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Energy+Environmental Economics

SB100 Joint Agency Report

CEC Workshop

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Agenda

- **PATHWAYS**
  - Modeling
    - Overview
    - Linking to RESOLVE
  - SB100 Assumptions/Plan
    - New Reference Scenario: PATHWAYS 2019 IEPR Aligned
    - Mitigation Scenarios: High Electrification, High Biofuels, and High Hydrogen
- **RESOLVE**
  - Modeling
    - Deep Dive
  - SB100 Assumptions/Plan
    - State-wide Scale-up
    - Candidate Resources
    - Costs
    - Reliability
    - Land-Use Considerations

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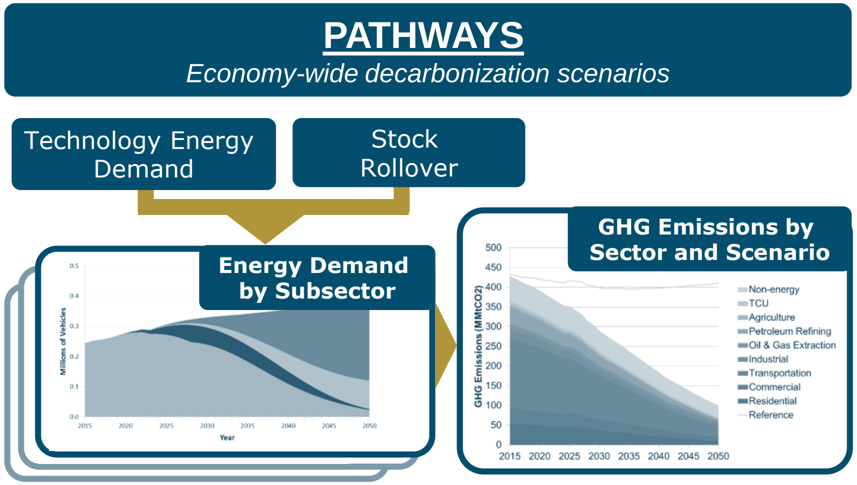
PATHWAYS Modeling: Overview

PATHWAYS Modeling Approach

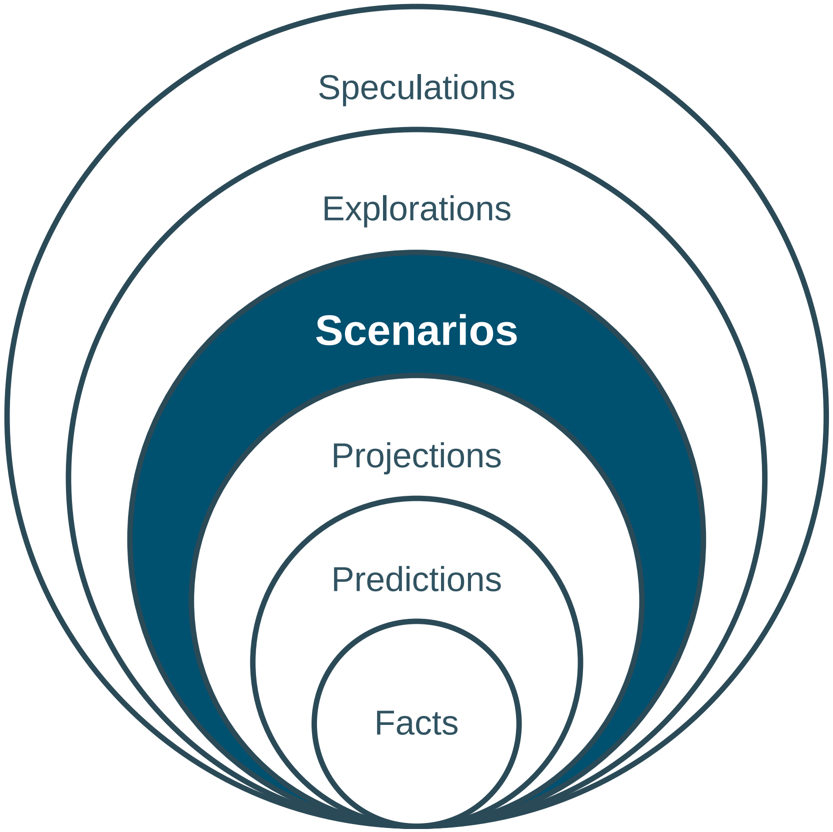
+ **Economy-wide infrastructure-based GHG and energy analysis**
  - Captures "infrastructure inertia" reflecting lifetimes and vintages of key equipment: building appliances and on-road vehicles
  - Models physical energy flows within all sectors of the economy
  - Allows for rapid comparison between user-defined scenarios
  - Tracks electrification load shapes by sector and end use

+ **Scenarios test "what if" questions**
  - Reference or counterfactual scenario for consistent comparison in future years
  - Multiple mitigation scenarios can be compared that each meet the same GHG emissions goal
    - Single economywide "budget" for fossil emissions and biomass



PATHWAYS: A User-defined Scenario Tool

PATHWAYS scenarios evaluate <u>uncertain</u> and <u>complex</u> futures



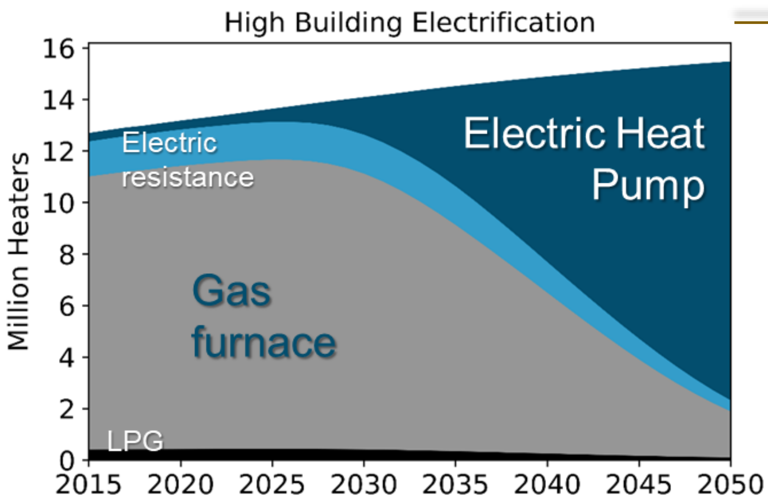
- **PATHWAYS does not make *forecasts.***
  - PATHWAYS makes *back-*casts
  - Allows hypothesis testing predicated on meeting emissions targets
  - Reference scenarios aligned with other data sources (e.g. IEPR) & expert judgment of current trends

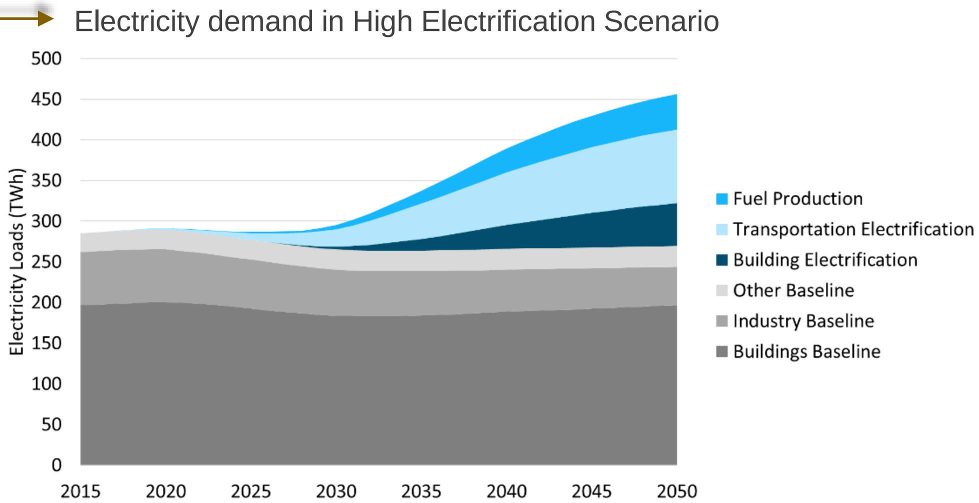
PATHWAYS Energy Demand Representation

- **Demand sectors generally follow IEPR load categories**
- **Comprehensively benchmarked to IEPR in 2016 for CARB 2017 Scoping Plan Update**
  - Updated 2019 benchmarking to check for discrepancies for CARB draft updated Reference

Sector	Representation	Notes
Residential Buildings	Stock-rollover by subsector	11 subsectors + misc. end uses + housing stock
Commercial Buildings	Stock-rollover by subsector	7 subsectors + misc. end uses + square footage
Transportation	Stock-rollover by subsector	4 on-road subsectors; Off-road is by fuel use
Industry	Fuel use	Some representation of subsectors & end use
Petroleum Refining	Fuel use	
Oil & Gas Extraction	Fuel use	
Transportation, Communication, & Utilities (TCU)	Fuel use	Includes water-pumping loads, streetlighting, etc.
Agriculture	Fuel use	

PATHWAYS Electricity Demand & Energy Efficiency





- **Bottom up electricity demand projection based on end use appliance stocks, macroeconomic drivers (number of households, etc.)**
- **Efficient appliance shares assumed based on historical data, future mitigation measure (or for calibration to efficiency metric)**
- **Efficiency can only be estimated by comparing load projection to a counterfactual scenario without efficiency and taking the difference**
  - Accounting for electrifying end uses is tricky

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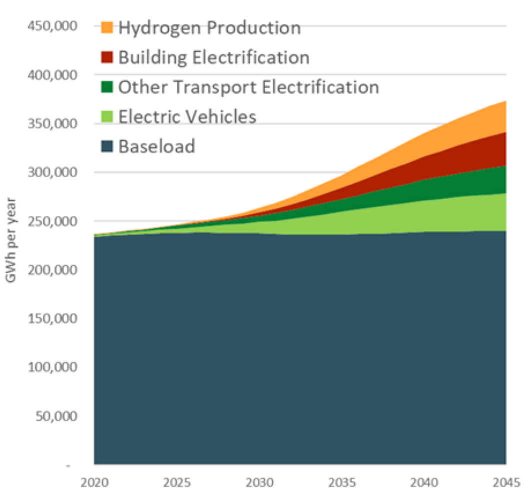
PATHWAYS Modeling: Linking to RESOLVE and SB 100 Assumptions

PATHWAYS Provides Info to RESOLVE for Integrated Electricity Scenarios

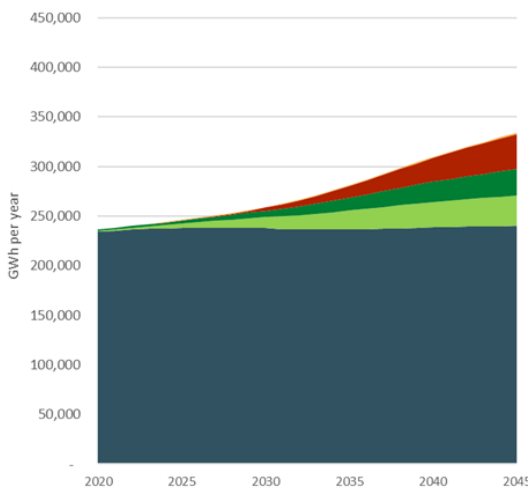
- **PATHWAYS provides to RESOLVE**
  - Annual loads by category (GWh/yr)
  - Some load shape information for key new loads and load modifiers (normalized 8760 profiles)
  - Electricity sector GHG trajectory consistent with economy-wide goals (MMT CO_2/yr)
- **These loads may be incorporated directly or as load modifiers to an existing load forecast (e.g. CEC IEPR)**

