Simultaneous planning of generation, transmission, and storage capacity for 2030 and beyond using the SWITCH model

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Electricity planning with variable renewables

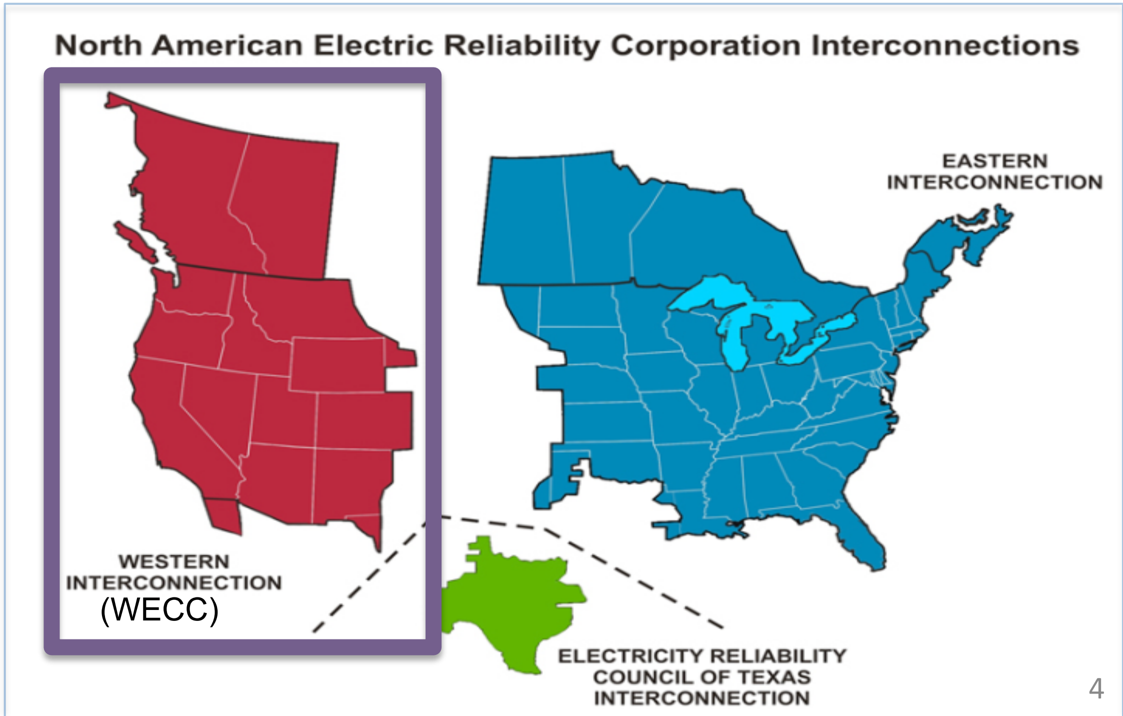
- Power systems with high fractions of wind and solar power will require investment in various sources of flexibility
  - Transmission, storage, gas, geographic diversity, demand response, efficiency, etc.
  - How do we make tradeoffs with respect to flexibility sources while meeting long-term carbon and/or renewable energy targets at least cost?
- Both spatial and temporal aspects will become increasingly important in planning

Long-term electricity planning using SWITCH

- SWITCH used here as a scenario analysis tool
  - Results are *not* projections
- *Long-run investment* framework is fundamental
  - Long-term investments reach far past the margin
  - Pre-market framework
    - minimize costs, then design market
  - System-wide approach
  - Many different timescales
- SWITCH can provide valuable insight with respect to:
  - Future carbon emissions
  - Feasibility and makeup of energy pathways
  - Consistency of short and long term policy goals
  - Estimates of possible costs

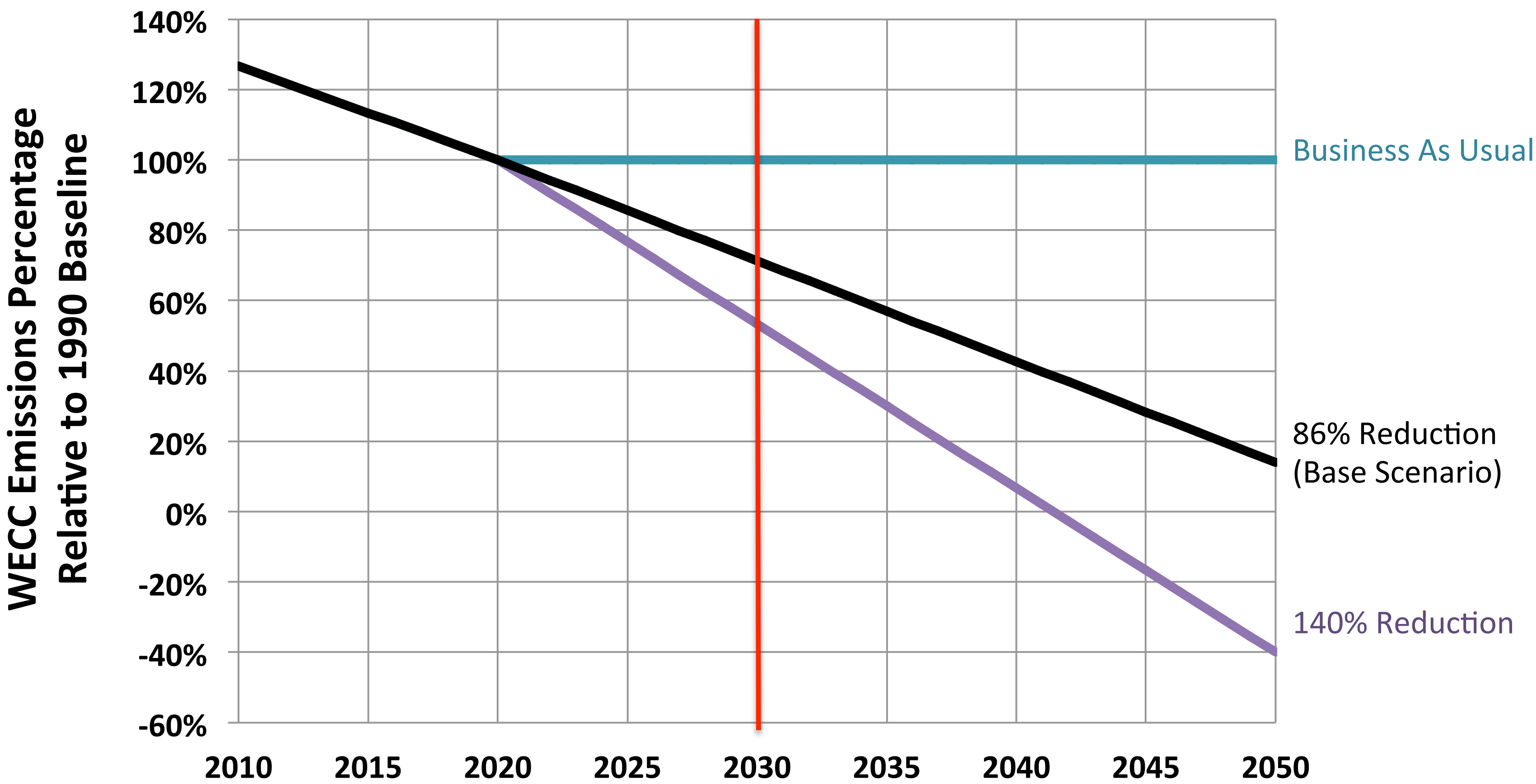
SWITCH-WECC: A planning tool for the electric power system

