Building a Healthier and More Robust Future: 2050 Low Carbon Energy Scenarios for California

Modeling Climate Change for the 2050 Grid and Supporting High Renewables in 2030

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Max Wei
Lawrence Berkeley National Laboratory

Team members

Max Wei, Dev Millstein, Eleonara Ruffini

Lawrence Berkeley National Laboratory

Shuba Raghavan, Patricia Hidalgo-Gonzalez, Rodrigo Henriquez-Auba, Dan Kammen, Josiah Johnston

Renewable and Appropriate Energy Lab (RAEL), Energy and Resource Group,

University of California, Berkeley

Madison Hoffacker; Rebecca Hernandez

UC-Davis

Other contributors: Anand Gopal, Kaiyu Sun, Tianzhen Hong **(LBNL)**

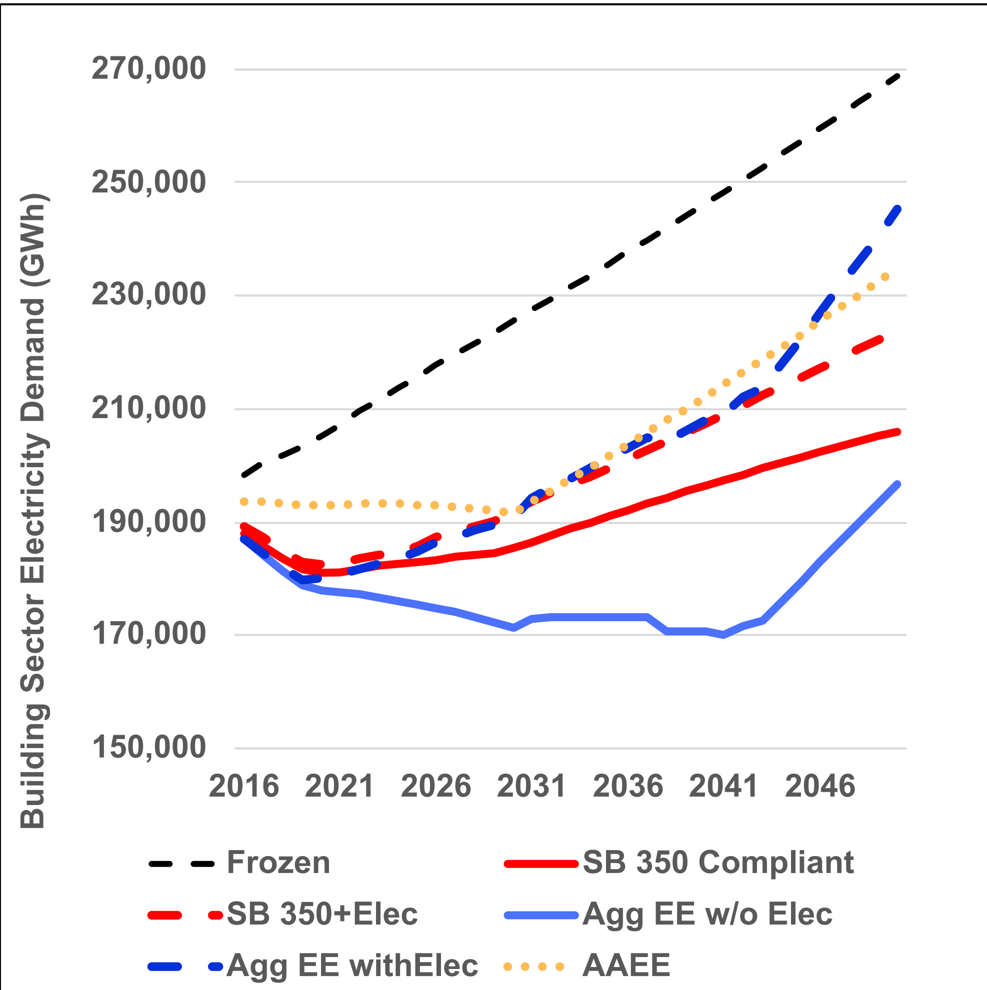
Brian Tarroja, Amir Agofoucha **(UC-Irvine)**

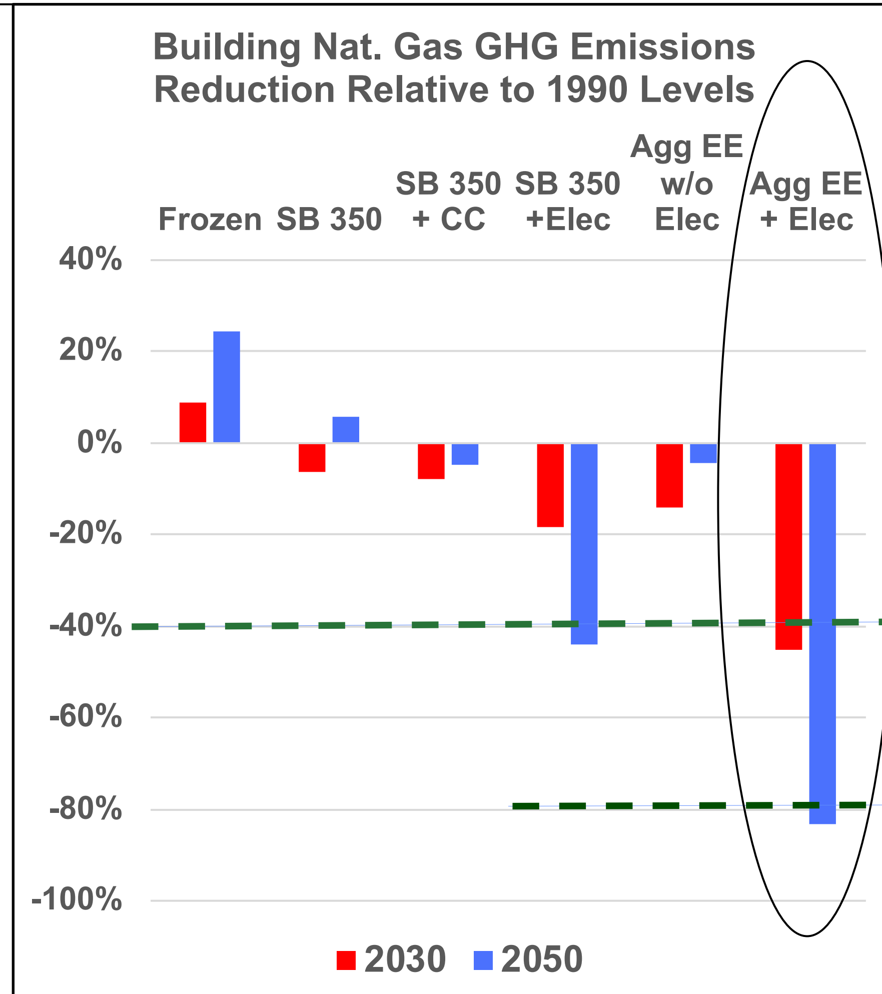
Julia Szinai, Florin Langer-James **(UC-Berkeley)**