Example: CAISO loads used for CAISO in CPUC 2019 Reference System Plan 2045 Framing Analysis

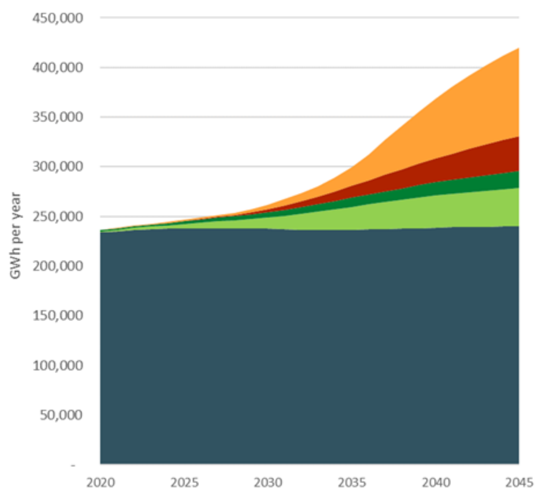
High Electrification



High Biofuels



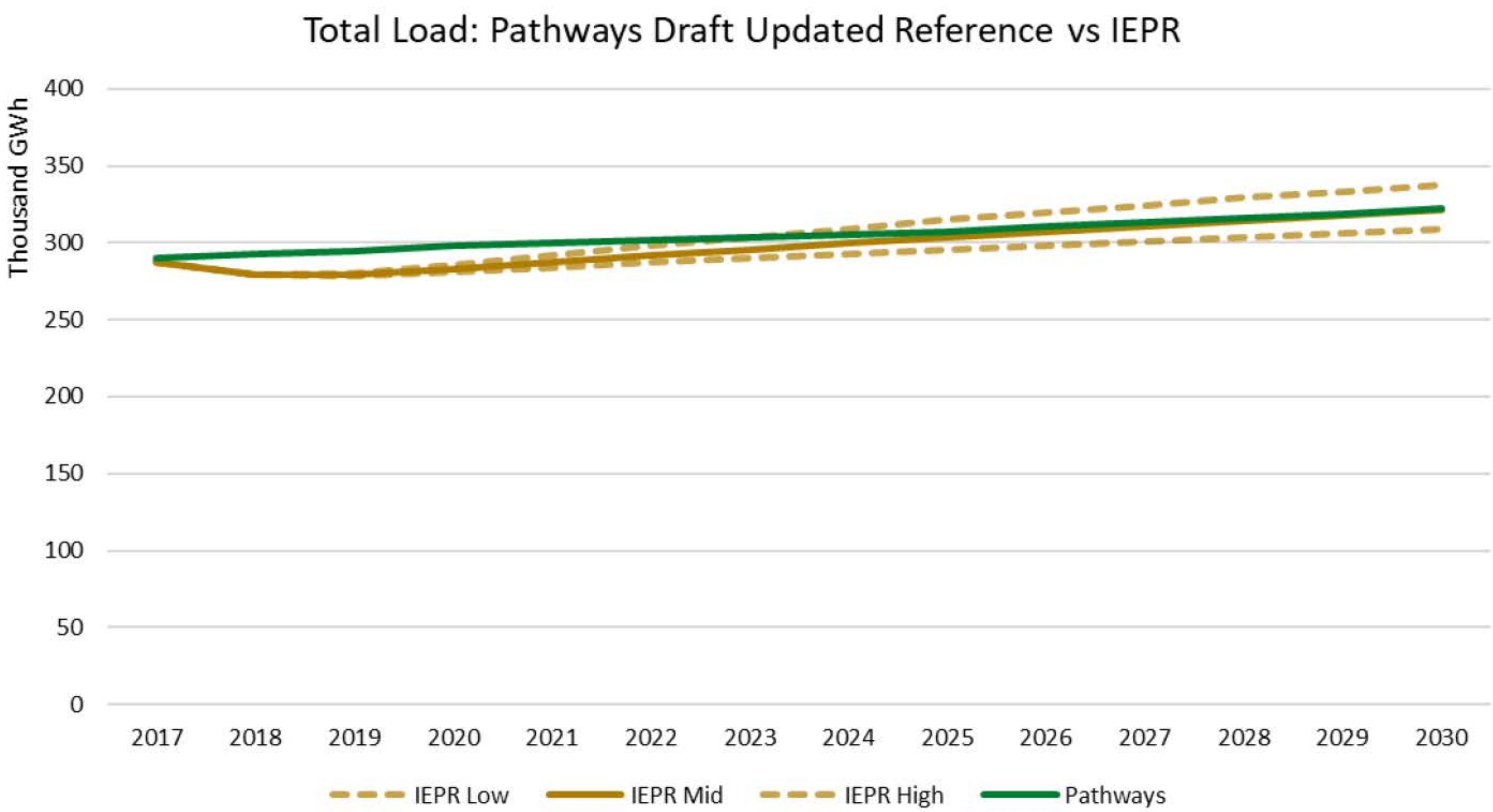
High Hydrogen



PATHWAYS: SB100 Assumptions

+ **Four PATHWAYS Scenarios will be used in SB100 modeling:**
  - Reference Scenario:
    1. Updated statewide reference scenario aligned with 2019 IEPR-CED
  - Mitigation Scenarios (used in 2018 CEC Study and 2019 CPUC IRP Reference System Plan 2045 Framing Analysis):
    2. High Electrification
    3. High Hydrogen
    4. High Biofuels
+ **PATHWAYS load assumptions from these four scenarios will be used as an input to RESOLVE**
+ **PATHWAYS will cover all sector assumptions outside of the electric sector (e.g. transportation, buildings, etc.)**

Updated Reference with Electricity Load Benchmarked to 2019 IEPR



Mitigation Scenario Loads Selected from E3 2018 Study for CEC

Mitigation Scenarios	Scenario description
High Electrification	**Electrification of buildings and transportation, high energy efficiency, renewables, limited biomethane**
No Hydrogen	No fuel cell vehicles or hydrogen fuel, includes industrial electrification
Reference Smart Growth	Less reductions in vehicle miles traveled, additional GHG mitigation measures in other sectors
Reduced Methane Mitigation	Higher fugitive methane leakage, additional GHG mitigation measures in other sectors
Reference Industry EE	Less industrial efficiency, additional GHG mitigation measures in other sectors
In-State Biomass	Less biofuels with no out-of-state biomass used, additional GHG mitigation measures in other sectors
Reference Building EE	Less building efficiency, additional GHG mitigation measures in other sectors
No Building Electrification with Power-to-Gas	No heat pumps or building electrification, additional GHG mitigation measures in other sectors
High Biofuels	**Higher biofuels, including purpose grown crops, fewer GHG mitigation measures in other sectors**
High Hydrogen	**More fuel cell trucks, fewer all-electric vehicles**

Electrification Assumptions in Selected PATHWAYS Mitigation Scenarios

Sector		2050 High Electrification	2050 High Biofuels	2050 High Hydrogen
Buildings	HVAC & Water Heating		100% electric sales by 2040	
	Cooking, Clothes Drying, & Other		90% electric sales by 2040	
Transportation	Light-duty vehicles	100% ZEV sales by 2035 (96% of stock by 2050)	81% ZEV sales by 2035 (69% of stock by 2050)	100% ZEV sales by 2035 (96% of stock by 2050)
	Trucks	27% of trucks are BEVs	27% of trucks are BEVs	65% of trucks are ZEVs, including high hydrogen
	Off-road		High electrification of rail, ports, & off-road diesel	
Industry			Minimal industry electrification	

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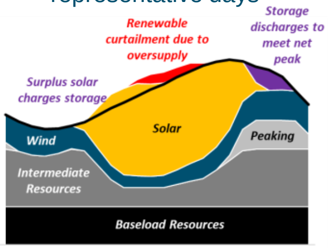
RESOLVE Modeling: Overview

RESOLVE: Optimal Capacity Expansion Under Aggressive Clean Energy Goals

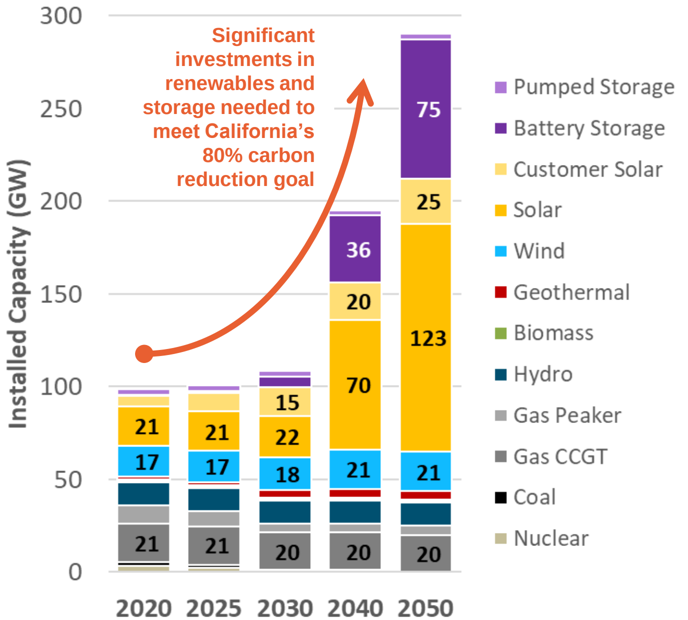
- RESOLVE is a linear optimization model explicitly tailored to study of electricity systems with high renewable & clean energy policy goals
- Optimization balances fixed costs of new investments with variable costs of system operations, identifying a least-cost portfolio of resources to meet needs across a long time-horizon

Operational module simulates hourly system operations for a sample of representative days



Reliability module ensures portfolio can meet load during extreme conditions using an ELCC approach

Least-cost plan cooptimizes investments and operations to meet clean energy policy targets, selecting from a diverse set of potential resources including wind, solar, storage, DSM, and natural gas



Example RESOLVE result from *Long-Run Resource Adequacy under Deep Decarbonization Pathways for California* (Calpine, 2019)

RESOLVE is a Zonal Model

RESOLVE
Investment Decisions
System Operations

+ "Main" zones:

- Optimal investment decisions
- Detailed treatment of operating reserves

+ Other zones:

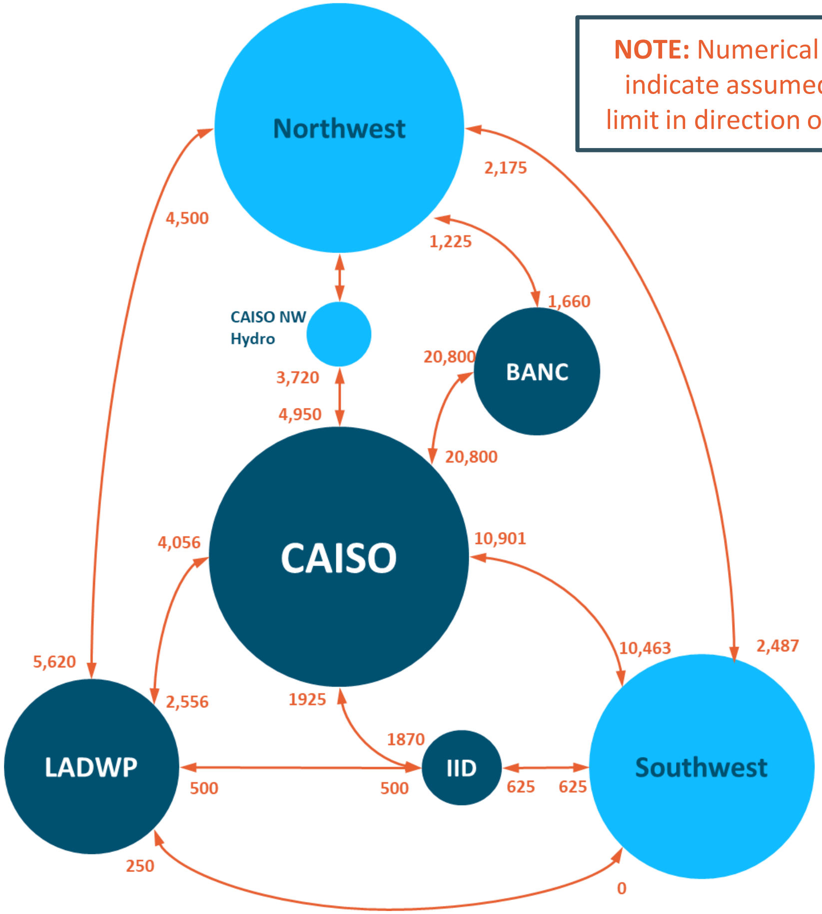
- Exogenous resource assumptions and loads by scenario

+ Flows may be impacted by:

- Min and max intertie flow constraints
- Min and max simultaneous flow constraints for groups of interties
- Ramping constraints on interties
- Hurdle rates

+ Regional Topology

NOTE: Numerical values indicate assumed flow limit in direction of arrow

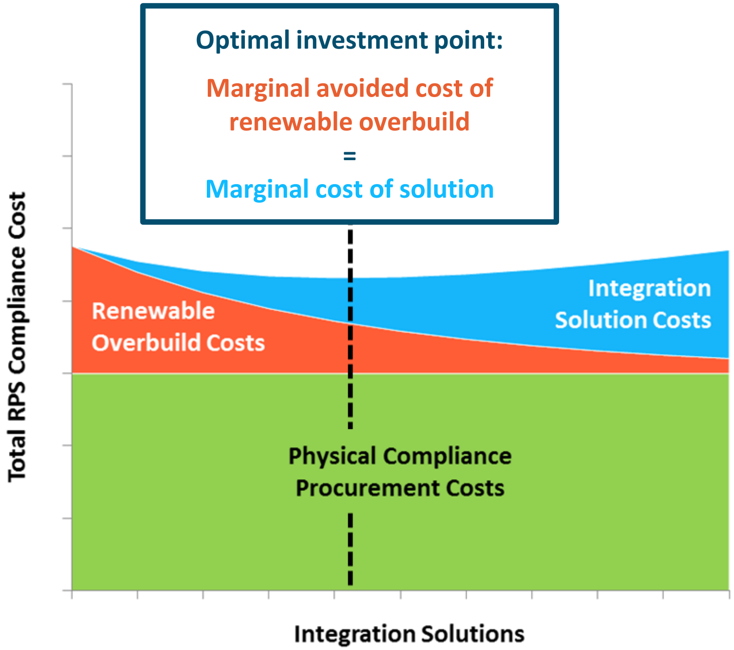


Scale-up from CAISO Main Zone to Statewide Zonal Model

+ **The RESOLVE model is currently only able to model a single constraint for the each of RPS, PRM, and GHG emissions targets.**
+ **In the CPUC IRP RESOLVE model has a CAISO main zone and all the above constraints are optimized for the CAISO zone.**
+ **For this SB100 analysis, all four California balancing area authorities will be modeled as being part of a single California zone.**
  - Existing resources for the individual BAAs will be represented on a BAA level
  - Resource additions will be reported at a statewide level
+ **Additionally, certain inputs and assumptions will be scaled up to represent statewide values including demand components, PRM constraints, RPS constraints, GHG constraints, reserves requirements**

RESOLVE Provides a Framework for Valuation of Flexible Resources

- Sizing the electric system to deliver every MWh of renewable generation is cost-prohibitive
- Reduction of renewable curtailment and overbuild provide value to ratepayers
- Flexible resources are selected when their benefits—primarily reduced renewable overbuild—are greater than their costs
- Scenarios to evaluate benefits of increased regional integration



RESOLVE Co-optimizes Investment and Operational Decisions

- **RESOLVE allows portfolio optimization across a long time-horizon (20-30 years)**
  - Investments made in multiple periods
- **Operational detail directly informs investment decisions to economically address primary drivers of renewable integration challenges**
- **Fixed costs capture capital, financing, and fixed O&M associated with new infrastructure and economically retiring resources**
- **Optimization is constrained by many factors, including:**
  - Hourly load
  - RPS target
  - Planning reserve margin
  - GHG limit

RESOLVE
Objective Function

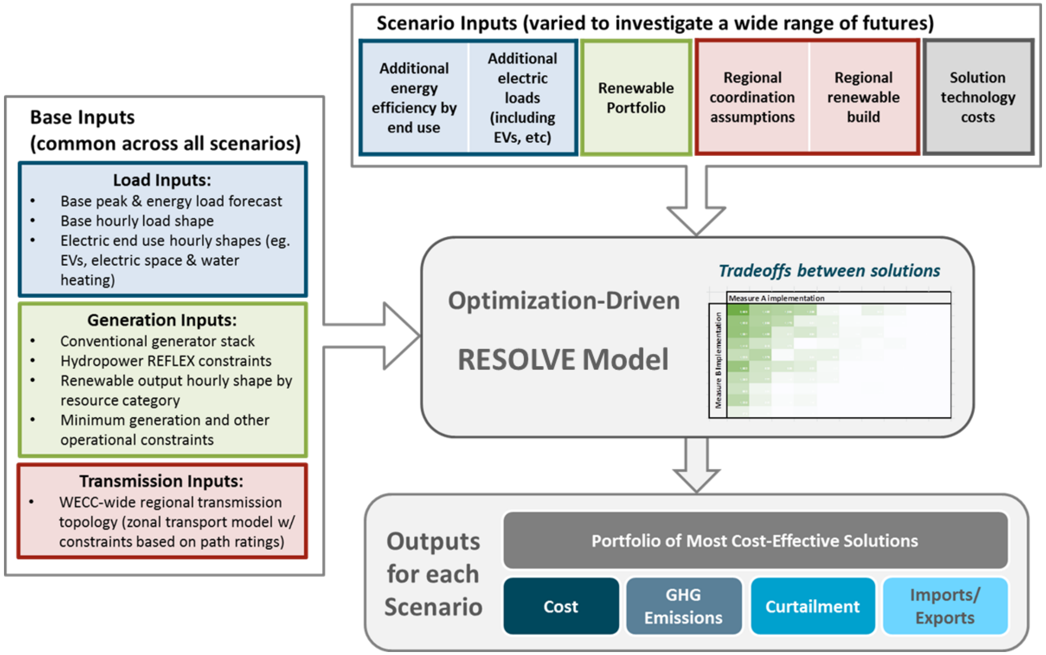
+ **Fixed Costs of New Resources**
  - Generation (thermal, hydro, renewables)
  - Energy storage
  - Shed demand response
  - Energy efficiency

+ **Fixed Costs of New Transmission**

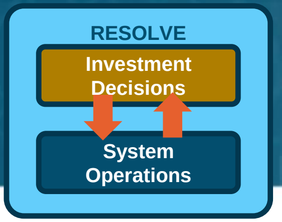
+ **System Operating Costs**
  - Fixed & variable O&M
  - Start costs
  - Fuel costs
  - Carbon
  - Hurdles

Flexible Model Design Facilitates Scenario Analysis

+ **RESOLVE is designed to allow easy scenario analysis of a variety of uncertainties**
+ **Assumptions on key uncertainties can be easily adjusted in scenarios to allow analysis of future risks:**
  - Future resource costs
  - Future building and transportation electrification
  - Future availability of zero-carbon drop-in fuels
  - Future technology development of alternative zero-carbon resources

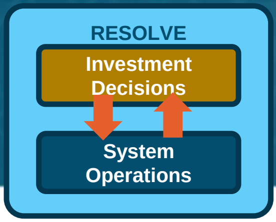


Generation Capacity Expansion



+ **RESOLVE takes a fixed trajectory for the installed capacity of existing and planned resources**
  - Costs for planned capacity are not accounted for directly in the model, since they do not affect the optimization
+ **The capacity of new build resources are variables that the model can optimize, expanding existing units or building completely new units**
  - Resource build decisions are linear, which may result in partial unit builds
  - New build resources can be capacity limited by year (e.g., if resource potentials change by year)
+ **Existing thermal resources can be economically retired if ongoing fixed cost is not supported by value of system services**
+ **Resources can be capacity limited in each model year**
  - Capacity limits represent any constraint (site-specific or otherwise) that prevent incremental build
+ **Capacity costs are denominated in \$/kW-year, consisting of:**
  - Capital costs
  - Ongoing fixed costs
  - Tax and debt service costs
  - Investment Tax Credit (as applicable)
+ **Storage costs are broken into additive power (\$/kW-year) and energy (\$/kWh-year) components**
  - Allows RESOLVE to optimize duration of energy storage by selecting power and energy independently

RPS and GHG Targets



- **Both RPS and GHG targets are implemented in RESOLVE**
  - RPS requirement is based on retail sales
- **Resources can be designated as RPS-eligible, and RESOLVE will pick new build resources to meet the RPS target**
- **Alternatively, fuel-based resources can "blend" biomethane to meet RPS and/or GHG targets**
- **RESOLVE can select renewable resources in excess of RPS target if those resources are economic**

RESOLVE's Niche: Energy Limited Resources

- **Most capacity expansion models can't fully endogenize reliability and economic aspects of energy-limited resources, including:**
  - Wind and Solar
  - Energy Storage
  - Efficiency
  - Demand response and demand-side flexibility
  - Transmission between regions
- **RESOLVE has many energy-limited constraints:**
  - Energy and ancillary service markets: Linearized unit commitment and production simulation, day selection
  - Load following reserves: increase with renewable penetration
  - Resource adequacy:
    - Capacity contribution surface for wind and solar
    - Batteries: duration and declining marginal capacity value
  - Energy sufficiency: Dunkleflaute constraints
  - Local and distribution system: enforce resource adequacy constraints in local areas (not incorporated in current modeling; would require input development)

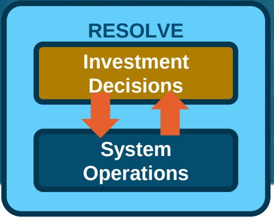
RESOLVE Resource Representations

+ **In this section, we focus on the representation of major resource classes in RESOLVE**
  - Resources that do not fall into one of these categories can likely be creatively modeled using existing functionality
+ **Certain features or capabilities are only available for certain classes of resource**

