GO PRICING 



### 100% Renewable

Reduce your carbon footprint without doing anything differently.

REDUCE YOUR  
CARBON USE 

Texas (ERCOT):  
\$10/month plus  
wholesale price  
(3 cents/kWh)



# California ISO: \$16/month + more than 25 cents/kWh

**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

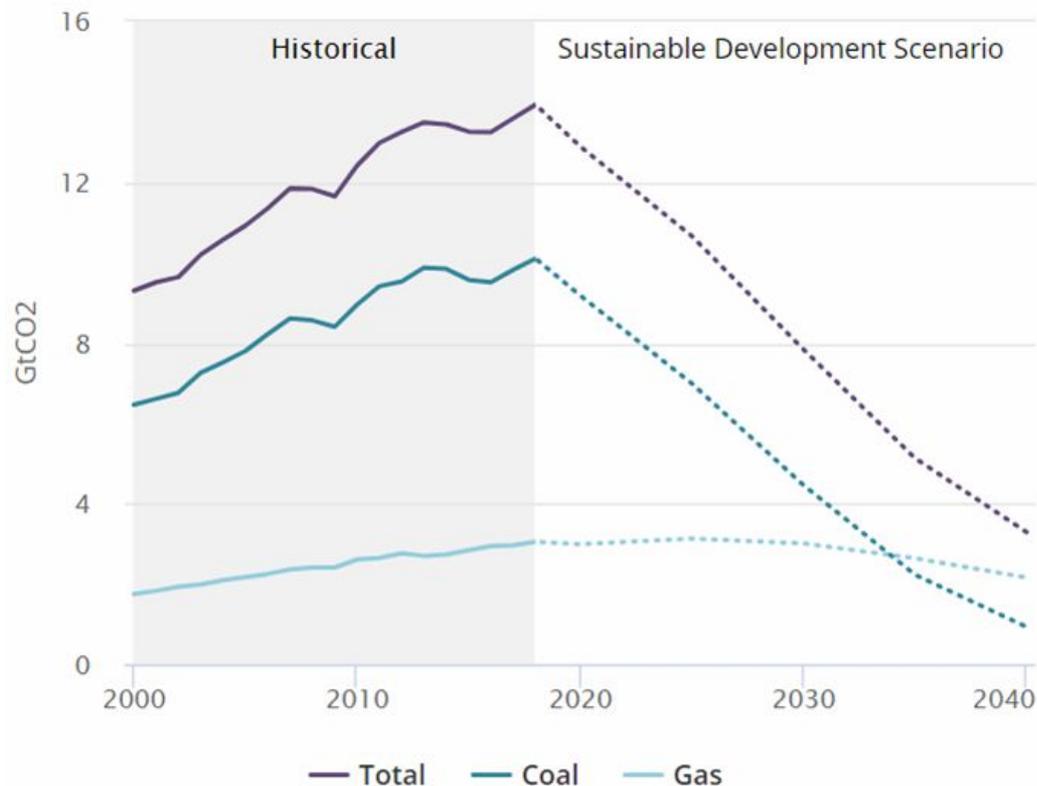
# Rich free-ride on poor thanks to net metering