- Objective: minimize net present cost of meeting demand in all simulated hours in all investment periods
  - Subject to: carbon and renewable policy constraints, linearized operational constraints, resource constraints, etc.
- Temporal Resolution:
  - 4 investment periods: 2020, 2030, 2040, 2050
  - 144 distinct hours simulated per period
    - Dispatch simulated simultaneously with investment decisions
- Geographic Resolution:
  - Western North American Power System (the WECC)
  - 50 load areas
  - Thousands of possible wind and solar projects
  - Plant-level existing generators



Carbon emissions forced to decline over time

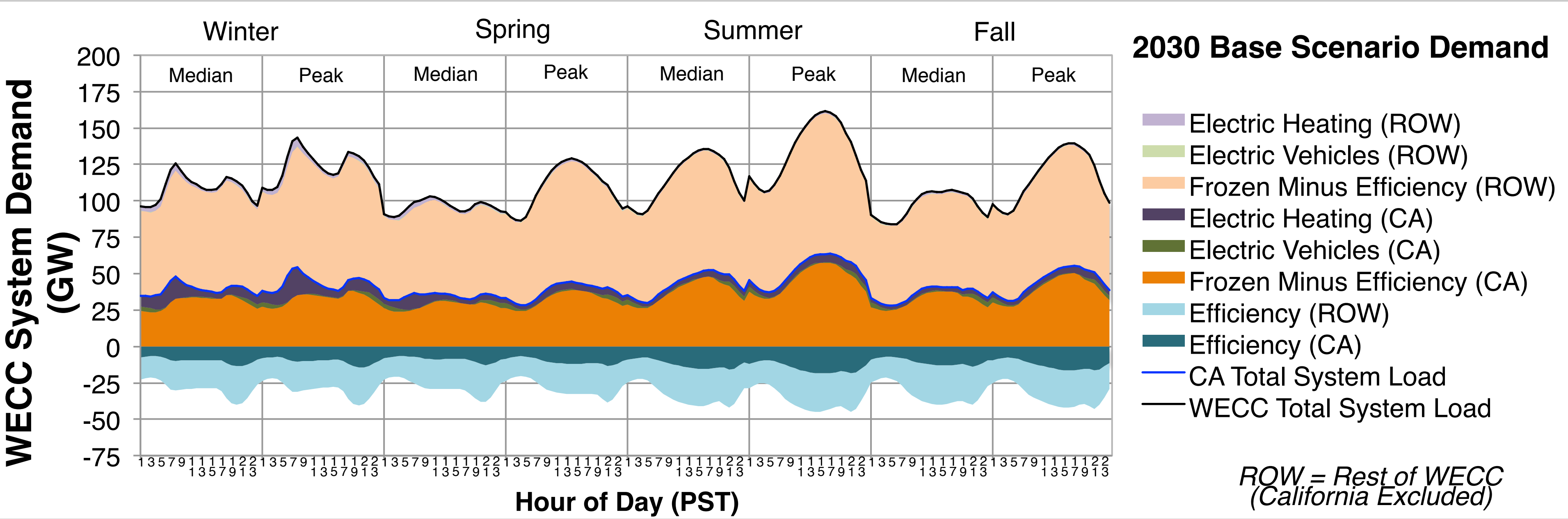
Parameter	Base scenario defaults that are varied in sensitivity scenarios
Carbon cap (WECC-wide)	100% of 1990 emissions levels in 2020 Linear decrease to **86%** below 1990 emissions levels in 2050 -Decarbonization of electricity easier than for other sectors



Base scenario assumes aggressive efficiency by 2030

Parameter	Base scenario defaults that are varied in sensitivity scenarios
Demand profile	Electrification of heating and vehicles
	Technical potential energy efficiency

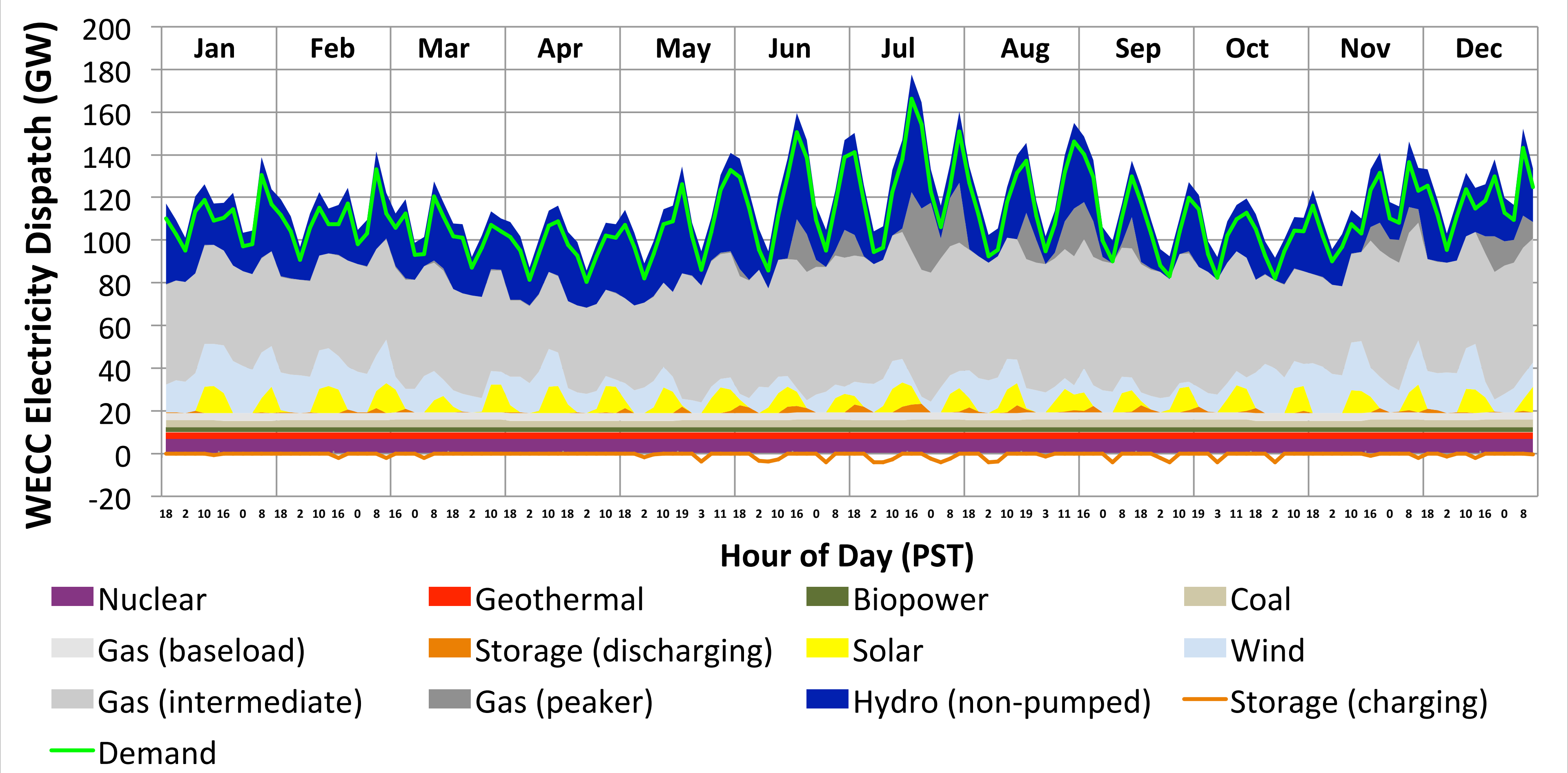
- We're headed to 2050
  - Start deep efficiency and electrification early, otherwise, we'll likely miss 2050 carbon targets
    - Limited biofuels for transport → Electrification
    - Very low GHG building heating → Electrification