✗ *Not applicable*
◔ ◑ ◕ *Partial functionality*
✓ *Full representation*

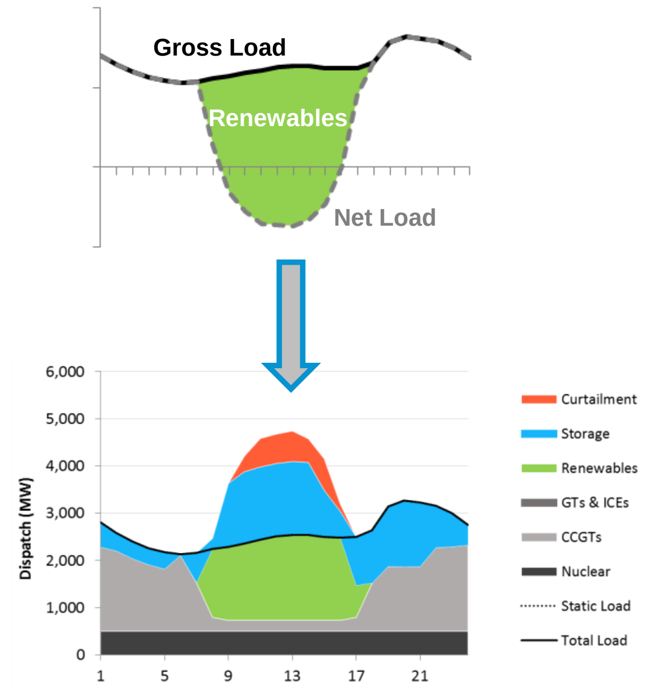
Category	Sub-Category	PRM Capacity Value	Dispatchable Power	Charging Capability	Provides Reserves	Energy Budget	Ramping Constraints	Emissions	Economic Retirement	Share Energy Between Days
Thermal	"Baseload"	✓	✓	✗	◑	✓	✗	✓	✓	✗
	Dispatchable	✓	✓	✗	✓	✓	✓	✓	✓	✗
Renewables		◑	◑	✗	◑	✗	✗	✗	✗	✗
Battery Storage		✓	✓	✓	✓	✗	✓	✗	✗	✓
Hydro	Dispatchable	✓	✓	✗	✓	✓	✓	✗	✗	✓
	Pumped Hydro	✓	✓	✓	✓	✓	✓	✗	✗	✓
Demand Response	Shed	✓	✓	✗	✗	✓	✗	✗	✗	✗

Hourly Model Brings Operational Challenges into Investment Decisions

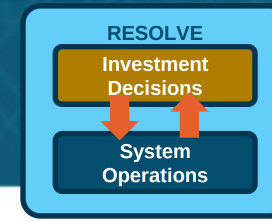


+ **For each year in the simulation, a subset of days are selected and weighted to reflect long-run distributions of:**
  - Daily load, wind, and solar
  - Monthly hydro availability
+ **Operations modeled using linear dispatch formulation**
  - Upward and downward operating reserve constraints
  - Parameterization of subhourly renewable curtailment due to downward reserve shortfalls

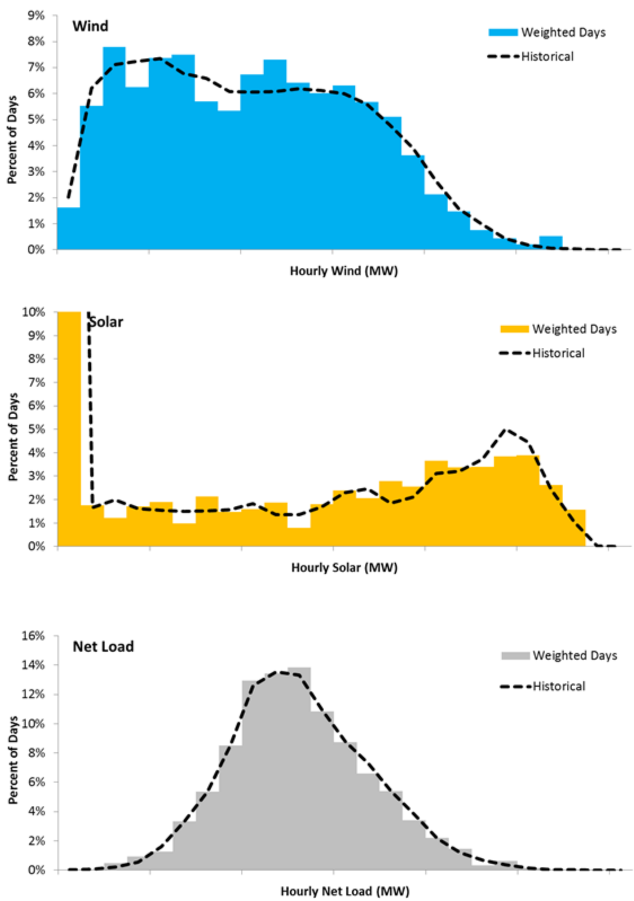
Captures operational impacts of renewable integration challenges



Sampled Days Capture Expected Distribution of Net Loads



Example Comparison of Distribution of Days



+ **For each year in the analysis horizon, RESOLVE models operations for 37 separate representative dispatch days**
  - Mapping of selected days to historical dates is saved in the Scenario Tool (part of the RESOLVE toolkit)
+ **Day sampling algorithm (not part of the RESOLVE toolkit) is designed to approximate long-run distributions of:**
  - Hourly load
  - Hourly solar
  - Hourly wind
  - Hourly net load
  - Daily hydro energy
  - Monthly hydro energy
  - Monthly renewable capacity factors by site

RESOLVE: SB100 Assumptions

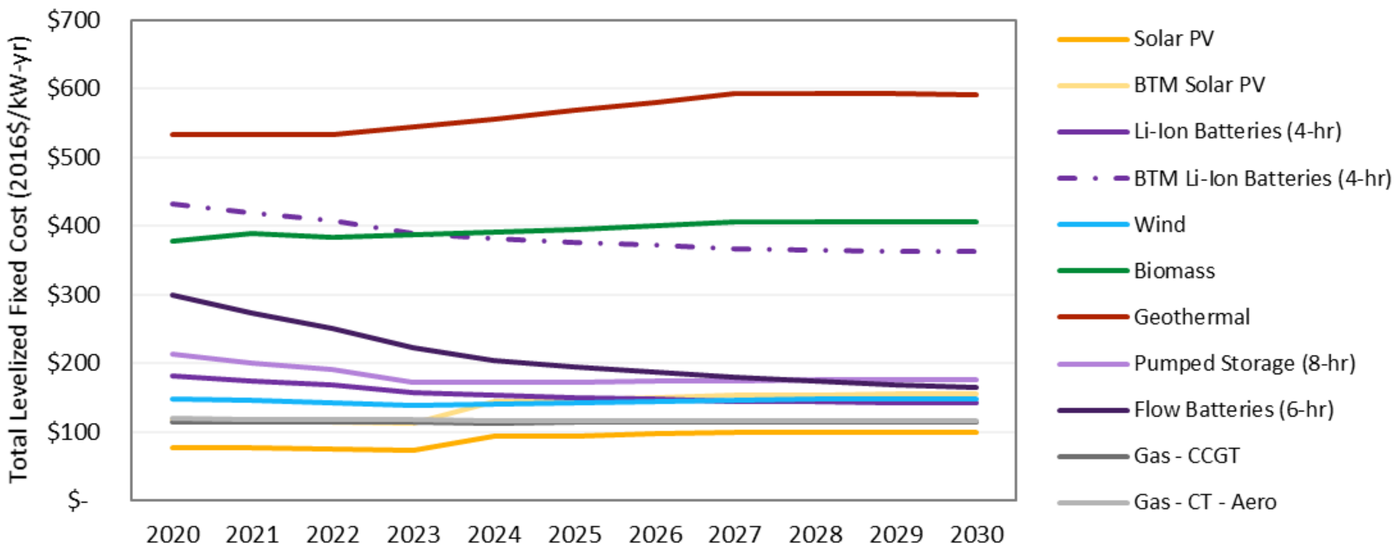
Available Candidate Resources

- "Candidate" resources represent the menu of options from which RESOLVE can select to create an optimal portfolio.
- Publicly-available data on cost, potential, and operations are used to the maximum extent possible to develop candidate resource assumptions.
- Both supply and demand-side resources are included as candidate resources.
- Supply-side Candidate Resources:
  - Natural gas: CCGT, CT
  - Renewables: Solar PV, Wind, Offshore Wind, Geothermal, Biomass
  - Utility-Scale battery storage: Li-ion, Flow
  - Pumped storage
  - Carbon Capture and Sequestration (CCS)
  - Hydrogen Fuel Cells
- Demand-side Candidate Resources:
  - Behind-the-meter PV
  - Behind-the-meter Li-ion Storage
  - Shed Demand Response

Resource Cost Assumptions

+ Renewable resource capital and fixed O&M cost forecasts based on 2019 National Renewable Energy Laboratory Annual Technology Baseline (NREL ATB).
+ Storage resource capital and fixed O&M cost forecasts based on Lazard Levelized Cost of Storage 5.0 and NREL Solar + Storage study.
+ Financing costs based on NREL ATB.
+ Shed DR costs (not shown on plot) are included as a supply curve based on the LBNL California Demand Response Potential Study.

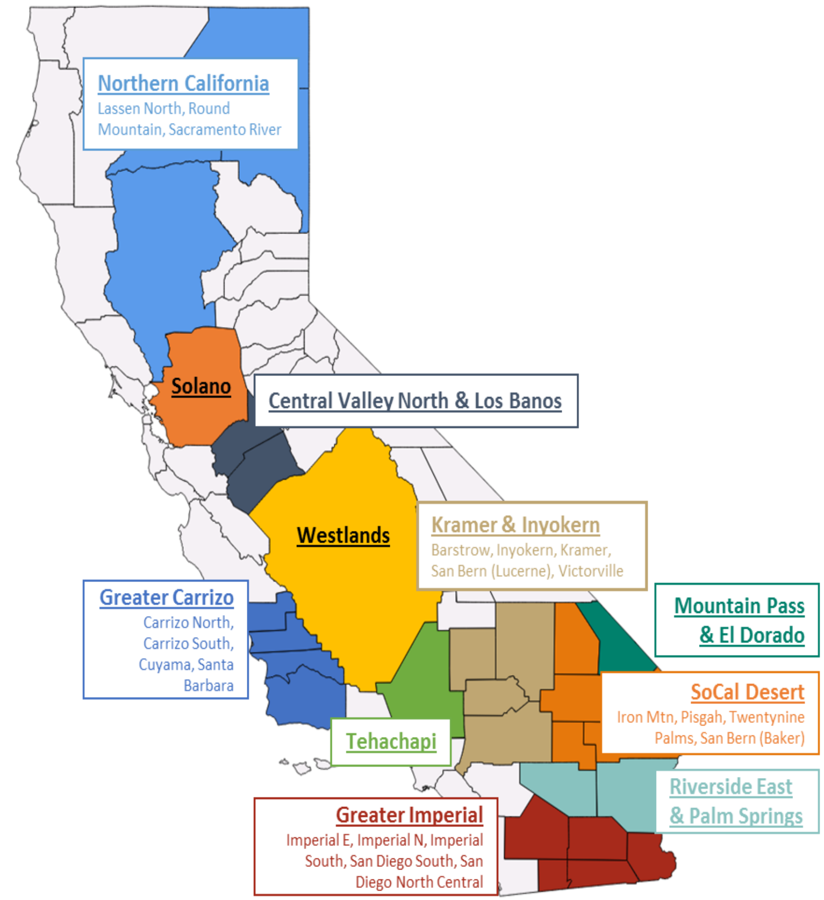
Total Levelized Fixed Cost of Some Candidate Technologies



*Costs shown are US-wide and do not include regional multipliers applied to all technologies or project-specific multipliers applied to renewable projects in the supply curve.
**The chart above capture the total fixed costs of resources only. Does not include variable costs (e.g. fuel) which are modeled in RESOLVE.