Building decarbonization

In the building sector, how can the state meet 2030 and 2050 targets for GHG reductions?

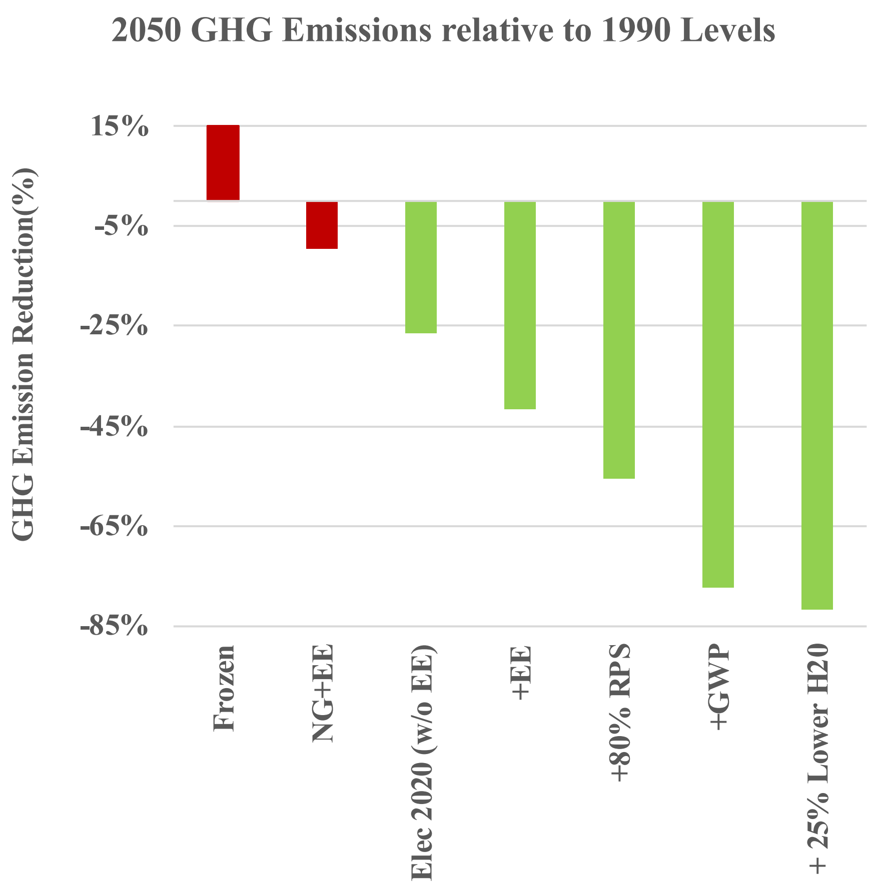
Aggressive energy efficiency and electrification is needed for the Buildings sector to meet SB 32 and EO-3-05





*GHG reduction goals: 40% reduction in emissions by 2030 (SB 32) and an 80 % reduction in emissions by 2050 (Executive Order S-3-05).

Building Sector Example – Electrification of water heaters needs gradual phase-in by 2020 to avoid stranded assets



Key Findings:

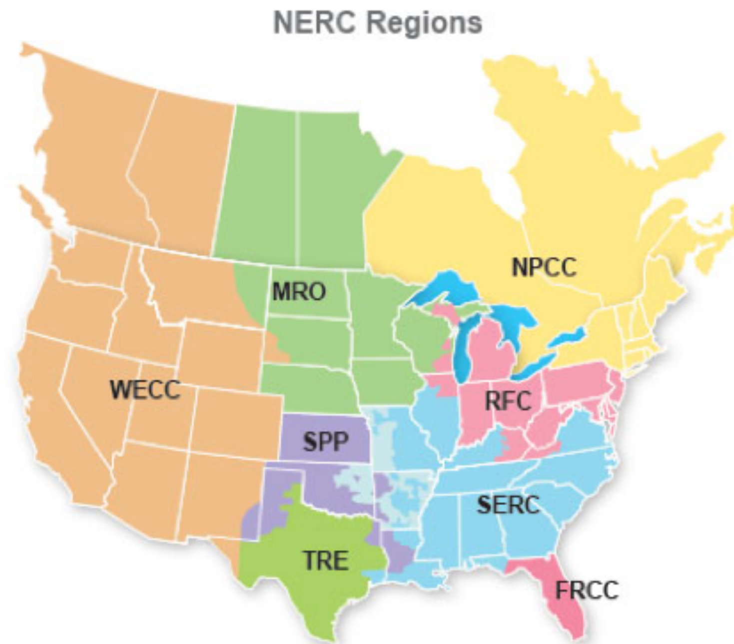
- 80% reduction of 2050 GHG emissions from 1990 level is feasible
- The shift from natural gas to electrification has to begin no later than 2020 coupled with the adoption of high efficiency electric heat pump technologies
- 25% reduction in hot water usage will help the sector to meet the SB 32 emissions target.