Base scenario assumes continued carbon reductions, but no new renewable energy policies

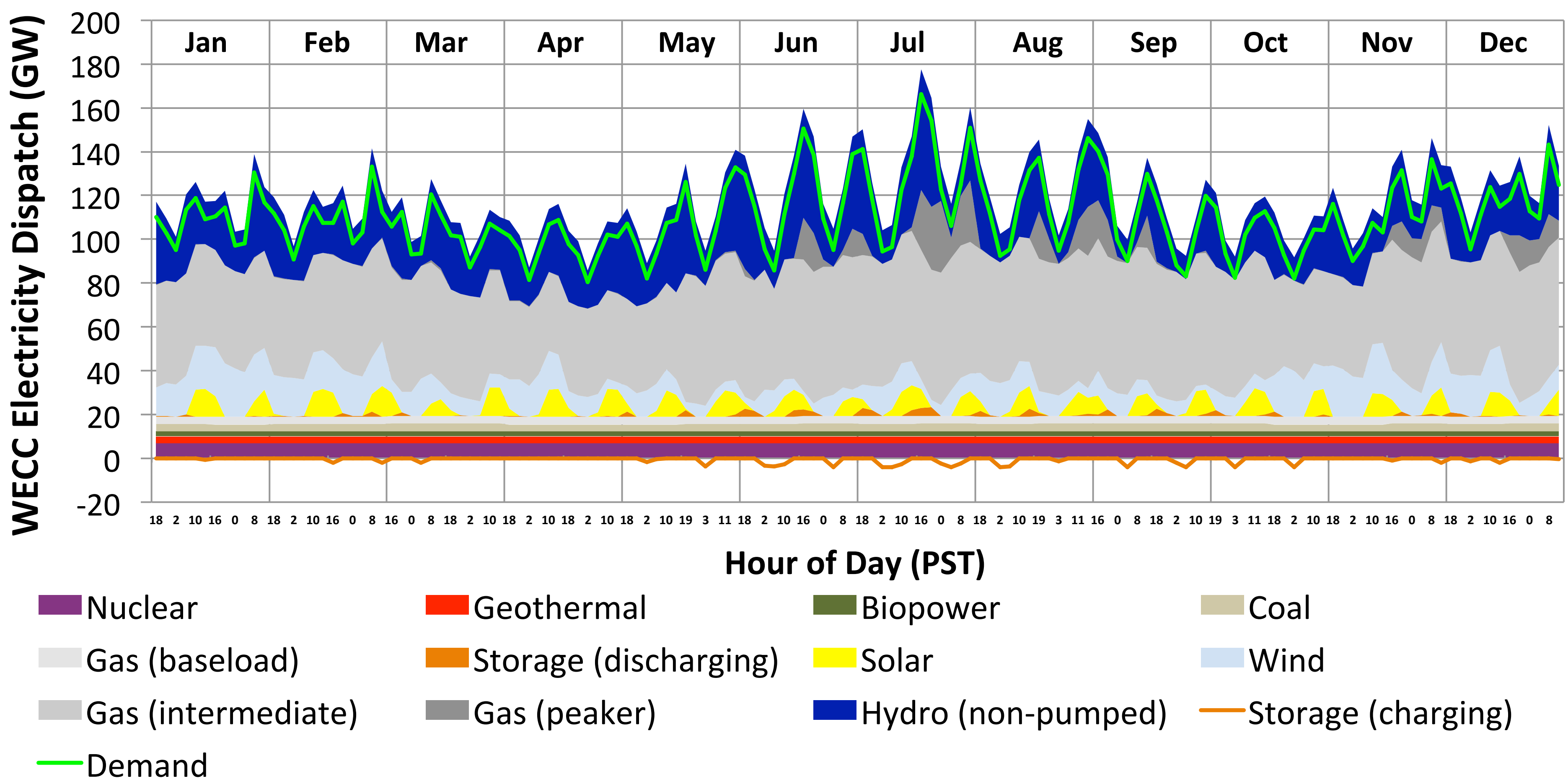
Parameter	Base scenario defaults that are varied in sensitivity scenarios
Generation fleet	New biomass excluded from electric power
	New nuclear excluded (existing nuclear given option to run)
	Solar (and other generation) costs as projected by Black & Veatch
Gas price	NEMS Annual Energy Outlook Base Case 2012
Policy	12 GW distributed generation mandate in California excluded
	33% RPS in California by 2020 included, higher CA targets excluded

Base scenario dispatch: gas dominates integration



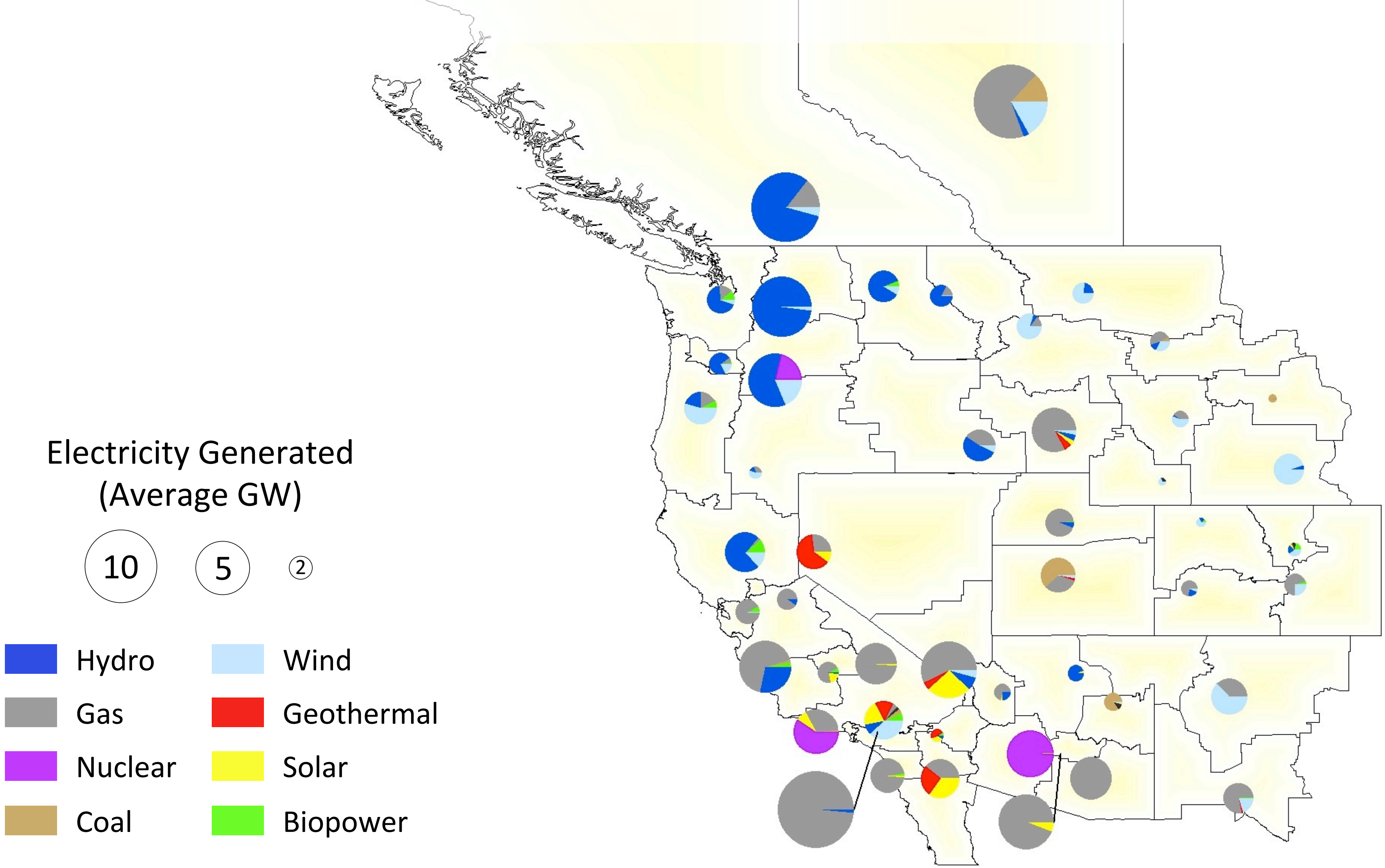
Base scenario dispatch: gas dominates integration