# Climate policy matters

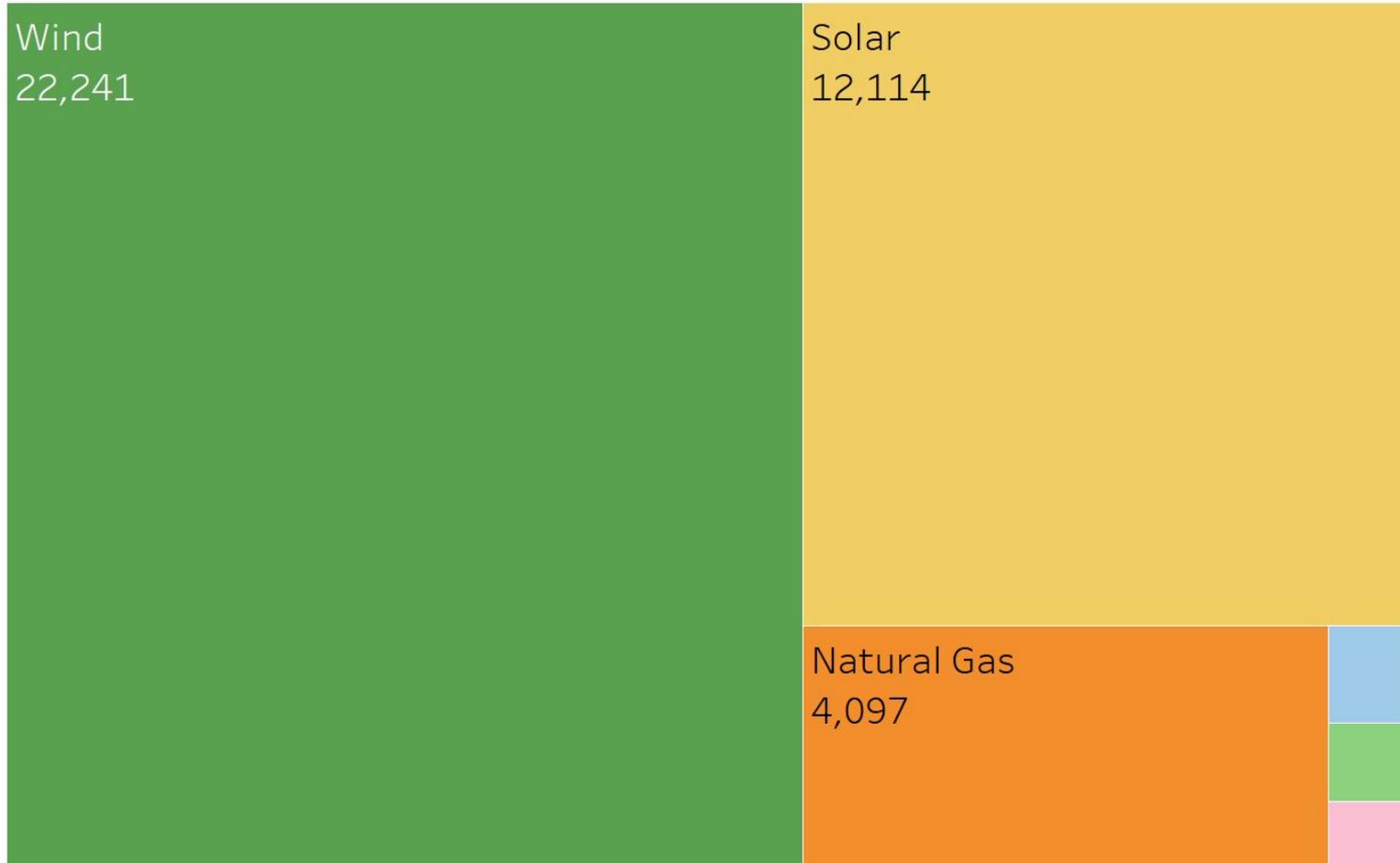
## Power sector CO2 emissions



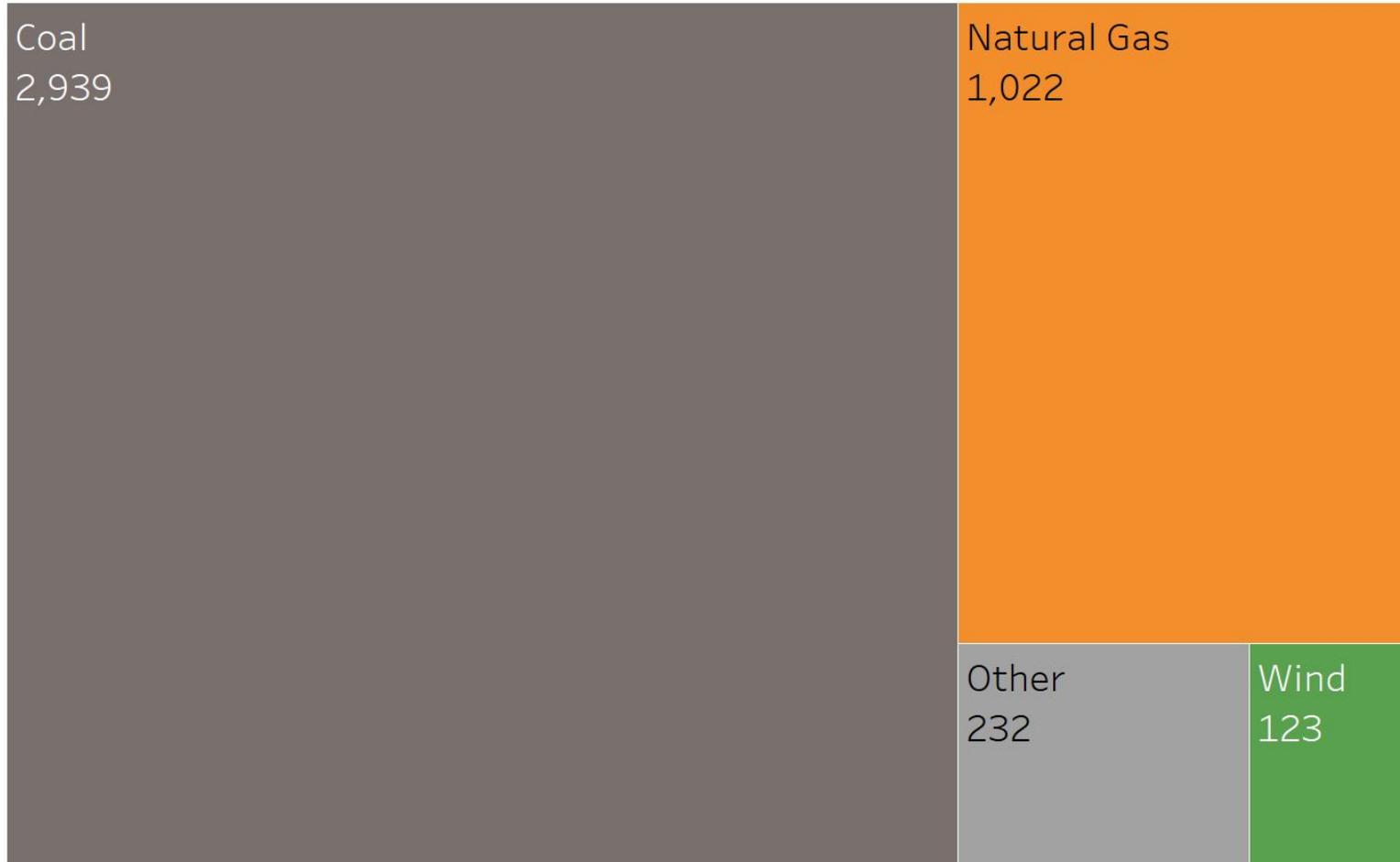