Land-use Considerations

+ **In-state resource supply curves developed by Black & Veatch for RPS Calculator v.6.3:**
  - Biomass: 1,150 MW
  - Geothermal: 1,850 MW
  - Utility-Scale Solar PV: 353,000 MW
  - Wind: 2,250 MW
+ **Out-of-state resources are constrained in portfolios:**
  - 3,600 MW of wind reflecting existing transmission and 1 new transmission line each to NM and WY
  - No new transmission built to accommodate new wind

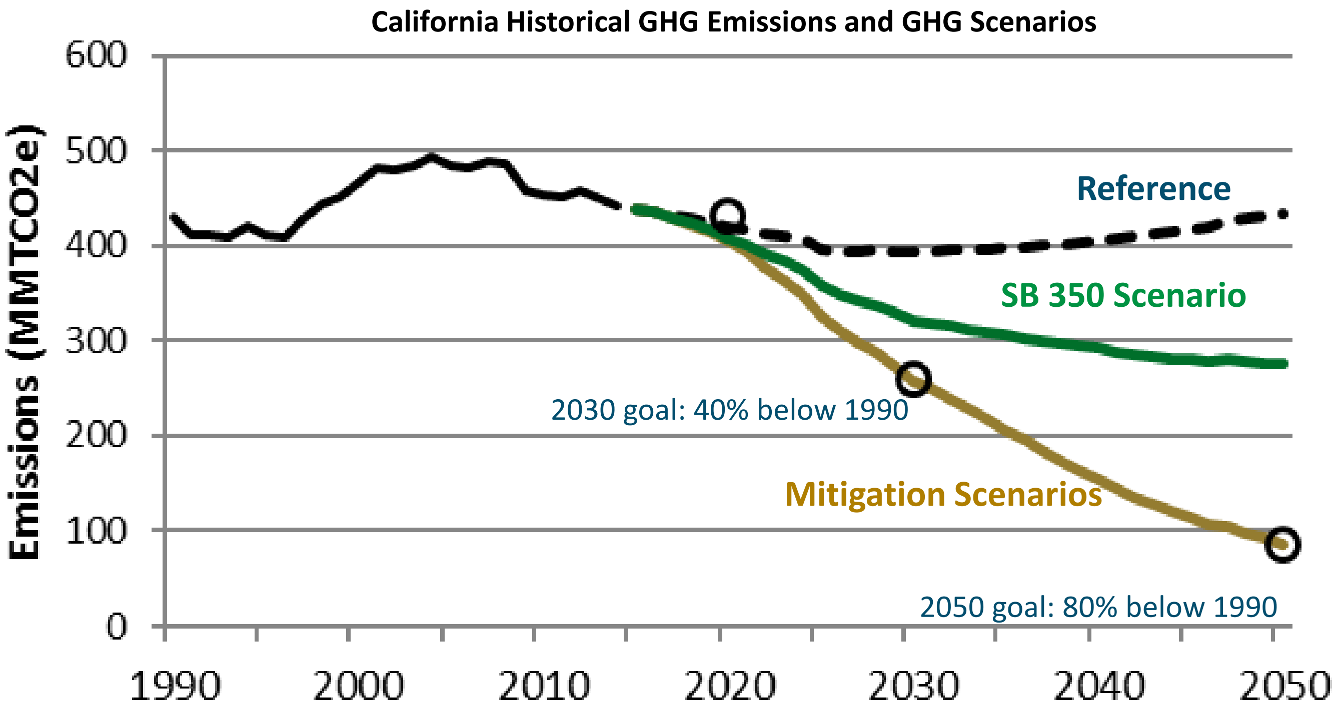


Next Steps & Thank You

Appendix: PATHWAYS

2018 CEC Study: Ten 80 x 50 Mitigation Scenarios (CEC-500-2018-012)

- **By 2020: return GHGs to 1990 levels** (AB 32, 2006)
- **By 2030: 40% below 1990 levels** (SB 32, 2015)
- **By 2050: 80% below 1990 levels** (EO B-30-15 and EO S-3-05)
- ***By 2045: Carbon neutrality*** *(EO B-55-18)* ***not evaluated in CEC analysis***



See https://www.ethree.com/projects/deep-decarbonization-california-cec/

How were PATHWAYS loads incorporated into analysis for CPUC 2019 RSP?

+ **2018 IEPR provided base loads through 2030, including EE**
+ **PATHWAYS (CEC 2018 scenarios) provided load modifiers for electrification loads and post-2030 load growth**
  - Building electrification is relatively small new load through 2030 even in "High Electrification" (~< 3 TWh)
  - Vehicle electrification roughly comparable with IEPR, with increased assumed electrification of trucks and off-road ("other transportation")

Table 4. Other transport electrification forecast options (GWh) (Example from CPUC IRP Inputs & Assumptions)

RESOLVE Scenario Setting	2020	2022	2026	2030
No Incremental Other Transport Electrification	-	-	-	-
CEC 2018 IEPR - Mid Demand	222	306	520	683
CEC 2018 Deep Decarbonization - High Biofuels	1,198	1,734	3,596	6,615
CEC 2018 Deep Decarbonization - High Electrification	1,198	1,734	3,596	6,617
CEC 2018 Deep Decarbonization - High Hydrogen	1,127	1,590	3,054	5,107

2018 PATHWAYS scenarios used in IRP

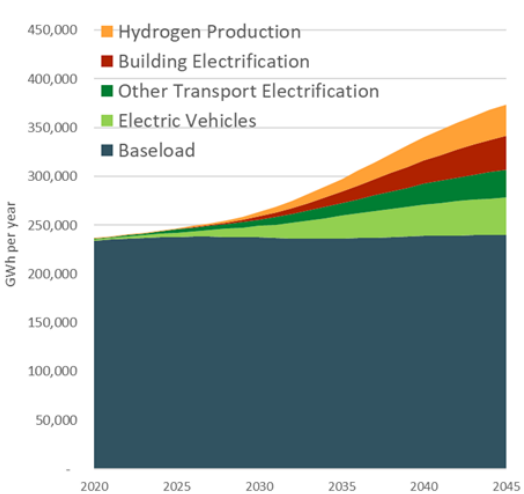
+ High Electrification, High Hydrogen, & High Biofuels all hit the same economywide GHG targets and include relatively high electrification across the economy.
  - The main differences relate to the level of on-road vehicle electrification.
  - The High Biofuels scenario assumes more imported biofuels reduce the need for transportation electrification.
  - The High Hydrogen scenario assumes very high shares of hydrogen fuel cell trucks, with reduced numbers of EV trucks and freeing up some biofuels to decarbonize other sectors.

Fuel Metrics in 2050

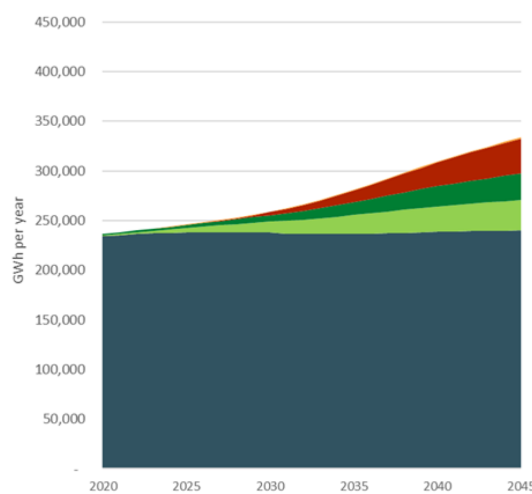
Exajoules in 2050	High Electrification	High Biofuels	High Hydrogen
Hydrogen	0.11	0.00	0.32
Advanced Biofuels	0.56	0.86	0.56