- Base scenario assumes much efficiency AND no new renewable policy by 2030
- Amount of gas generation allowed by carbon cap is still enough to balance renewables – storage largely dormant
- Storage installed after 2030 to meet stringent carbon cap

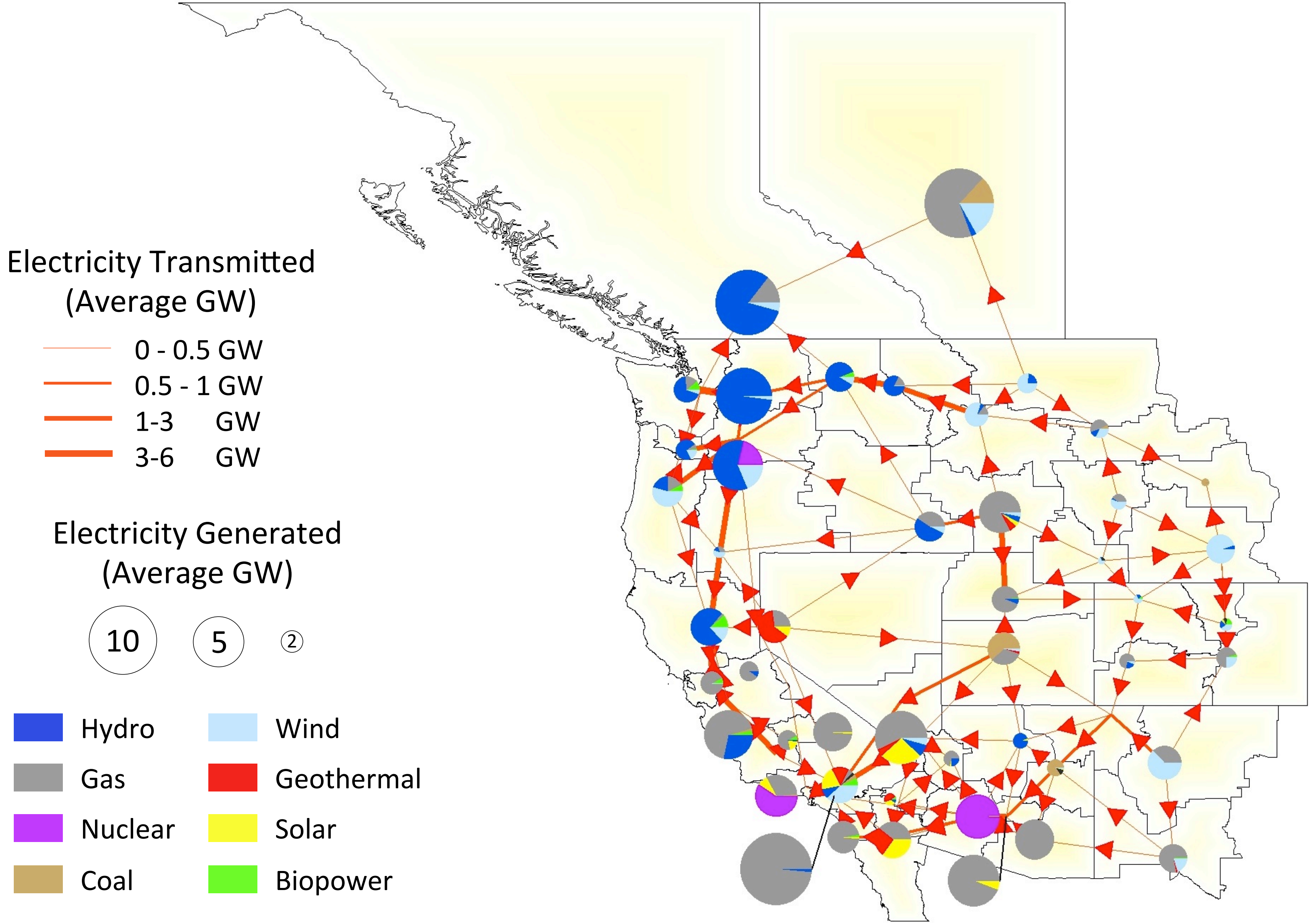


Base scenario in 2030: California diverse, dominated by gas

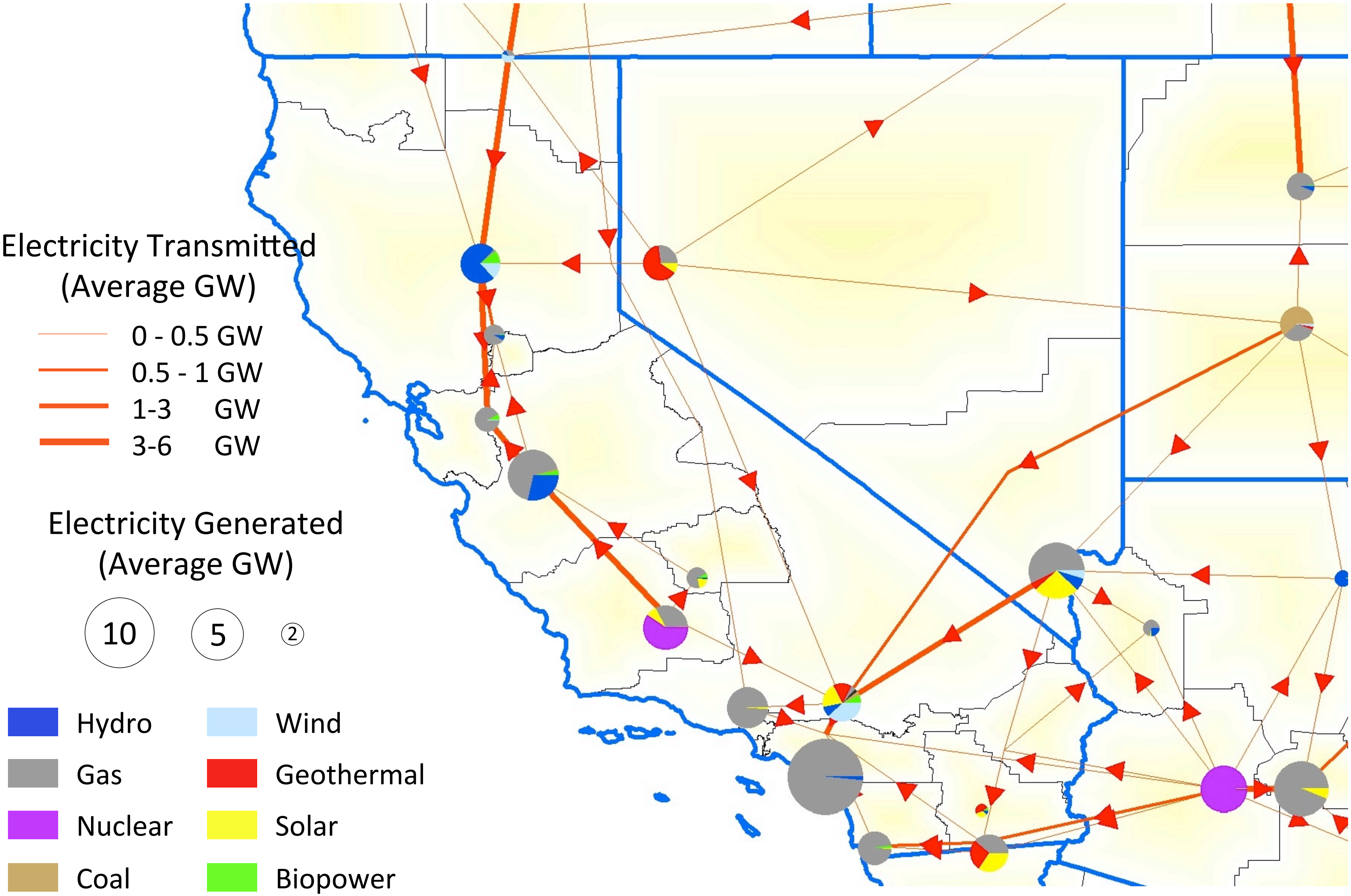
- Natural gas replaces most WECC coal by 2030
  - Provides flexibility to integrate intermittent renewables