IEA. All rights reserved.



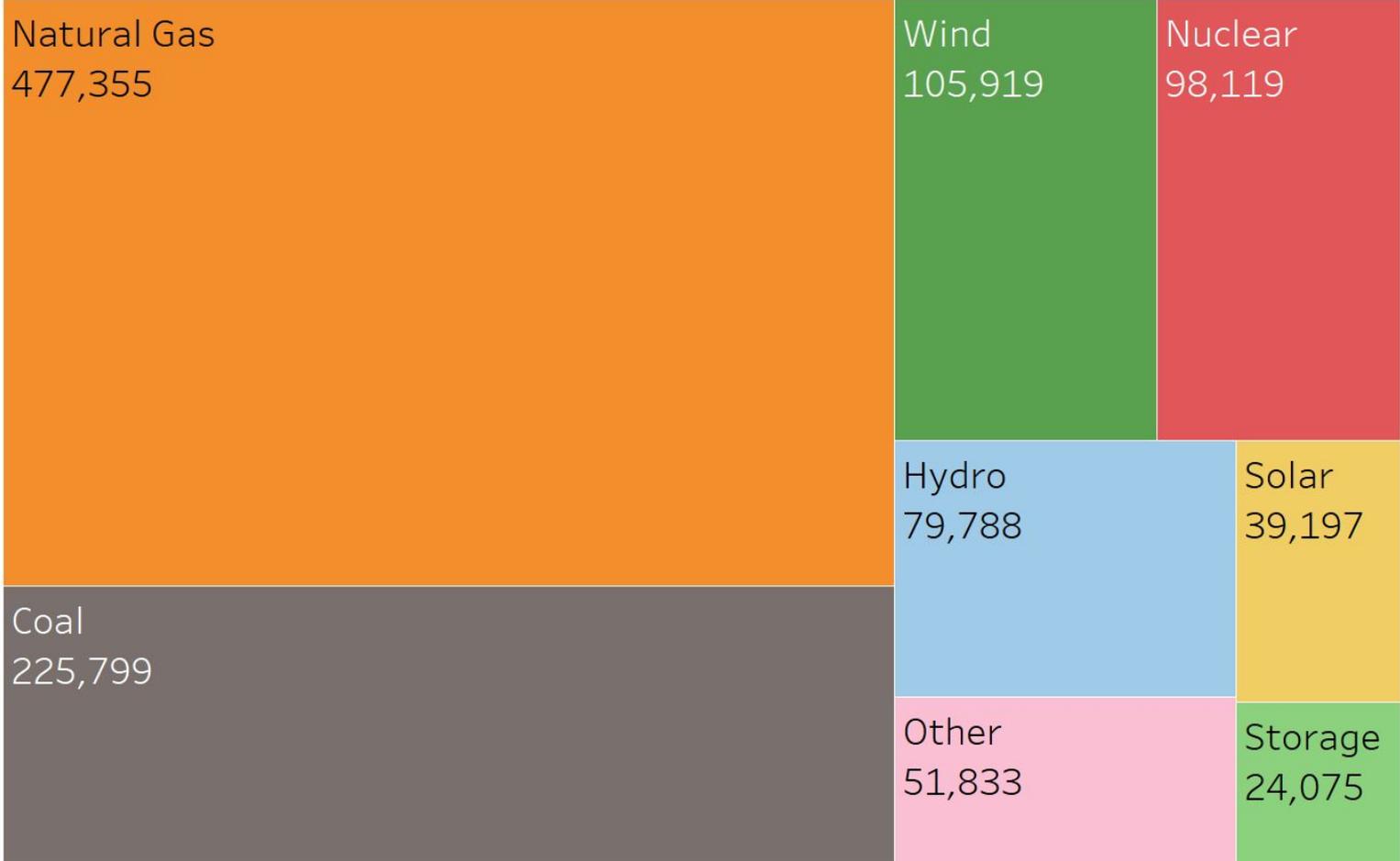
# 2020 Planned (Summer Capacity MW) EIA, Mar 2020