Policy Implication:

- Gradual phase in will avoid stranded assets resulting in lower societal costs.
- Equipment rebates and incentives to help large scale adoption of high efficiency electric heat pumps necessary to trigger market transition.

Ref: S. Raghavan, M. Wei, D. Kammen, Scenarios to decarbonize residential heating in California, Energy Policy 109 (2017) 441-451

SWITCH WECC Grid Capacity Expansion Model



- Capacity expansion deterministic linear program
- Minimizes total cost of the power system:
  - Generation investment and operation
  - Transmission investment and operation
- Geographic:
  - — Western Electricity Coordinating Council
  - — 50 load areas
- Temporal:
  - — 4 investment periods: 2016-2025 (“2020”); 2026-2035 (“2030”); 2036-2045 (“2040”); 2046-2055 (“2050”);
  - — 144 distinct hours simulated per period
    - Dispatch simulated simultaneously with investment decisions

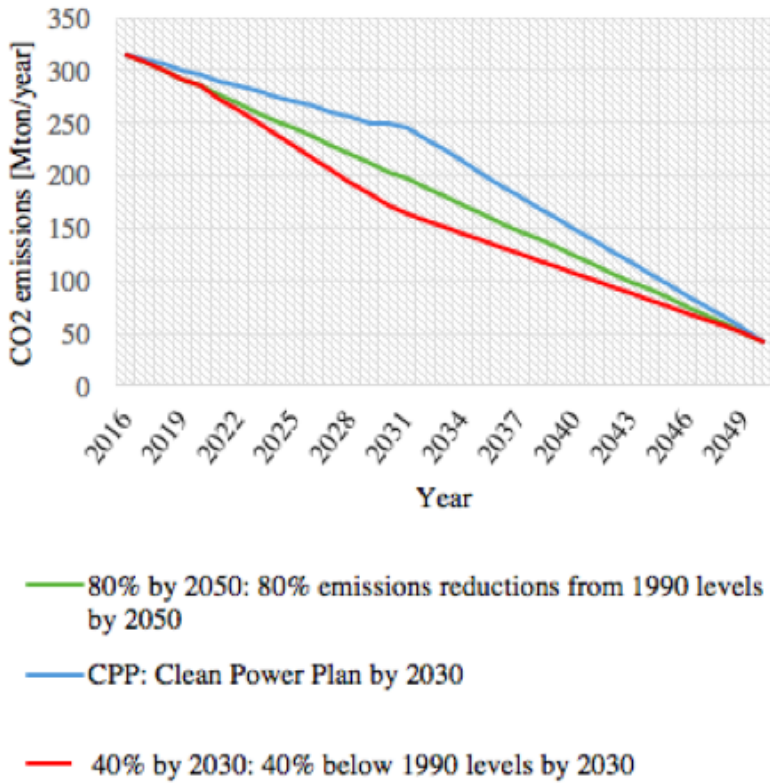
Power Sector – path dependency

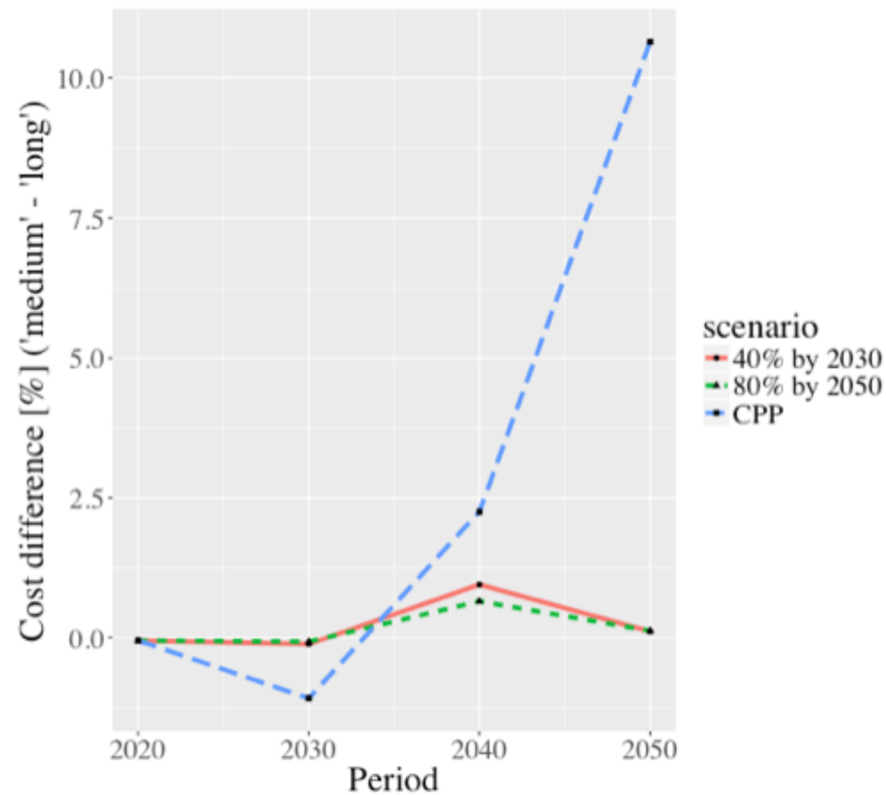
In the power sector, what is the impact of “path dependence”? i.e. planning power system buildout for 2030 targets vs longer term planning for 2050 goals across the WECC?