Base scenario in 2030: electricity transmission largely dormant

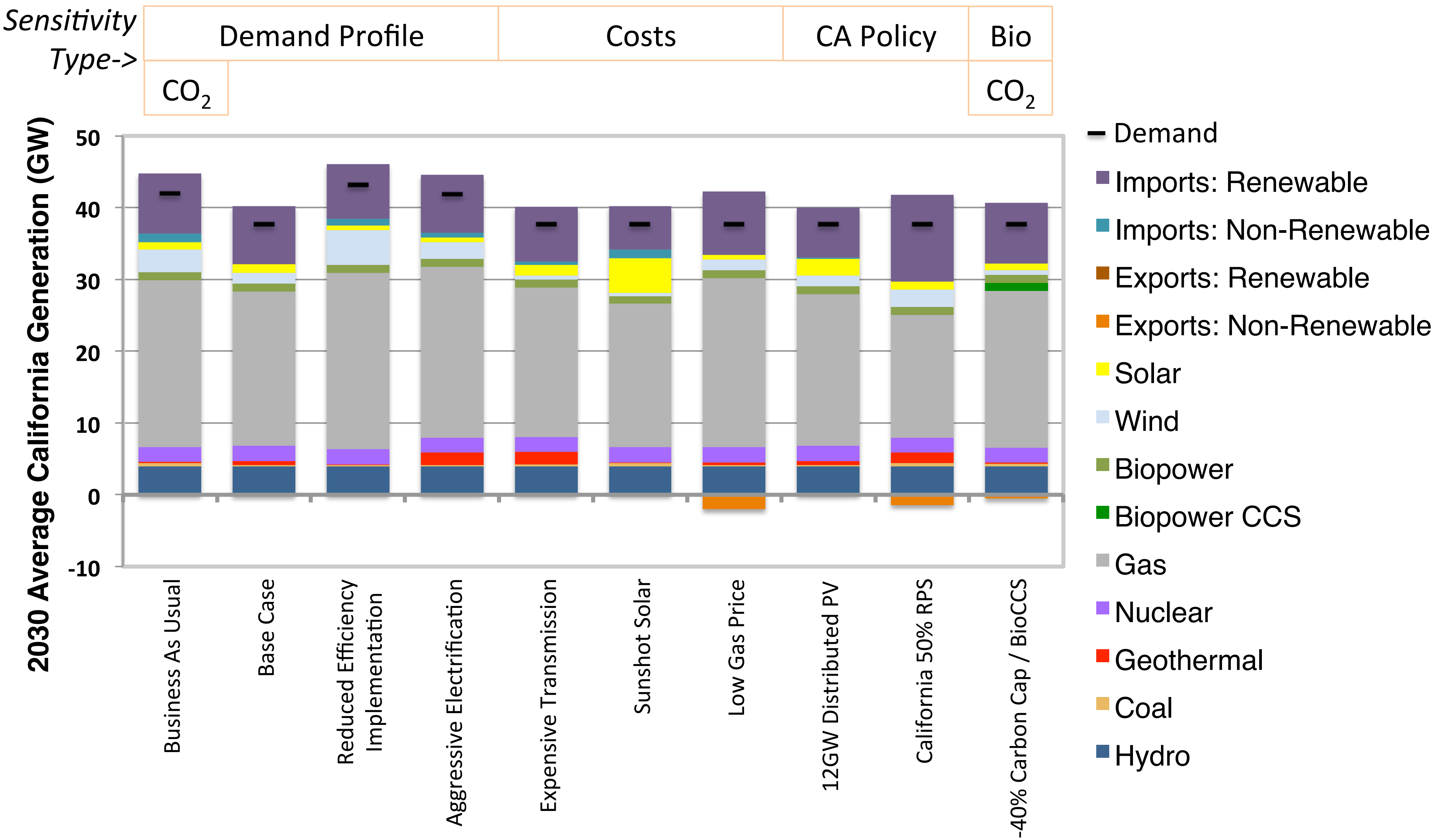


Base scenario: wind and hydro imported from Northwest



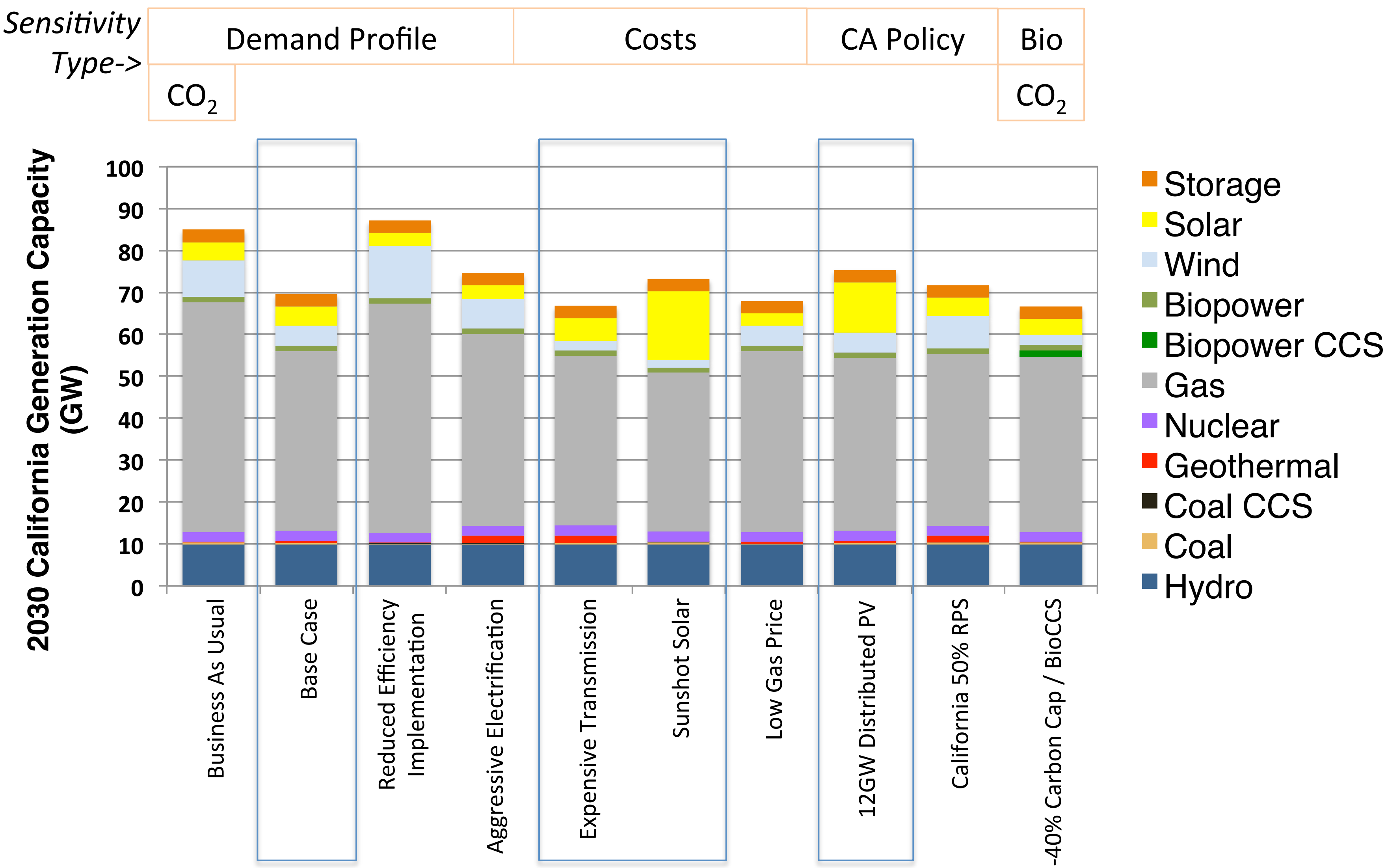
Average California power mix in 2030

- Consistent with pathway to 2050 GHG targets
- Transmission dominated by bundled RECs