# 2020 Retiring (Summer Capacity MW) EIA, Mar 2020



# Summer Capacity MW, EIA, Mar 2020



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

# Carbon pricing

KEY STATISTICS ON REGIONAL, NATIONAL AND SUBNATIONAL CARBON PRICING INITIATIVE(S)

61 Carbon Pricing initiatives implemented or scheduled for implementation

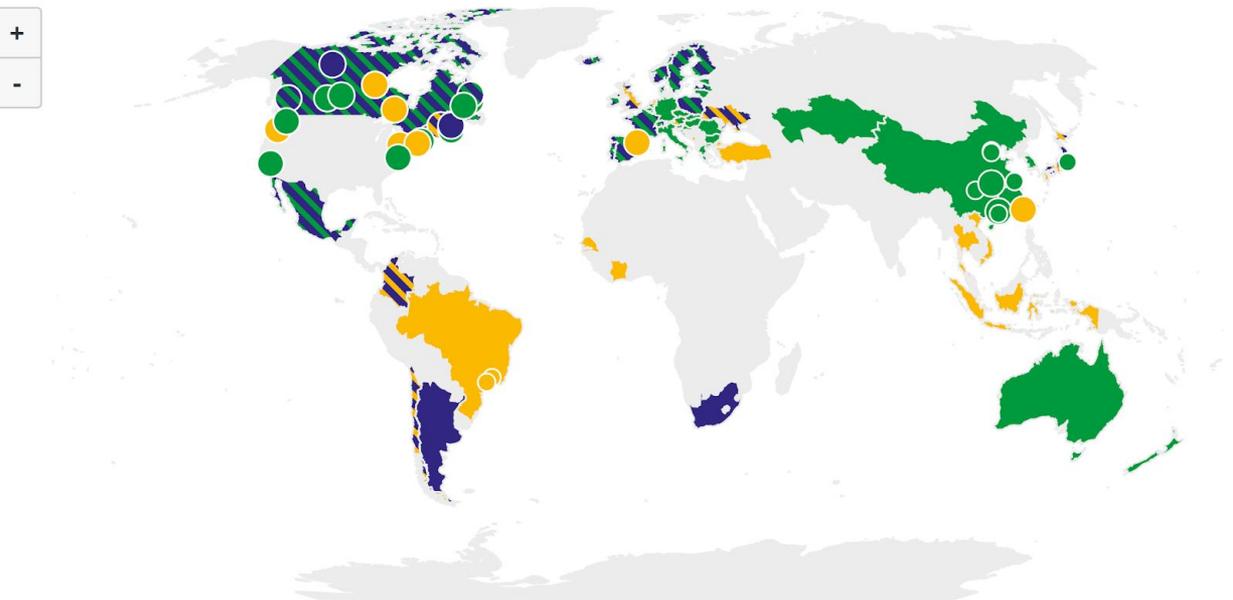
46 National Jurisdictions are covered by the initiatives selected