Path dependency for Grid Buildout in WECC

Hidalgo-Gonzalez, P., et al, "2030/2050 Power system planning path dependency in western North America" (Submitted)

Key Finding: it is more effective and cost-efficient to optimize the power system with long term GHG goal foresight (an 80% reduction by 2050) rather than first optimizing for a medium-term target (2030) without foresight of a 2050 stronger target.





Policy impact: Important to have stringent medium term targets for cost-efficient grid decarbonization

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Renewable & Appropriate Energy Laboratory RAEL

Impact of climate change on power system

How does climate change impact the build out of the electricity system across the WECC in the 2050 timeframe?

Long-term Power System Planning – WECC Deterministic Scenarios

Description of Scenarios

- 5 electricity demand scenarios varying assumptions on:
    - Efficiency
    - Electrification
    - Electrical vehicles and demand response
- 3 climate change scenarios changing assumptions on:
    - Monthly hydropower availability
    - Hourly loads

Climate Change impact on 2050 Grid Buildout (WECC Deterministic Scenarios)

Results

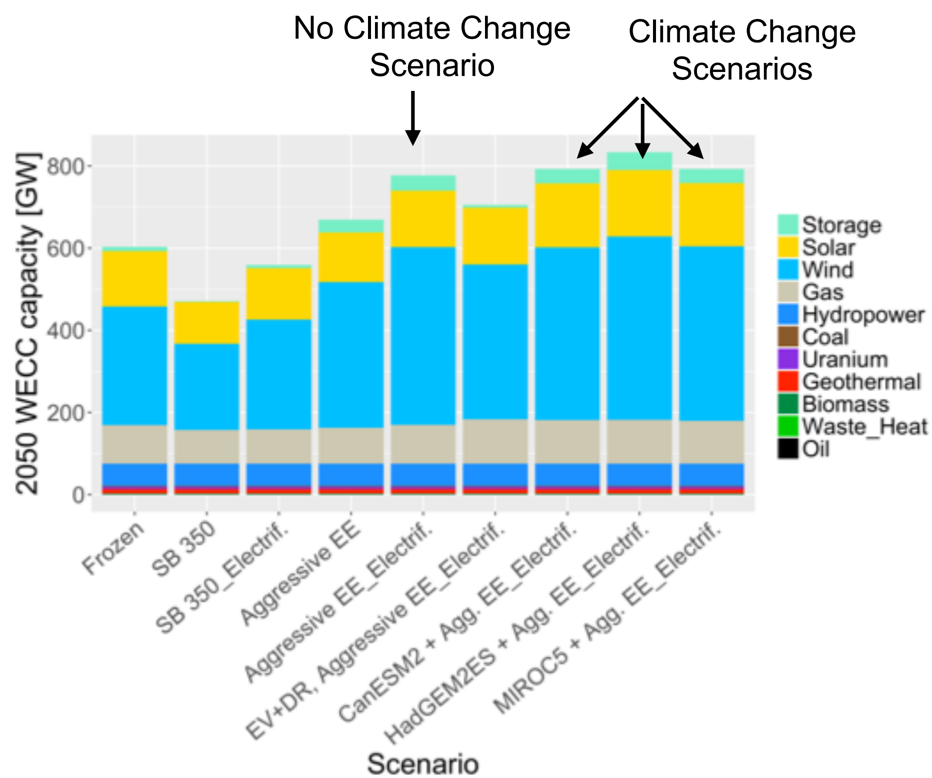
Key finding: A warmer climate is projected and climate impacts to heating and cooling demand are felt today; but within the assumptions of the study, electricity grid impacts are muted (~5% more capacity in 2050)

Other Key findings:

- Wind (~51%) and solar (~20%) dominate the mix.
- In the aggressive efficiency and electrification scenarios, there is an increase in CAES (up to 5%) compared to the other cases.
- Transmission expansion needs to be planned in coordination with the rest of the WECC to minimize costs for California, especially under climate change.
- Savings can be observed in the EV+DR scenario (1% cheaper than frozen and 5% cheaper than aggressive EE and electrification).

Policy implications:

- Encourage not only solar power deployment, but also wind power and CAES due to its role to minimize costs.
- It is relevant to take climate change into account in power systems studies for future regulation.