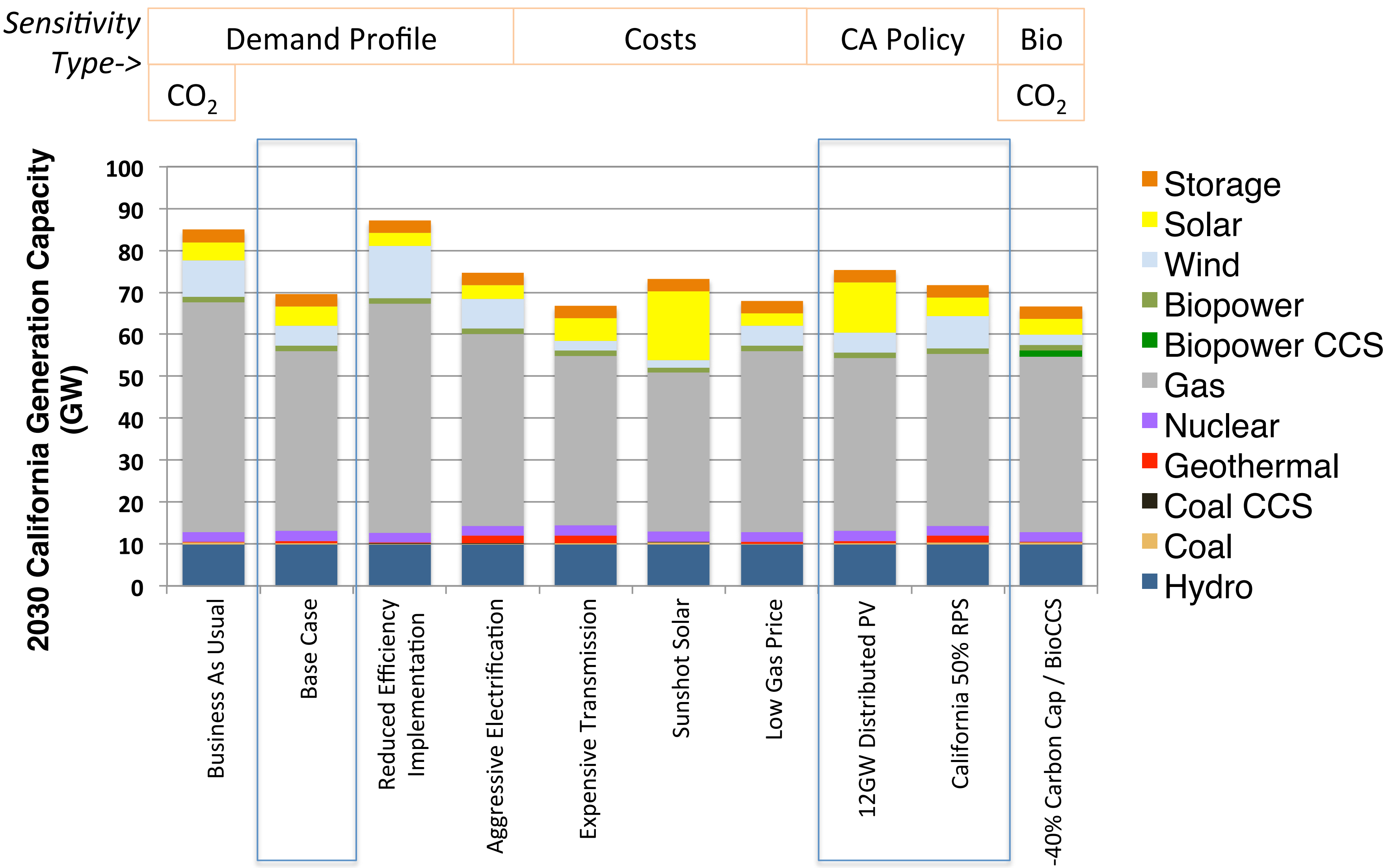


California generation capacity in 2030

- Sunshot solar and distributed PV mandate cite capacity in state
- Expensive transmission moves renewables into state



- California renewable polices effective at reducing gas capacity factor in the state, but perhaps not at reducing installed gas capacity