Electricity Loads

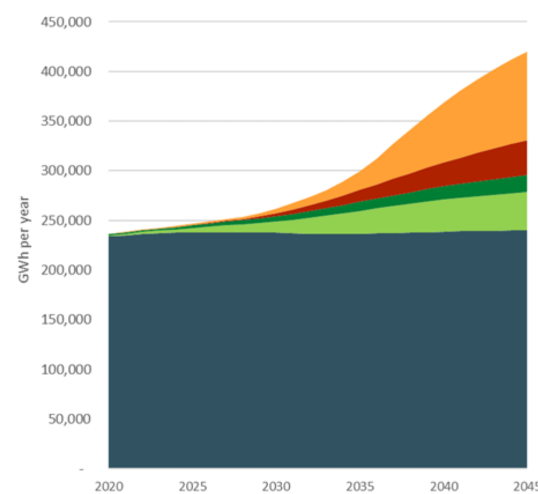
High Electrification



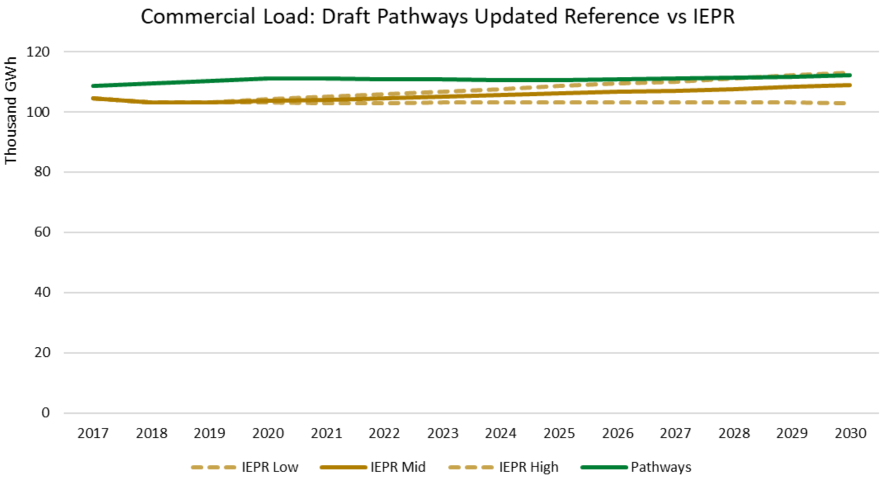
High Biofuels

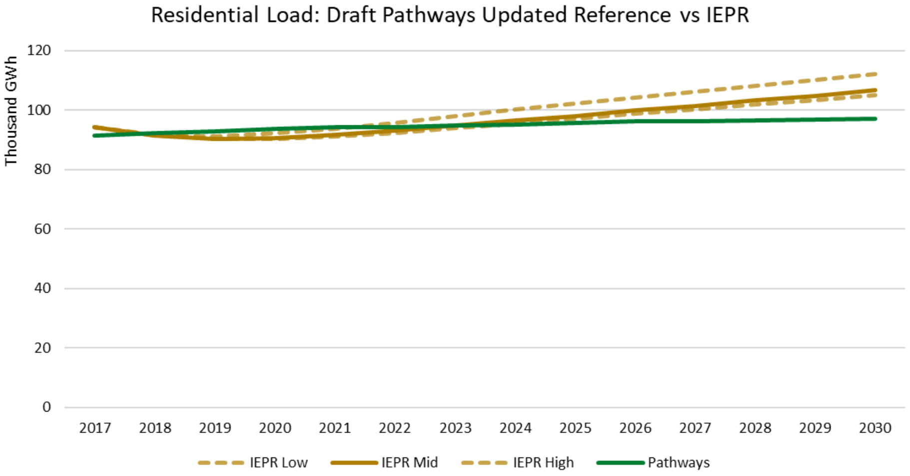


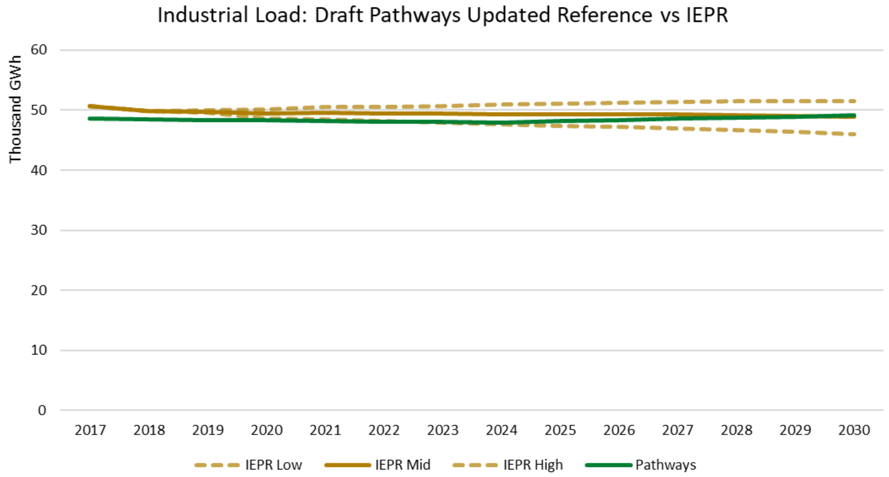
High Hydrogen

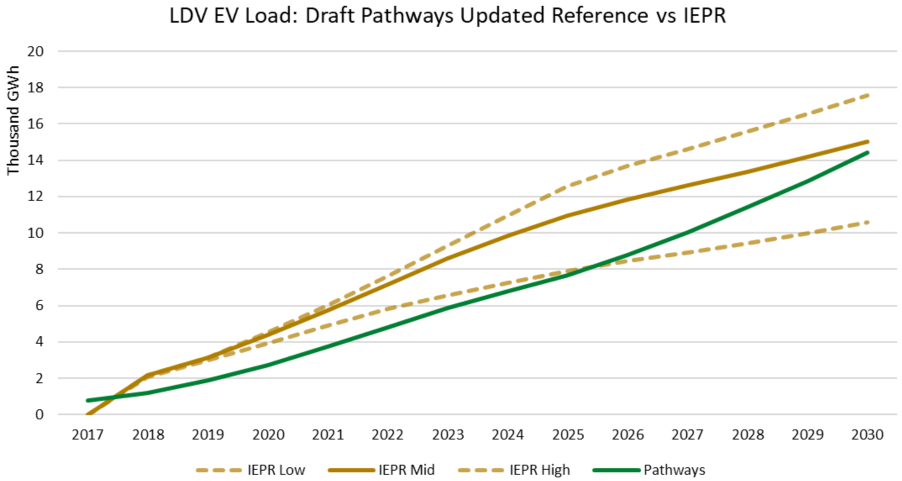


IEPR Comparison for key sectors









	IEPR Low	IEPR Mid	IEPR High	Pathways
2030 LDV ZEV population	2.7 million	3.7 million	4.4 million	4.27 million

- Post-2030 LDV ZEVs in PATHWAYS Reference is not constrained by IEPR and based on modeled stock-rollover assumptions: 19 million on-road by 2045

2030 GHG Mitigation Strategies in High Electrification Scenario

	Sector	2030 GHG reduction strategy
Efficiency	Buildings	10% reduction in total building energy demand relative to 2015
	Transportation	12% reduction in per capita light-duty vehicle miles traveled relative to 2015
	Industry	30% reduction in total industrial energy demand relative to 2015
Electrification	**Buildings**	**50% new sales of water heaters and HVAC are electric heat pumps**
	Light-duty vehicles	**6 million ZEVs (20% of total) and >60% of new sales are ZEVs**
	Trucks	4% of trucks are BEVs or FCEVs (6% of trucks are hybrid & CNG) 32% electrification of buses, 20% of rail, and 27% of ports
Low carbon fuels	**Electricity**	**74% zero-carbon electricity, including large hydro and nuclear (~70% RPS)**
	Advanced Biofuels	10% of total (non-electric power generation) fossil fuels replaced with advanced biofuels
Non-combustion GHGs	Reductions in methane and F-gases	37% reduction in methane and F-gas emissions relative to 2015 19% reduction in other non-combustion emissions relative to 2015

2050 GHG Mitigation Strategies in High Electrification Scenario

	Sector	2050 GHG reduction strategy
Efficiency	Buildings	34% reduction in total building energy demand, relative to 2015
	Transportation	24% reduction in per capita light-duty vehicle miles traveled relative to 2015
	Industry	30% reduction in total industrial energy demand relative to 2015 90% reduction in refinery and oil & gas extraction energy demand
Electrification	**Buildings**	**100% new sales of water heaters and HVAC are electric heat pumps**
	Light-duty vehicles	**35 million ZEVs (96% of total) and 100% of new sales are ZEVs**
	Trucks	47% of trucks are BEVs or FCEVs (31% of trucks are hybrid & CNG) 88% electrification of buses, 75% of rail, and 80% of ports
Low carbon fuels	**Electricity**	**96% zero-carbon electricity (including large hydro)**
	Advanced Biofuels	46% of total (non-electric power generation) fossil fuels replaced with advanced biofuels (0.56 EJ)
Non-combustion GHGs	Reductions in methane and F-gases	62% reduction in methane and F-gas emissions relative to 2015 42% reduction in other non-combustion GHGs relative to 2015

High Biofuels & High Hydrogen Assumptions

	Sector	2050 High Biofuels	2050 High Hydrogen
Efficiency	Buildings	*Same as High Electrification*	*Same as High Electrification*
	Transportation	*Same as High Electrification*	*Same as High Electrification*
	Industry	*Same as High Electrification*	*Same as High Electrification*
Electrification	Buildings	*Same as High Electrification*	*Same as High Electrification*
	Light-duty vehicles	25 million (69% of total), and 81% of new sales are ZEVs	*Same as High Electrification*
	Trucks	27% of trucks are BEVs	65% of trucks are ZEVs, including high HFCVs
Low carbon fuels	Electricity	93% zero-carbon electricity (including large hydro)	92% zero-carbon electricity (including large hydro)
	Advanced Biofuels	59% of liquid & gaseous fuels replaced with advanced biofuels (0.86 EJ)	*Same as High Electrification*
Non-combustion GHGs	Reductions in methane and F-gases	*Same as High Electrification*	*Same as High Electrification*

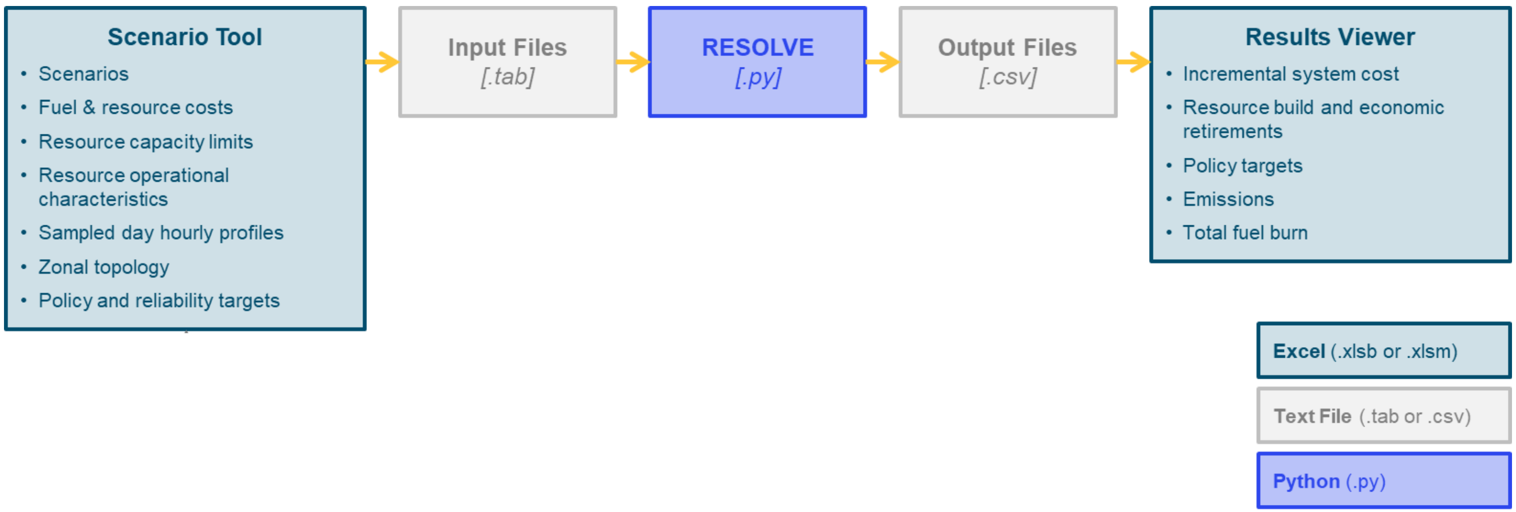
Energy+Environmental Economics

Appendix: RESOLVE

RESOLVE

The RESOLVE Toolkit

+ **The RESOLVE toolkit includes Excel spreadsheets as the main UI**
  - RESOLVE Python code reads tab-delimited input files and produces result CSVs



RESOLVE Applications

+ **IRP and long-term scenario analyses**
+ **Asset valuation**
+ **Bid/Portfolio analysis**

+ **A handful of organizations run RESOLVE internally**
  - HECO, SMUD, CPUC, PG&E, Resero Consulting, LADWP

Resource Potential by Resource Zone

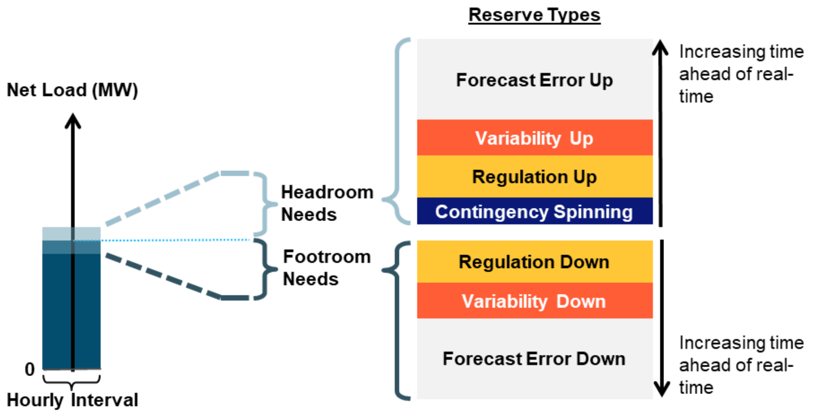
Resource Zone	Solar	Wind	Geothermal
Greater Imperial	35,216	-	1,352
Inyokern North Kramer	23,653	-	24
Northern California Ex	41,532	866	469
Riverside Palm Springs	57,071	-	32
Solano	15,656	542	135
Carrizo	9,907	287	-
Central Valley North Los Banos	12,873	173	-
Mountain Pass El Dorado	248	-	-
Kern Greater Carrizo	8,329	60	-
Kramer Inyokern Ex	4,508	-	-
North Victor	4,608	-	-
Sacramento River	23,484	-	-
Southern California Desert	5,608	-	-
Solano subzone	-	18	-
Southern California Desert_Ex	43,713	-	-
Tehachapi Ex	1,488	-	-
Tehachapi	4,801	275	-
Westlands Ex	4,404	-	-
Westlands	56,151	-	-
Humboldt	-	34	-