Power Sector – Stochastic Optimization under Climate Change in the WECC

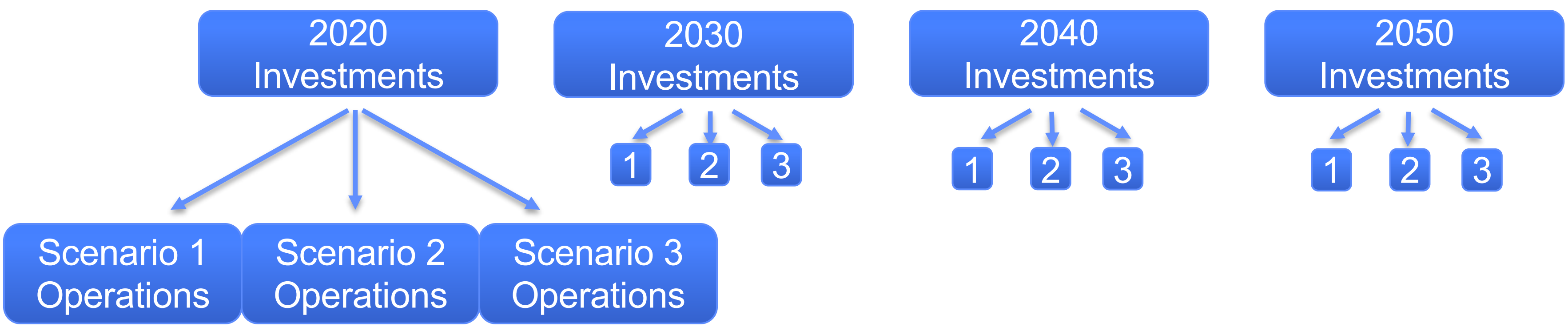
In the power sector, what is the impact of non-deterministic inputs in climate change scenario and hydrological inputs?

Stochastic Optimization under Climate Change in the WECC

Hidalgo-Gonzalez, P., et al, “Stochastic power system planning under climate change in western North America” (In preparation)

Modeled and implemented Stochastic SWITCH WECC (Python, Pyomo)

- **Three scenarios (CanESM2ES, HadGEM2ES and MIROC5) with equal probabilities are modeled**
- **Mathematical formulation: Two stages optimization**
- **Investment decisions are equal for the three scenarios (robustness)**
- **Operation decisions are specific to the scenario**
- **Objective function: expected value of the cost of the three scenarios**



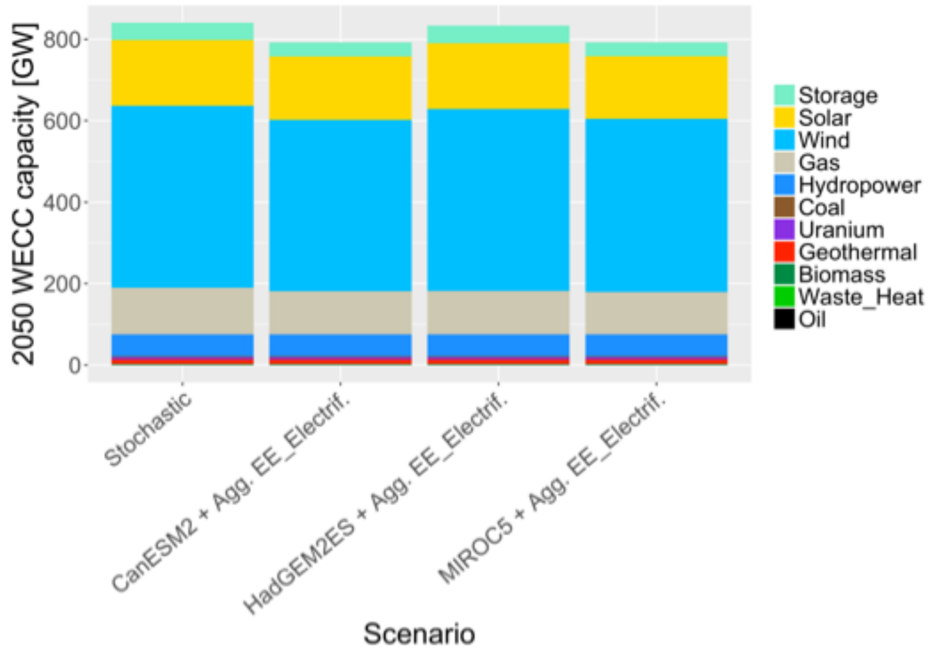
Stochastic Optimization under Climate Change in the WECC

Hidalgo-Gonzalez, P., et al, “Stochastic power system planning under climate change in western North America” (In preparation)

Results: Installed capacity by 2050

Key findings:

- Capacity installed in the WECC by 2050 in the “Stochastic” or resilient simulation is higher (840 GW) than in the rest of the scenarios (790 GW - 830 GW).
- The “Stochastic” simulation installs more flexibility (gas and CAES) than the deterministic cases.
- Transmission installed to/from CA in the “Stochastic” case was 145 GW, while the deterministic cases ranged between 137 and 144 GW. Thus, CA requires more transmission for the resilient case in order to minimize costs under climate change.



Policy implications:

- Future regulation requires stochastic/resilient climate change studies to avoid underestimating total capacity and flexibility needs in the system (that are underestimated by deterministic studies).

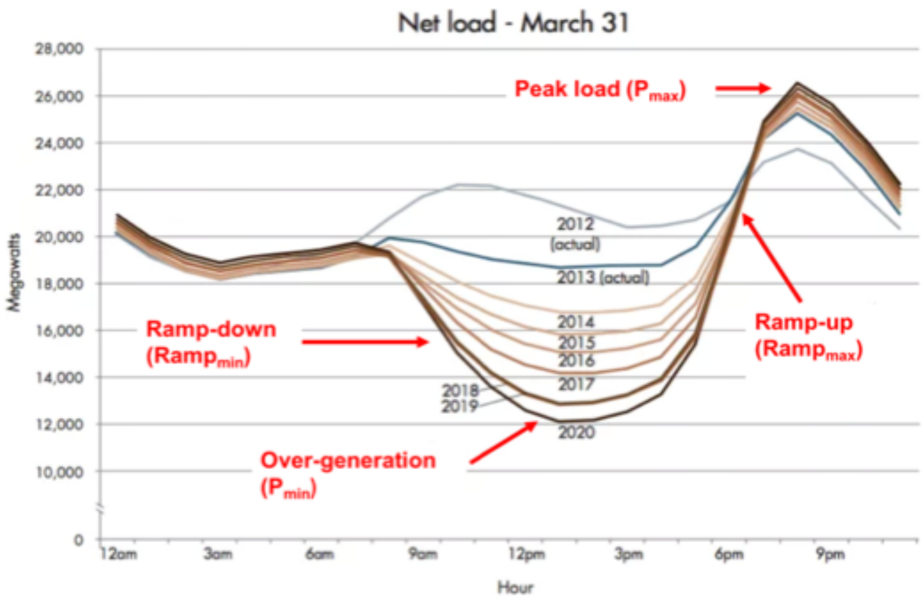
Supporting high renewables in 2030

What are technologies/ approaches to support very high renewables and California net load curve (“duck curve”) in 2030?