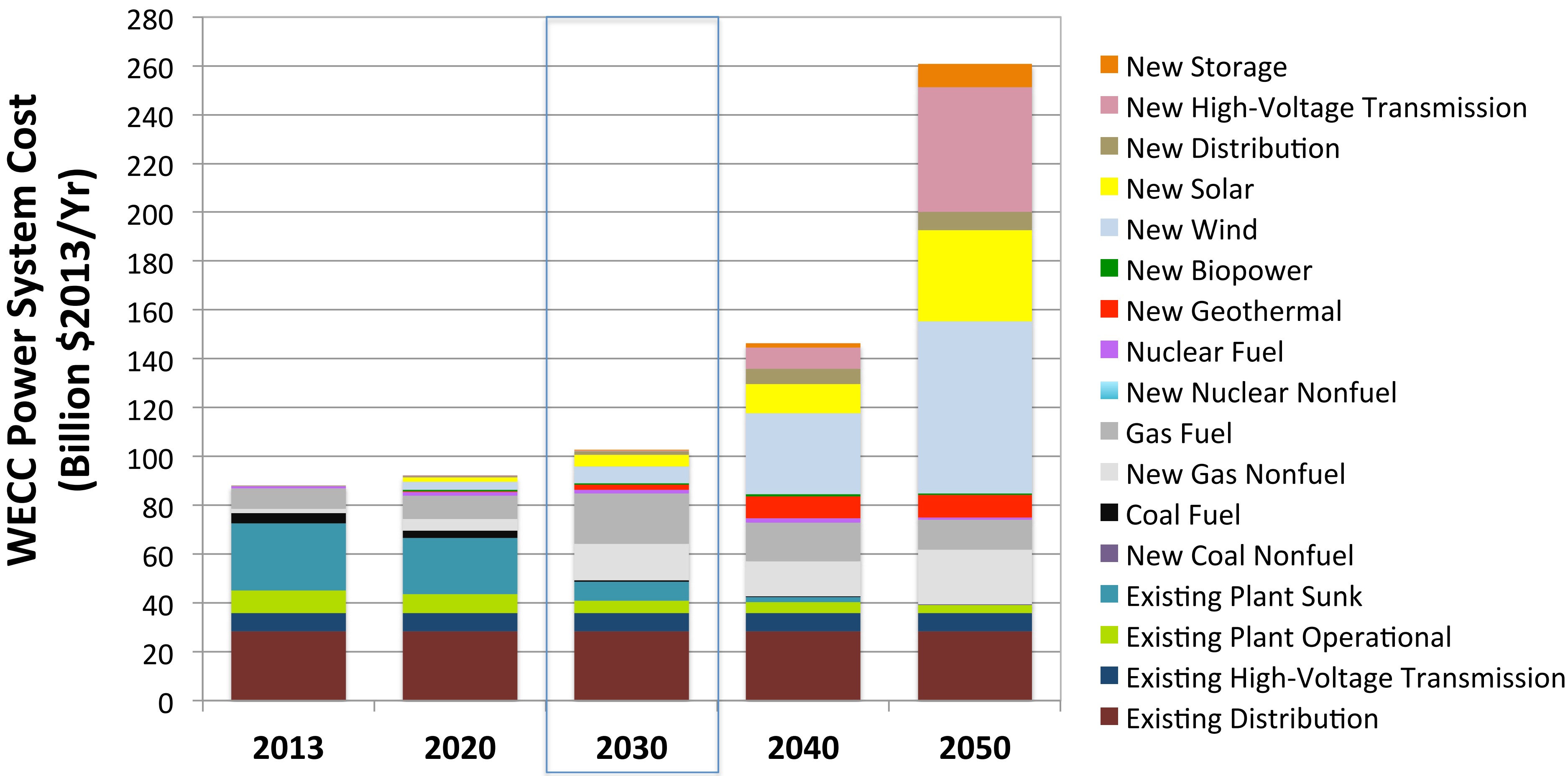


Observations: transmission, storage and CCS

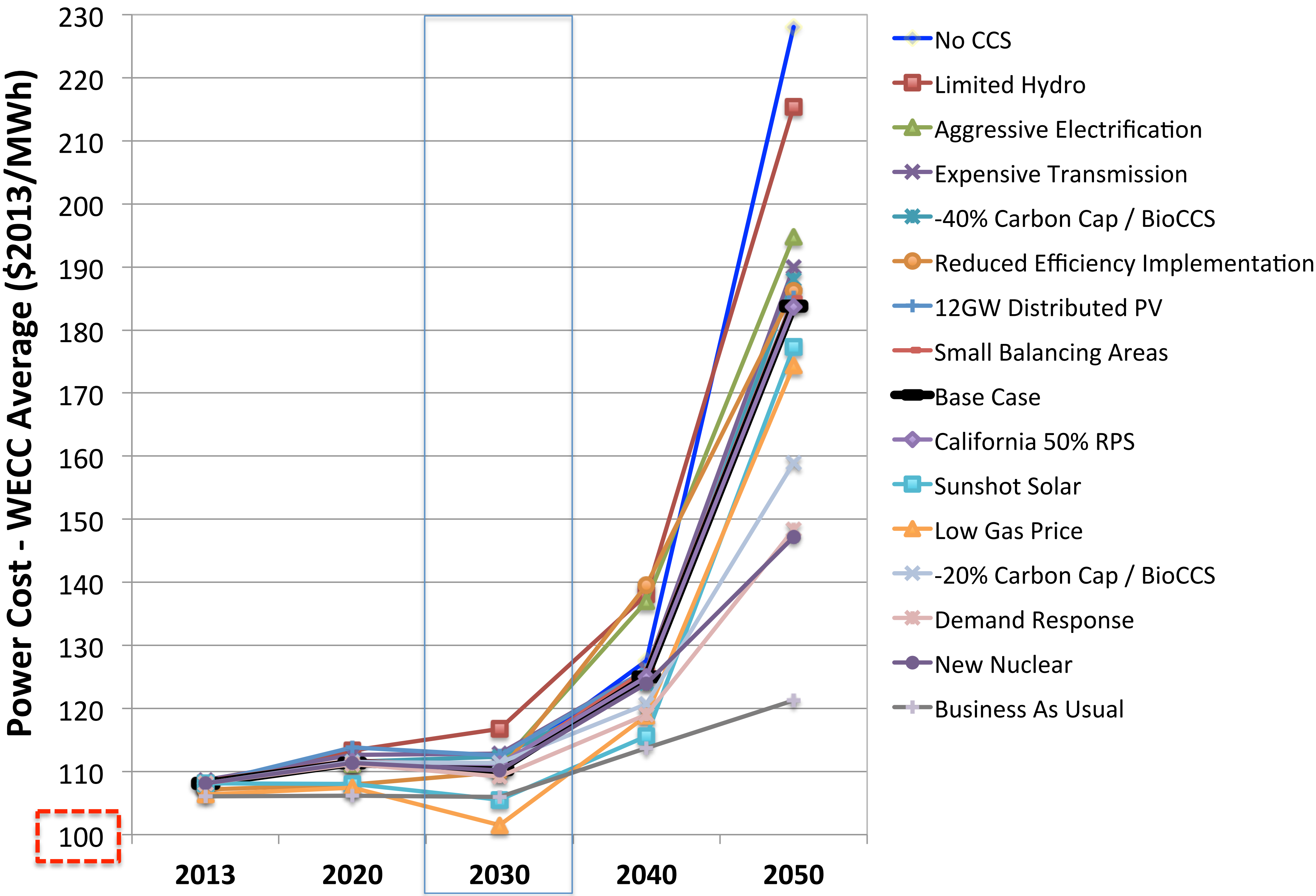
- Most new transmission and storage built after 2030 to enable integration of increasing fractions of intermittent renewables
  - Dependent on a multitude of efficiency measures
- Much new transmission needed after 2030 to meet increasingly stringent carbon caps.
- Natural gas phased out between 2030 and 2050 to meet the carbon cap
  - If carbon capture and sequestration (CCS) is available, gas CCS is built by 2050
- In scenarios with an aggressive carbon cap that reduces emissions below zero, biomass CCS already installed by 2030

Base scenario power cost – present day and 2030 similar

- Key drivers of 2030 power cost:
  - Energy efficiency gains
  - Availability of inexpensive gas
  - Declining costs of solar power



Power cost in 2030 isn't the big story.. look at 2050!