32 Subnational Jurisdictions are covered by the initiatives selected

In 2020, these initiatives would cover  
**12 GtCO<sub>2</sub>e**, representing **22.3%** of  
global GHG emissions

Total value (US\$ Bn) of carbon pricing initiatives in  
2020

Summary map of regional, national and subnational carbon pricing initiatives



- ETS implemented or scheduled for implementation
- ETS or carbon tax under consideration
- ETS implemented or scheduled, ETS or carbon tax under ...

- Carbon tax implemented or scheduled for implementation
- ETS and carbon tax implemented or scheduled
- Carbon tax implemented or scheduled, ETS under consideration

# How does transition depend on market rules and policy?

Long run model

Not steady state

Must model energy market

# The model

Entry and exit based on forward looking, rational investors

Each resource has anticipated cash flows for life of plant

- Capacity payments (if any)

- Energy and reserve revenues

- Less fixed and variable costs

Most uneconomic resources exit; most economic resources enter

Approximate equilibrium found where expectations are consistent

# Must model energy market

Energy revenues depend critically on resource structure

Some resources are substitutes, some are complements

Even with a fixed resource structure, energy rents are hard to compute

- Day-ahead market is a large mixed-integer program (MIP)

  - Determines schedule and prices (financially binding)

- Intraday is done every hour to reschedule (for planning)

- Real time is economic dispatch every 5 minutes

Many days in the year

# Entry and exit is a long run decision

Life of plant is 20 to 40 years or more

State space is infinite dimensional

Resource structure

Market rules

Climate policy

Extent of price responsive demand

Evolution of technologies

# Simplifying assumptions

Transmission constraints do not bind

Bids and offers for energy and capacity are competitive

Exception: hockey-stick offers when resource is near its upper limit

# Scarcity pricing

Case 1: Near shortage, reserve price increases rapidly to value of lost load

(e.g., \$9000; this is an Operating Reserve Demand Curve)

Case 2: Reserve price jumps to VOLL when violate reserve requirement

# Climate policy

Investors anticipate carbon price path over life of plant

# Technology

Combined cycle becomes more flexible over time

Next-gen nuclear has lower entry, fixed, and variable costs (after 2030)