1. Coordinated PEV storage
2. End use electrification
3. Renewable H2 scale up
4. (Other demand shifting - not covered here)

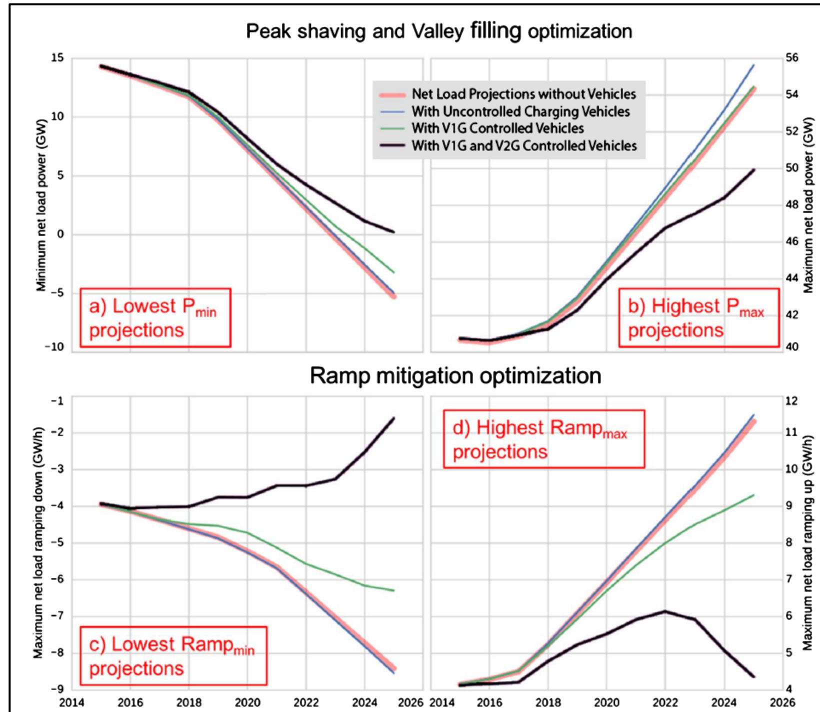
1. Support for High Renewables and "Duck Curve":

Coordinated EV charging with V1G-only capability provides renewables integration capability equivalent to 1.0GW of stationary storage



Four important problems indicated by "Duck Curve":

- Over-generation
- High evening peak load
- Sharp mid-morning down-ramps
- Substantial evening up-ramps



2025 Vehicle assumptions: 0.5M BEVs and 1M PHEVs

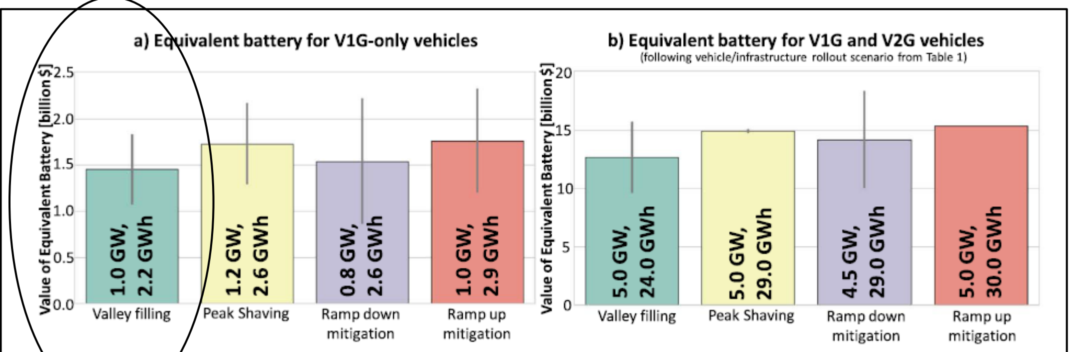


Figure 4. Capital cost value of equivalent grid-scale stationary storage that provides the same duck curve mitigation capability as EVs.