Supplementary slides about the SWITCH model

(won’t be presented at the workshop… read if you’re interested)

SWITCH-WECC Capabilities

Category	Currently, SWITCH can:	Currently, SWITCH cannot:	Planned capability:
Model uses	Create long-term investment plans that meet load, reliability requirements, operational constraints, and policy goals using projected technology costs. A simplified hourly dispatch algorithm within the investment framework captures aspects of wind and solar variability and mitigation measures for such variability	Perform detailed unit commitment and economic dispatch to simulate day-to-day grid operations	Check feasibility and performance of investment plans with an industry standard security-constrained unit commitment and economic dispatch model such as PLEXOS
Geographic extent and resolution	Model the Western Electricity Coordinating Council (WECC): California, Oregon, Washington, Idaho, Montana, Utah, Wyoming, Nevada, Colorado, Arizona, New Mexico, Baja Mexico Norte, British Columbia, Alberta		Expand to the electric power system of the entire continental United States and Canada
	Model 50 load areas or “zones” in the WECC within which demand must be met and between which power is sent	Perform bus or substation level analysis	
Technology options	Operate the existing generation within operational lifetimes		
	Retire existing generation infrastructure		
	Install and operate conventional and renewable generation capacity using projected fuel and technology costs. Natural gas fuel costs can be modeled with price elasticity	Determine economy-wide fuel prices	
	Install and operate storage technologies with multiple hours of storage duration for power management services		Install and operate storage technologies with shorter storage duration
	Use supply curve for biomass to deploy bioelectricity plants	Determine the optimal ratio of biomass allocation between electricity and other end uses	Determine the optimal ratio of biomass allocation between electricity and transportation
Transmission network	Install new transmission lines and operate them as a transportation network subject to transmission path limits	Enforce AC power flow, stability, and N-1 contingency constraints for the transmission network in the investment optimization	Enforce DC power flow, stability, and N-1 contingency constraints in PLEXOS
	Operate existing transmission lines subject to transmission path limits		Enforce DC power flow for the existing transmission network and limit power flow of existing network via phase angle in the investment optimization
Demand	Detailed hourly demand forecasts for 50 load area throughout WECC through 2050, including energy efficiency, electric vehicles, and heating electrification	Evaluate optimal energy efficiency installation or electrification decisions	

SWITCH-WECC Capabilities

Category	Currently, SWITCH can:	Currently, SWITCH cannot:	Planned capability:
Reliability	Ensure load is met on an hourly basis in all load areas	Account for sub-optimal unit-commitment due to forecast error; include treatment of electricity market structures	
	Maintain spinning and non-spinning reserves in each balancing area in each hour to address contingencies	Explicitly balance load and generation on the sub-hourly timescale; model system inertia or Automatic Generation Control (AGC)	Maintain regulation reserves
	Maintain a capacity reserve margin in each load area in each hour		
Operations	Cycle baseload coal and biomass generation on a daily basis and enforce heat-rate penalties for operation below full load		Enforce ramping constraints
	Enforce startup costs and part-load heat-rate penalties for intermediate generation such as combined cycle gas turbines (CCGTs)	Perform detailed unit-commitment in the investment optimization	Perform unit-commitment in PLEXOS
	Enforce startup costs for peaker combustion turbines		
	Shift loads within a day using projections of demand response potential		
	Operate hydroelectric generators within water flow limits	Model detailed dam-level water flow or environmental constraints	
Policy	Enforce Renewable Portfolio Standards (RPS) at the load-serving entity level using bundled Renewable Energy Certificates (RECs)	Model unbundled RECs	Enforce NOx and SOx caps
	Enforce a WECC-wide carbon cap or carbon price that escalates over time	Provide global equilibrium carbon price or warming target; assess leakage or reshuffling from carbon policies	
	Enforce the California Solar Initiative (CSI) and other distributed generation targets	Assess incentives for distributed generation	
Environmental Impacts	No capabilities currently	Enforce localized criteria air pollutant, water use, land use, and wildlife constraints	Tabulate regional criteria air pollutant, water use, and land use values for each scenario
Uncertainty	Perform deterministic, scenario-based planning	Perform stochastic planning	Develop robust optimization plans using multiple scenarios

Cost and fuel price inputs

Temporal / Spatial	Decadal (Investment Period)	Daily (Peak and median day of each month in Investment; 365 days in Dispatch Optimization)	Hourly (or 4-hourly in Investment Optimization)
Entire WECC System	• Base generator, storage, transmission, and distribution capital and fixed O&M costs • Natural gas wellhead price supply curve • Nuclear fuel price • Carbon price (if enabled)		
Balancing Areas	• Non-bio fuel prices • Natural gas price regional adjustment • Sunk transmission and distribution costs		
Load Areas	• Generator, storage, transmission, and distribution capital and fixed O&M cost local adjustment • Grid connection of non-sited generation (new bio, gas, nuclear, coal, storage) • New non-sited baseload fuel and variable O&M • Bio solid fuel price supply curve	• New flexible baseload fuel and variable O&M (coal, soon bio)	• New dispatchable generation fuel and variable O&M • New combined cycle startup costs • Storage variable O&M • Demand response load shifting • Transmission dispatch
Existing Plants or New Geo, Wind, and Solar	• Sunk existing generator and storage costs • Grid connection of sited generation (existing plants, wind, solar, geothermal) • Existing baseload fuel and variable O&M	• Existing flexible baseload fuel and variable O&M (coal, soon bio)	• Existing dispatchable generation fuel and variable O&M • Existing combined cycle startup costs

Independent variables

Temporal / Spatial	Decadal (Investment Period)	Daily (Peak and median day of each month in Investment; 365 days in Dispatch Optimization)	Hourly (or 4-hourly in Investment Optimization)
Entire WECC System	• Natural gas consumption (derived)		
Balancing Areas			
RPS Areas (Roughly Load Serving Entities)			• Transmit REC • Surrender REC
Load Areas	• Capacity installed of non-sited new generation and storage (gas, coal, bio, nuclear, storage) • New baseload output • Transmission capacity • Consumption level of solid biomass (derived)	• New flexible baseload power output (coal, soon bio)	• New dispatchable generation power output and operating reserve commitment • New combined cycle unit commitment • Storage charge and discharge • Demand response load shifting • Transmission dispatch
Existing Plants or New Geo, Wind, and Solar	• Retire or operate existing plant • Exiting baseload power output • New renewable capacity installed	• Existing flexible baseload power output (coal, soon bio)	• Existing dispatchable generation power output and operating reserve commitment • Existing combined cycle unit commitment

Constraints (all will have long-run marginal costs)

Temporal / Spatial	**Decadal** (Investment Period)	**Daily** (Peak and median day of each month in Investment; 365 days in Dispatch Optimization)	**Hourly** (or 4-hourly in Investment Optimization)
Entire WECC System	• Carbon emissions compliance • Natural gas price-consumption limits		
Balancing Areas	• California distributed PV and CSI compliance • Regional generator exclusions		• Operating reserve compliance
RPS Areas (Roughly Load Serving Entities)	• RPS compliance		
Load Areas	• Installed capacity limit of non-sited new generation (bio, CAES) • Solid biomass price-consumption limits • Baja Mexico export limit	• Storage, demand response, and hydro energy balance	• Meet demand • Meet capacity reserve margin • Generator, storage, and transmission capacity limits • Demand response limits
Existing Plants or New Geo, Wind, and Solar	• Installed capacity limit of sited generation (existing plants, wind, solar, geothermal)		• Existing plant capacity limits