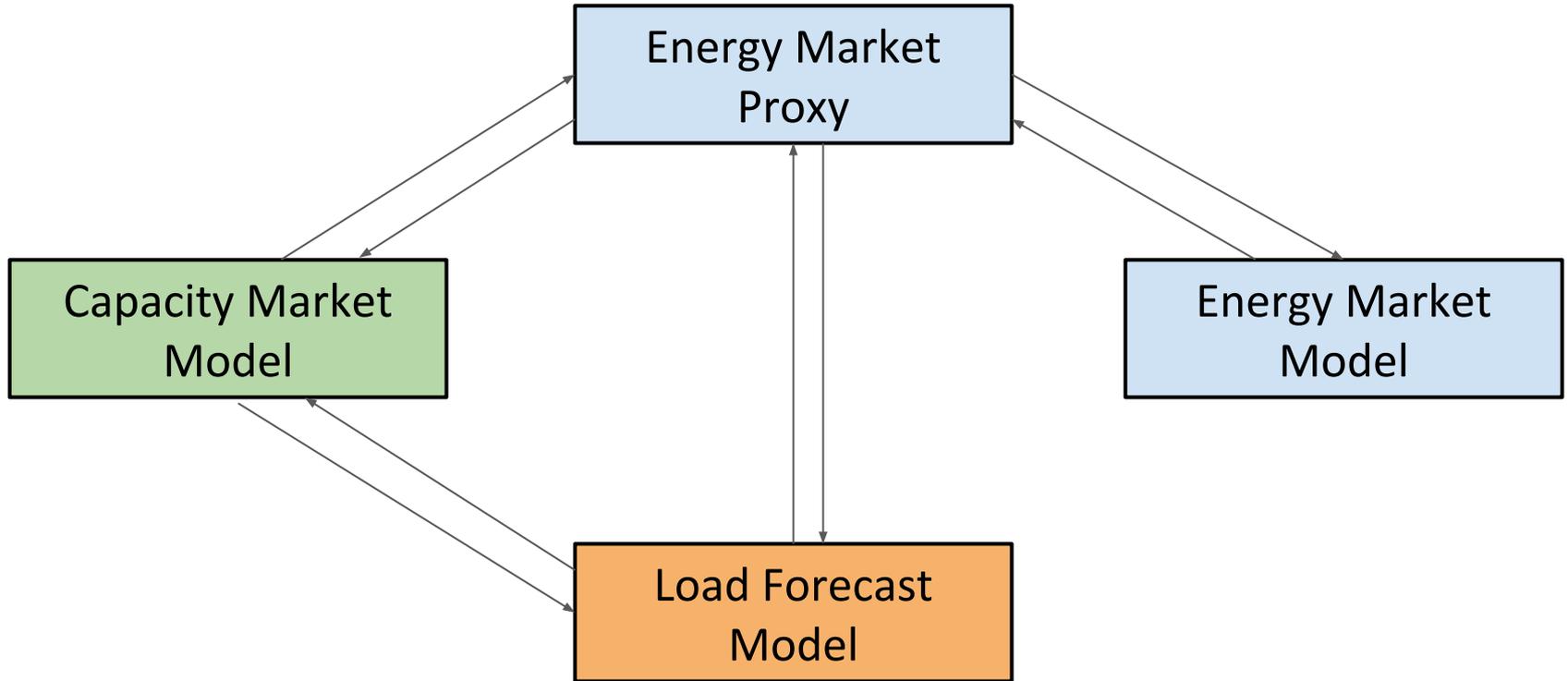
Renewables have lower entry and fixed costs and improved efficiency over time

Storage has lower entry and fixed costs

# Market rules

Reference case has efficient market rules

Inefficient rules are also considered



## Load Forecast Model

Forecast *net load* hourly

Load (traditional)

minus production from non-responsive resources:

Solar

Onshore wind

Offshore wind

Run of river hydro

Actual net load hourly

Actual net load in five-minute intervals

## Energy Market Model

For a *fixed resource structure*, get net load forecast

Run energy market for 365 days

- Energy and reserves co-optimized both day ahead and real time

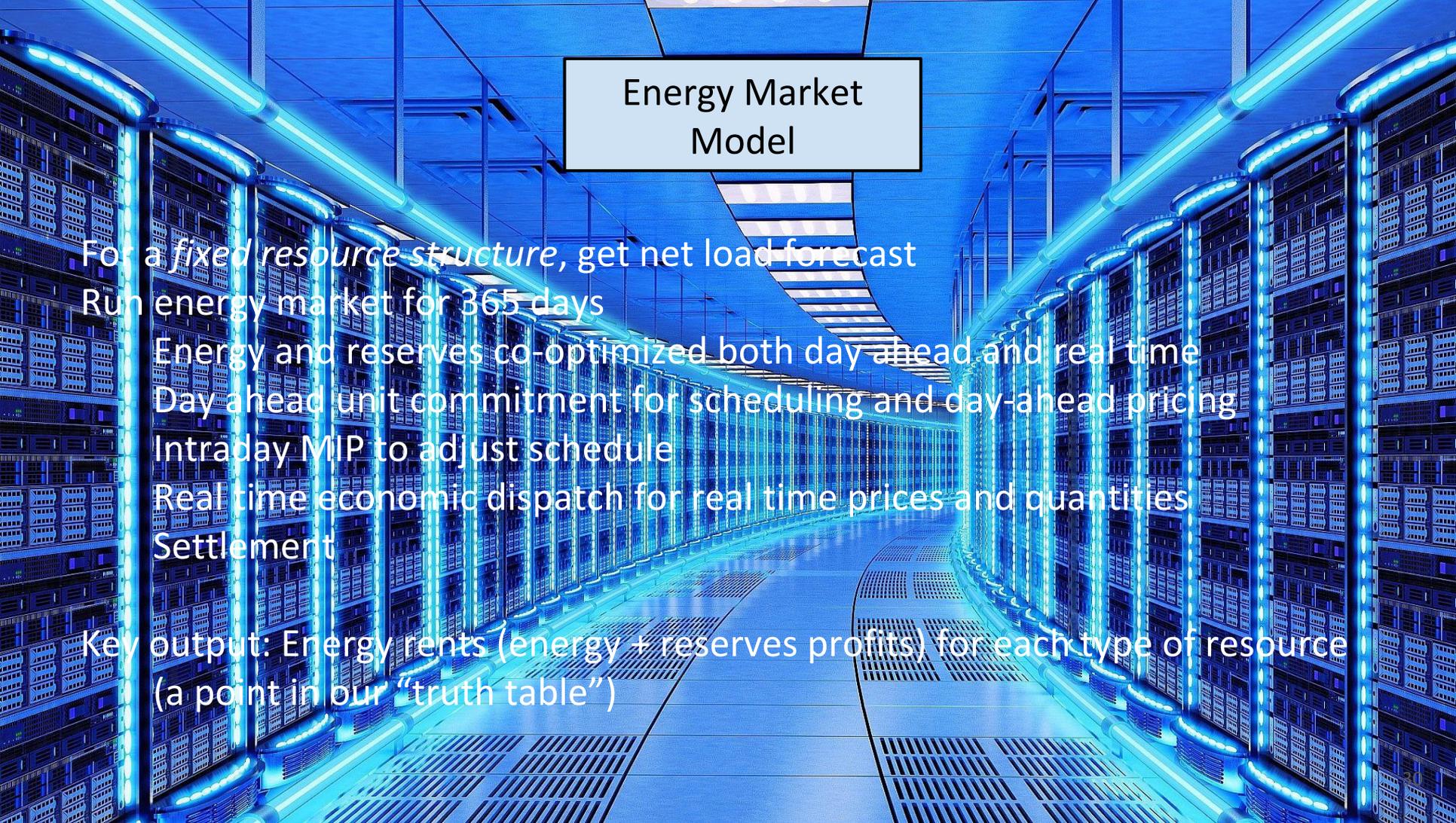
- Day ahead unit commitment for scheduling and day-ahead pricing