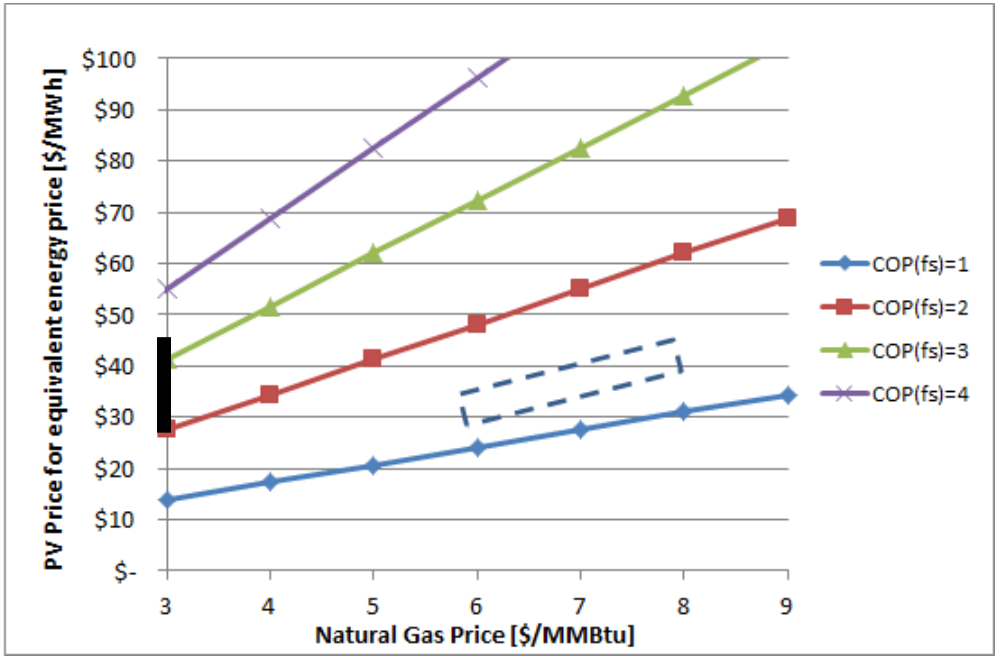
J Coignard, S Saxena, J Greenblatt and D Wang, Clean vehicles as an enabler for a clean electricity grid, accepted for publication to Environ. Res. Lett.

2. Support for high renewables: electrified end uses e.g., industry electrification w/ electric boilers – Getting closer to "Heat parity"

Key finding: Electric boilers can utilize otherwise curtailed renewable power and energy cost is comparable to natural gas at the lowest current PPA prices.

- This can support California "duck curve" over generation; and reduce GHG

***PV price for equiv. energy price to gas:* $30-45/kWh** *within range of lowest solar PPA prices ($30-40/MWh)*



CO2 price at $20/tonne:

Policy impact: RD&D incentives and demonstrations for electric boilers and/or hybrid electric/gas boilers and control systems can encourage greater adoption

2. Potential industry electrification of boiler systems in Food/Beverages and Chemical sectors highlighted

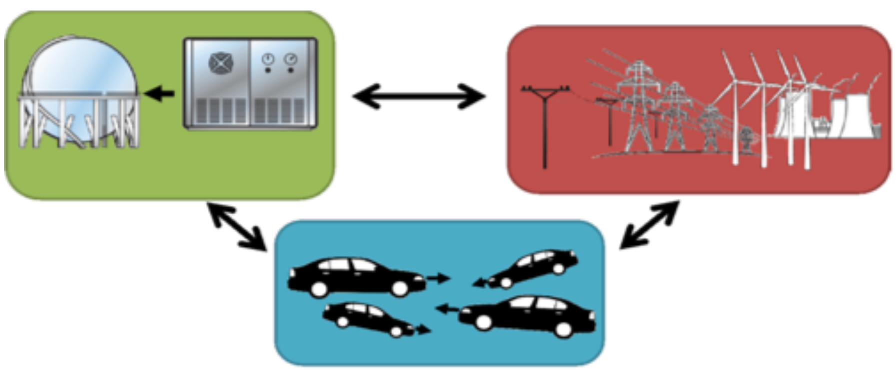
Industrial Sector	Boiler System	CHP	Process Heating	Temp L/M/H	Disposition for electrification
	Percentage On-site Nat. Gas Fuel Consumption				
Petroleum and coal products manufacturing	18%	14%	61%	HIGH	Hard b/c high degree of process design and own-use fuel consumption
Food and beverages	**44%**	11%	27%	MED/HIGH	**Good candidate (boiler systems)**
Non-metallic mineral proc	4%	5%	79%	HIGH	Very high temperatures make this challenging but technically possible
Chemical manufacturing	**29%**	13%	44%	MED/ HIGH	**Boiler system candidate**
Fabricated metal products	7%	5%	58%	HIGH	Induction heating/melting candidate
Primary Metals	6%	6%	74%	HIGH	Induction melting candidate
Paper Mills	27%	36%	26%	HIGH	High degree of integrated process design
Transportation equipment	22%	2%	30%	MED/HIGH	Driers ok for electrification but Furnace challenging

3. Support for High Renewables and “Duck Curve”: H2 Resources for Renewable Integration in California

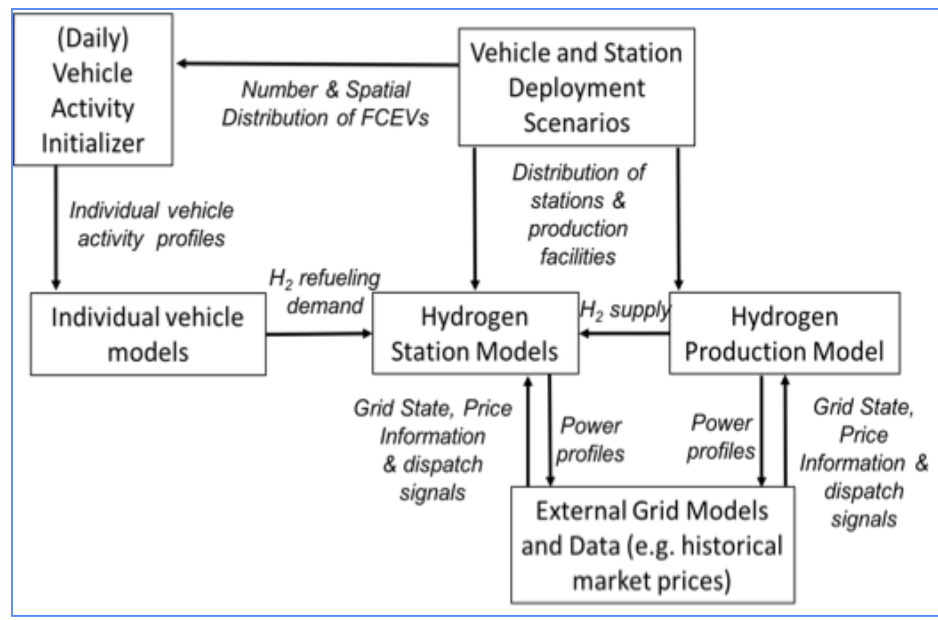
(Saxena, Wei, DOE TV-043)