Operating Reserve Requirements

RESOLVE
Investment Decisions
System Operations

+ **RESOLVE holds multiple operating reserve types in its hourly dispatch:**
  - Contingency spinning
    - Set by single largest contingency of reserve sharing agreement
  - Load following up/down
    - Function of forecast error and resource variability
  - Regulation up/down
  - Frequency response
  - Minimum online generation
    - Can be a proxy for local volt/VAR or inertia needs

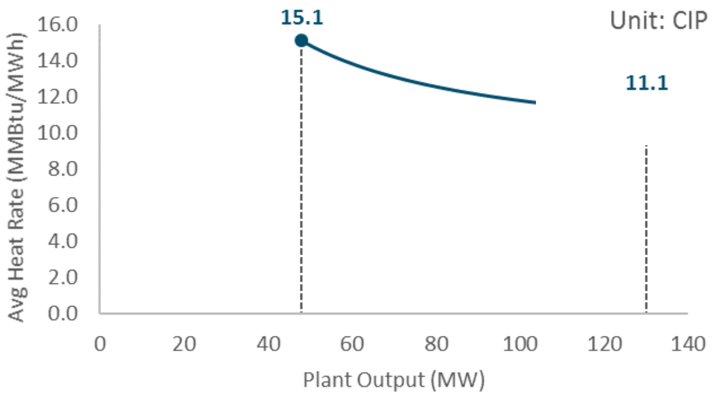
Schematic of Operating Reserves



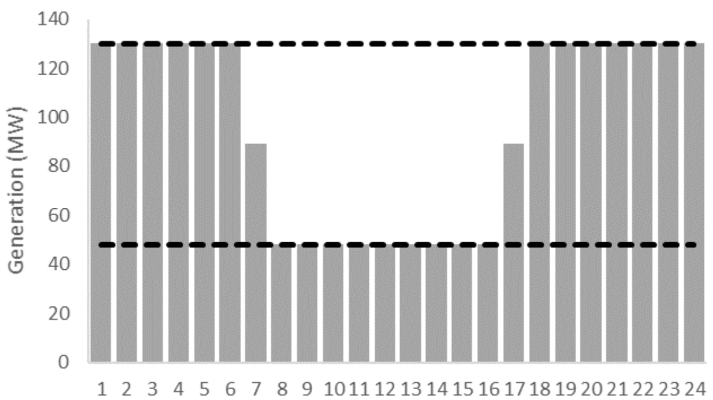
Thermal Resources

+ **Economic input parameters:**
  - Heat rate curve
    (based on fuel burn slope-intercept)
  - Variable O&M ($/MWh)
  - Start & stop cost ($/start-unit)
+ **Operating constraints (aggregated, linearized unit commitment):**
  - Pmax & Pmin (optional hourly) (MW)
  - Minimum up/down time (hr)
  - Ramp rates (% Pmax/hr)
  - Start fuel (MMBtu/MW-start)
+ **Optional parameters:**
  - Must Run toggle (run at Pmax)
  - Must Commit toggle
    (committed but flexible with operating range)

+ **Example Heat Rate Curve**



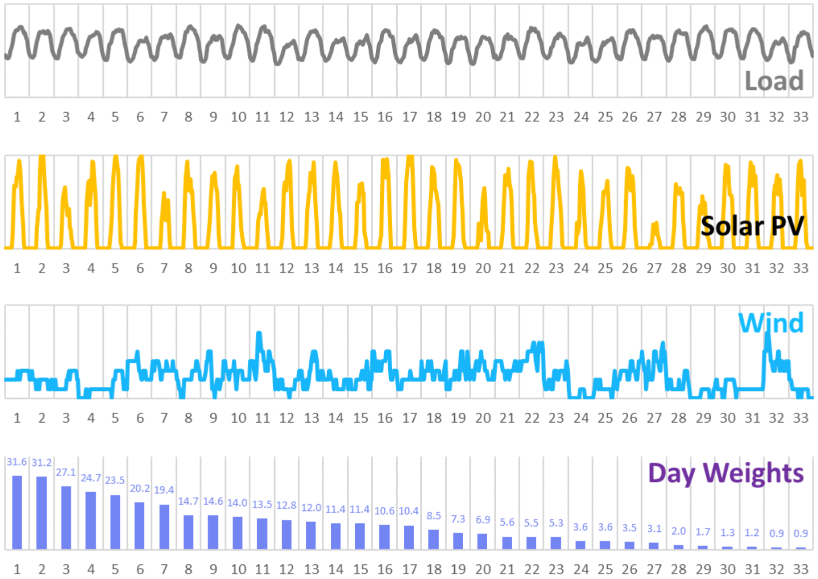
+ **Example Operating Constraints**



Variable Resources

- **Variable resource profiles are sampled using day sampling methodology**
- **Variable resources are generally assumed to be zero-marginal cost**
  - PTC for wind accounted for as part of fixed costs
- **Variable resources can provide load following reserves:**
  - Load following up:
    Pre-curtail resource hour-ahead (create headroom) and can be "un-curtailed" subhourly
  - Load following down:
    Reserve footroom in sampled resource profile to be curtailed subhourly
- **Variable resources provide capacity toward PRM based on ELCC surface**

- **Example Sampled Load, Wind, and Solar Profiles**

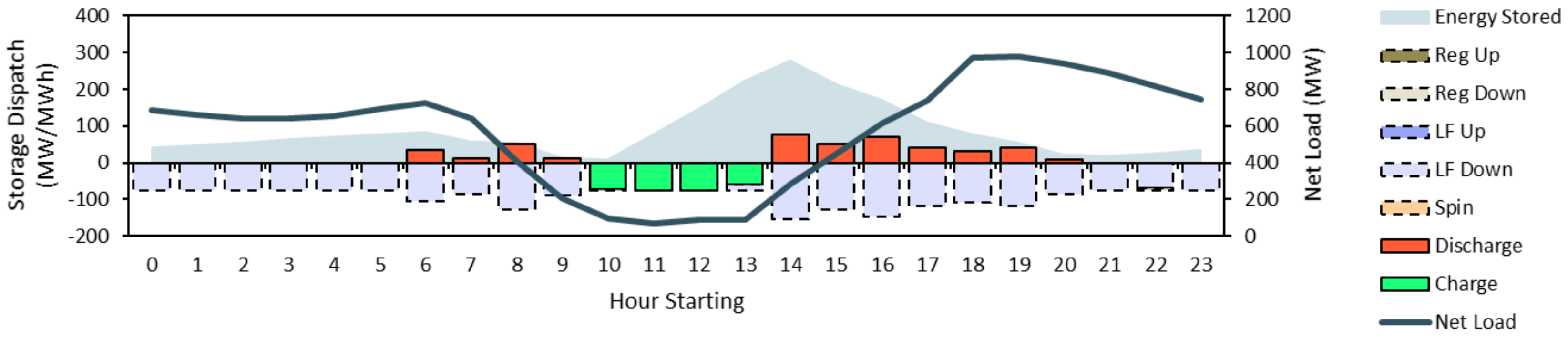


Battery Storage Resources

+ **Battery storage resources are capable of charging and discharging flexibly within a power and energy rating**
+ **Storage provides capacity toward PRM requirement based on NQC derate and qualifying duration**
+ **By default, storage losses do not count toward RPS**

+ **Storage dispatch is constrained by:**
  - Power rating (MW)
  - Minimum duration (hours)
  - Roundtrip efficiency (%)
  - Energy neutrality within each dispatch day

+ Example Storage Dispatch



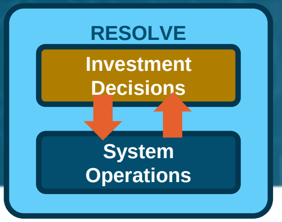
Hydro Resources

- **Hydro resources are generally modeled as having a daily energy budget that can be flexibly dispatched**
  - Basic Inputs
    - Daily output energy budget (MWh/day)
    - Operational capacity (MW)
  - Optional Inputs
    - Hourly Pmin/Pmax (MW)
    - Multi-hour ramping constraints (ΔMW/hour)
    - Maximum energy sharing across days (MWh)
- **Hydro resources are assumed to provide firm capacity (subject to NQC derate)**

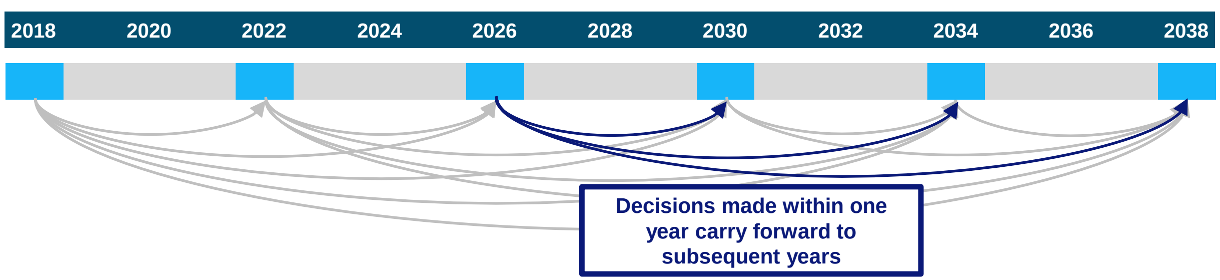
Shed Demand Response Resources

- **Shed DR resources are modeled linearly to approximate call/availability limitations**
- **Operational inputs:**
  - Nameplate capacity (MW)
  - Annual availability (hours/year)
  - Daily capacity factor (fraction of day for call hours)
    - A 4-hour DR call would be equivalent to a 16.7% capacity factor
- **Shed DR resources are considered firm resources (subject to NQC derate)**

RESOLVE Model Time Horizon



- **RESOLVE minimizes the NPV of total costs across a 20+ year time horizon**
  - Additional weight applied to last year of analysis to account for end effects
  - Because of computational complexity, RESOLVE is typically not used to model all years in analysis horizon
- **Because RESOLVE can "see" all future needs, it can help planners make proactive investment decisions to meet needs at lowest expected cost**



In each **modeled year,** the portfolio is explicitly modeled, and total cost is calculated as the sum of fixed costs of investment and operating costs

In **intermediate years,** the total cost of the portfolio is calculated by linear interpolation between the two adjacent modeled years