- Intraday MIP to adjust schedule

- Real time economic dispatch for real time prices and quantities

- Settlement

Key output: Energy rents (energy + reserves profits) for each type of resource  
(a point in our “truth table”)

A perspective view of a server room with rows of server racks on both sides. The racks are illuminated with blue light, and the floor has a grid pattern. The ceiling has recessed lighting. A white box with black text is centered at the top.

## Energy Market Model

For a *fixed resource structure*, get net load forecast

Run energy market for 365 days

Energy and reserves co-optimized both day ahead and real time

Day ahead unit commitment for scheduling and day-ahead pricing

Intraday MIP to adjust schedule

Real time economic dispatch for real time prices and quantities

Settlement

Key output: Energy rents (energy + reserves profits) for each type of resource  
(a point in our "truth table")

# 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 .05%)

Demand curve for price responsive demand explicitly modeled in MIPs and LPs

## Energy Market Proxy

Reduce list of units to almost sufficient statistics to describe resource structure  
From truth table (actual energy market rents), econometrically estimate

Energy rents for each resource type

Energy rents for each unit

Periodically call energy market model to compute exact energy rents

Update parameter estimates using expanded truth table

## Capacity Market Model

Simulate for years 2019 to 2113

Form expectations up to 50 years ahead

Run capacity market (if any)

Find capacity price where supply and demand intersect

Alternate exit (most uneconomic) and entry (most economic)

Run energy market for current delivery year (to expand truth table on equil path)

Update expectations (continue until expectations are consistent)

# Resource types (14)

Coal, CT, CC

Nuclear, Next-Gen Nuclear (2030 on)

Hydro, Run-of-River Hydro

Onshore Wind, Offshore Wind

Solar

Battery Storage (1, 2, 4, 8 hour duration)

# Other calibration factors

Initial list of units and characteristics

Operating costs, variable costs, fixed costs, fuel prices

Efficiency of renewables

Initial capacity values (updated with exponential smoothing based on performance)

Financial parameters (discount rate)

Demand parameters

# Scenarios

Market rules (capacity market, energy-only market, other)

Fuel prices (low, medium, high)

Carbon price (none, low-end 2°C, low-end 1.5°C, twice that)

Price response demand (none, annual growth 1 percentage point, twice that)



Results...

Detailed evidence of impact of market rules and policies on:

Market efficiency

Cost to load

Profits for suppliers

Reliability

...