Planning Reserve Margin Constraint

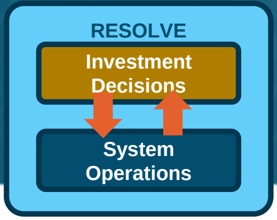
- In each year modeled, RESOLVE imposes a planning reserve margin constraint on the total generation fleet for the California zone
- Contribution of each resource to PRM requirement depends on its attributes

PRM Requirement ≤ **Available Capacity**

Available Capacity	
Firm Resource NQC	Based on CAISO NQC list
Hydro NQC	Based on CAISO NQC list
Renewable ELCC	Calculated in RESOLVE via ELCC surface
Imports	CAISO RA planning assumption
Storage NQC	Based on SERVM ELCC
Demand Response	Assumed to be equal to 1-in-2 ex ante peak load impact

PRM constraint designed to ensure that sufficient generation capability is available to meet load during system peak conditions

Calculating Resource ELCCs



+ **Effective load carrying capability (ELCC) is a probabilistic measure of a resource's contribution to system resource adequacy requirements**
+ **Marginal ELCC generally declines as a function of penetration**
  - For the first increment of solar PV installed, production is largely coincident with peak demand
  - As penetration of solar PV increases, "net load peak" shifts toward evening, when solar PV is limited (or zero)

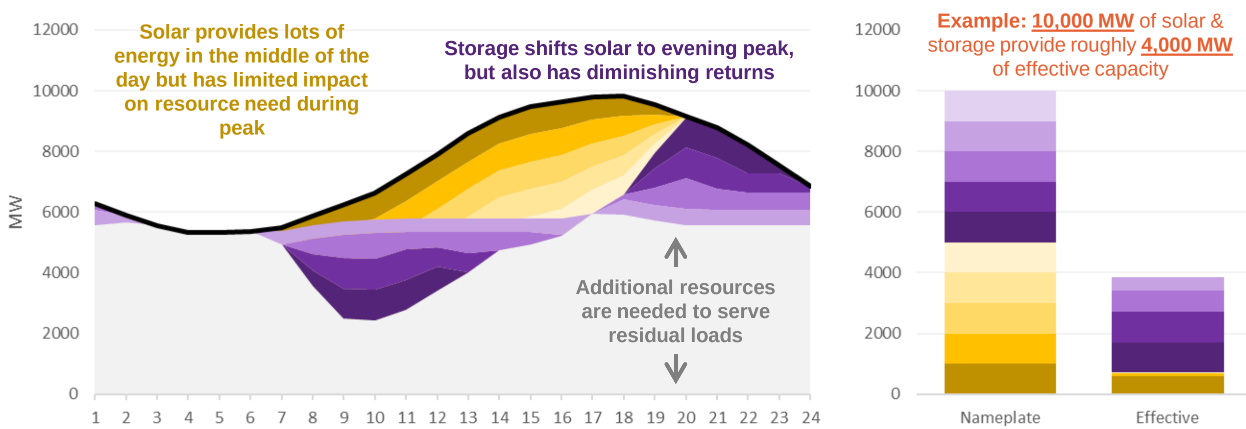


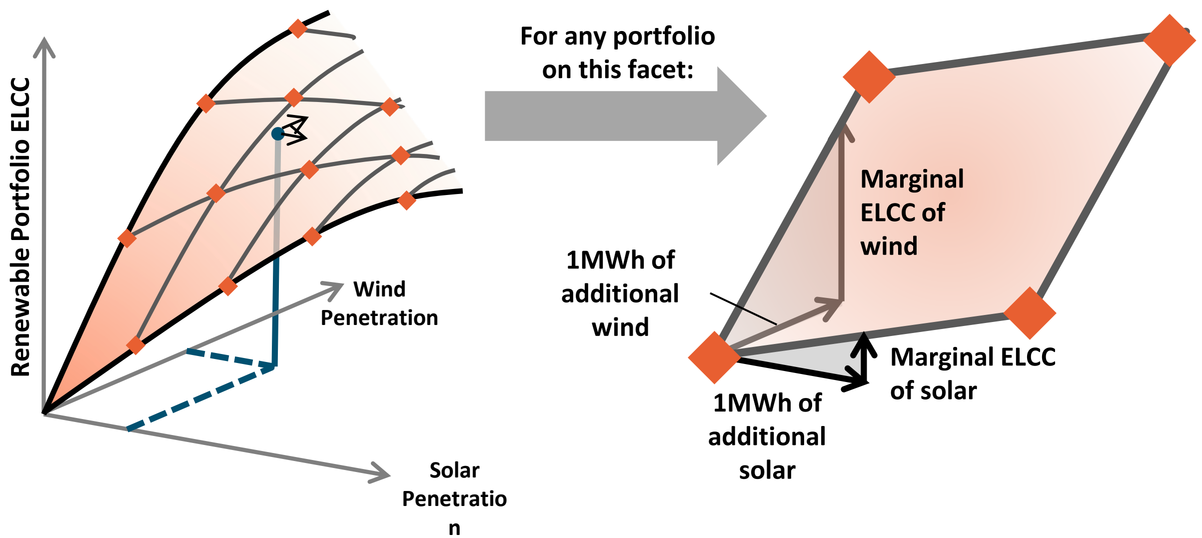
Figure is illustrative of model dynamics and not a model result

ELCC Surface in Two Dimensions (Wind + Solar)

RESOLVE
Investment Decisions
System Operations

+ **In current version of RESOLVE, we assume that wind and solar ELCCs are interactive, represented by an ELCC surface**
  - ELCC surface is expressed in RESOLVE as a piecewise linear function of wind and solar penetration

Example of ELCC Surface



RESOLVE Model Formulation Overview

Category	Constraint Group	Description	Importance
Capacity	Capacity Expansion	Tracks annual resource capacity, including economic resource buildout. Interacts with resource dispatch and reliability constraints.	High
	Economic Retirement	Supply resources can retire economically if ongoing fixed costs are higher than value of services provided to the system.	Low
	CA Deliverability Zones	Categorize renewable build into "Fully-Deliverable" and "Energy-Only" for CA.	Low
Power Balance	Zonal Power Balance	Ensure that generation and imports match loads in each modeled zone. **Sets the zonal marginal energy price.**	High
Loads	Economic EE Investment	Economically build EE (load modifiers).	Low
	EV Smart Charging	Optimally charge EVs to meet assumed driving pattern.	Low
	Hydrogen Electrolysis	Produce hydrogen for non-electricity uses.	Low
	Shed DR	Constrain shed DR programs to limited amount of dispatch per year.	Low
	Shift DR	Constrain shift DR programs to maintain energy neutrality and underlying availability shape.	Low
Operating Reserves	Reserve Requirements	Maintain sufficient frequency response, regulation up/down, load following up/down, and spinning reserves. **Sets operating reserve prices.**	Medium
Policy Targets	GHG Target	Meet an annual GHG target, including imported GHG accounting from external zones. **Sets marginal GHG price.**	High
	RPS/CES Target	Meet an annual RPS or CES target, including unspecified imports accounting. **Sets marginal REC price.**	High
Reliability	Planning Reserve Margin	Meet a PRM requirement based on pre-determined ELCCs for operational resources in each year. **Sets the annual capacity price.**	High
	Local Capacity Area	Build a certain amount of resources “locally”. Analogous to CA LCR zones.	Low
	Energy Sufficiency	Analogous to the single-hour PRM but evaluate if there is sufficient available energy across the year on a variable timescale.	Medium
Resource Dispatch	Operating Limits	Constrain output to operating limits (including hourly ramping) or expected output.	High
	Storage Energy Tracking	Track state of charge of storage resources to optimally dispatch for energy and reserves.	High
	Unit Commitment	Track commitment of longer-start (thermal) resources to constraint dispatch for energy and reserves.	Medium
	Hourly Profiles	Constrain variable resources to fixed production profiles, which can be optimally curtailed for integration or provide operating reserves.	High
Transmission	Transmission Flows	Limit energy flows between zones (including optional hourly ramps). RESOLVE is a zonal model. **Sets hourly congestion price for energy.**	High
	Transmission Expansion	Economically build transmission (increase path ratings). Interacts with resource dispatch and reliability constraints.	Low

Transmission Cost Characterization in RESOLVE

+ **Two different types of transmission costs associated with new renewables**
  1. Cost associated with delivery within CA
     – Applies to both in-state and out-of-state resources
  2. Cost associated with delivery of out-of-state resources to the CA boundary
     – Applies only to out-of-state resources

+ **Note: in selecting new resources, RESOLVE considers levelized fixed costs plus operating costs**
  - Although LCOE is a more common metric for describing renewables, it is not well-suited for resources that are dispatched in the optimization
  - Levelized fixed costs include installation costs, fixed O&M costs, and transmission costs

In-state transmission costs

- **For in-state renewables, transmission costs are based on RESOLVE's characterization of renewable transmission zones**
  - E.g.: Competitive Renewable Energy Zones (CREZs)
  - In-state Tx costs are incremental to the levelized fixed cost for each resource
- **In each CREZ, transmission upgrades may be required for resources to have full deliverability, e.g. FCDS (Full Capacity Deliverability Status)**
  - Some CREZs have existing FCDS capacity available
    - Transmission upgrade costs are only applied once this limit is reached
- **Data on costs and existing capacity provided by CAISO and CPUC RPS Calculator**
  - Costs range from $11/kW-yr to $89/kW-yr, depending on CREZ

Out-of-state transmission costs

+ **Out-of-state resources have additional cost associated with new Tx to deliver energy to the CA boundary**
  - These are incorporated into resource-specific levelized fixed costs in pre-processing
+ **Out-of-state Tx costs represent the cost to wheel power across adjacent utilities' systems or the cost of developing new transmission lines**
  - Costs are derived from OATTs and the CEC's Renewable Energy Transmission Initiative 2.0 (RETI 2.0) and correspond to full capacity deliverability
  - These costs vary by out-of-state zone and range from $29/kW-yr to $143/kW-yr
+ **Out-of-state resources will also incur in-state Tx costs**
  - Unless there is existing FDCS capacity in the relevant zone
  - Out-of-state resources are PRM-eligible if RESOLVE selects to use or build FCDS capacity for the in-state component

Example: Utah Solar

	Levelized fixed cost	($/kW-yr)	$	79
+	Out-of-state Tx cost	($/kW-yr)	$	69
	RESOLVE input levelized fixed cost	($/kW-yr)	$	148
+	In-state Tx cost	($/kW-yr)	$	34
	Total cost in RESOLVE	($/kW-yr)	$	182

Benchmark for out-of-state Tx costs

+ **SunZia project: 2000 MW of transmission connecting NM to AZ**
  - 520-mile path[1]
  - Total capacity of 3000 MW[1]
  - Estimated cost of $2B[2]

+ **Levelized fixed costs can be estimated using a levelization factor**
  - 11% levelization factor accounts for recovery of upfront costs as well as ongoing fixed O&M costs

+ **Estimate of $73/kW-yr for new transmission from NM to AZ**
  - Compare to RESOLVE out-of-state Tx costs:
    - NM to CA: $121/kW-yr
    - AZ to CA: $29/kW-yr

[1] SunZia 2019 Annual Progress Report, https://www.wecc.org/Reliability/SunZia%202019%20APR.pdf

[2] "Tx Path Uncertain for Massive New Mexico Wind Farm," RTO Insider, 1/29/2020, https://rtoinsider.com/caiso-sunzia-pattern-new-mexico-wind-farm-101338/