Hydrogen technologies could creates **synergies** between the electricity and transportation sectors:

- **Electrolytic hydrogen production** can be a flexible load, provide grid services, and support the integration of renewables, including exploiting otherwise-curtailed electricity
- Hydrogen refueling stations can also act as flexible loads, and smart integration with the electric grid may provide cheaper electricity and enable new revenue streams

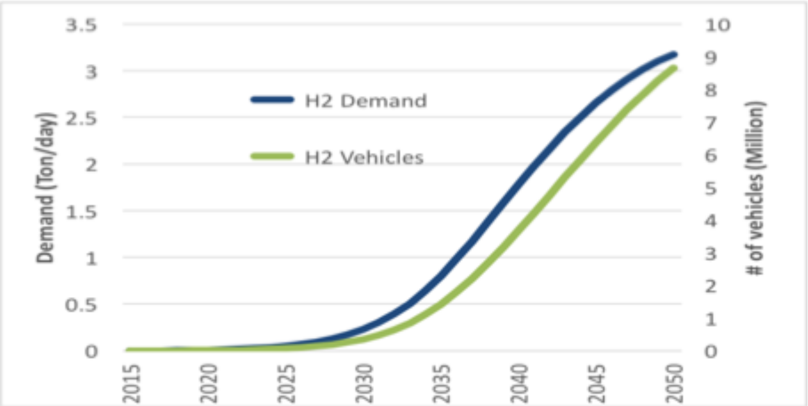


H2 VGI Model



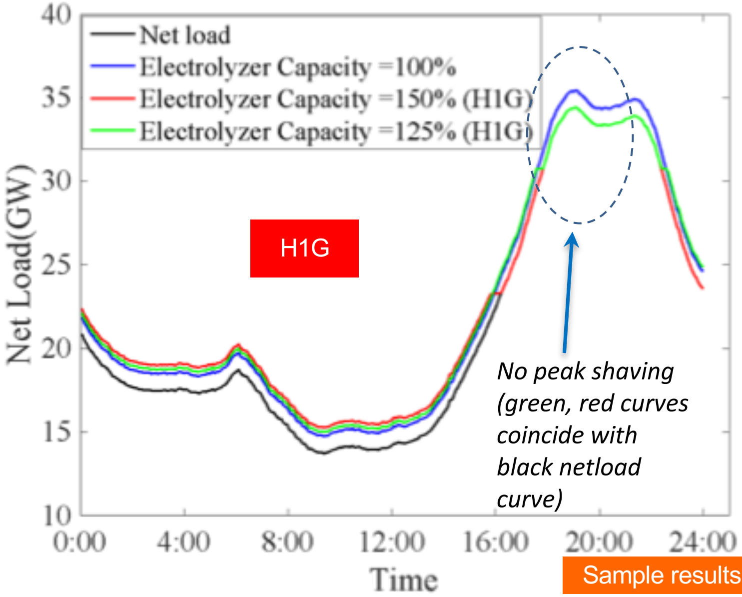
3. Optimal hydrogen production for grid support- Valley filling and peak shaving

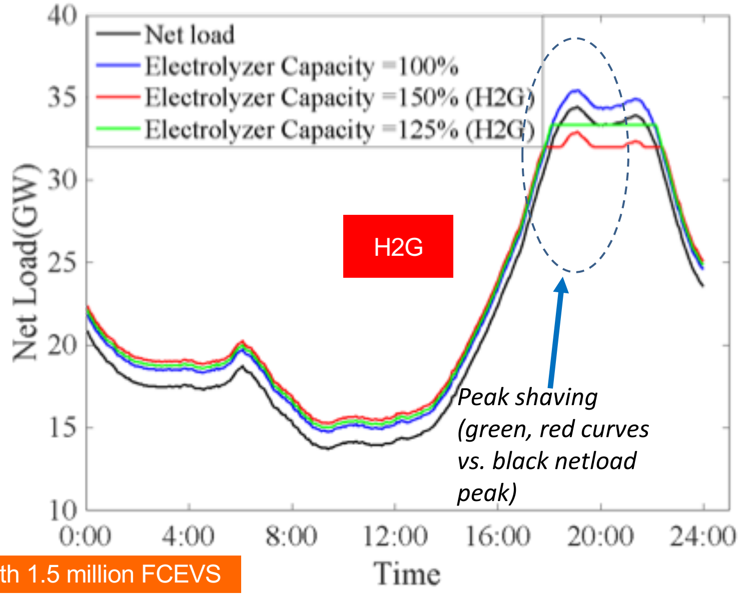
(Saxena, Wei)



We simulate a set of scenarios that look at different levels of hydrogen demand (Ton/day), size of the electrolyzer (MW), number of FCEVs on the road, and two hydrogen configurations.

H1G: Uni-directional energy flow to electrolyzer
H2G: Reversible electrolyzer which can feed power back to grid



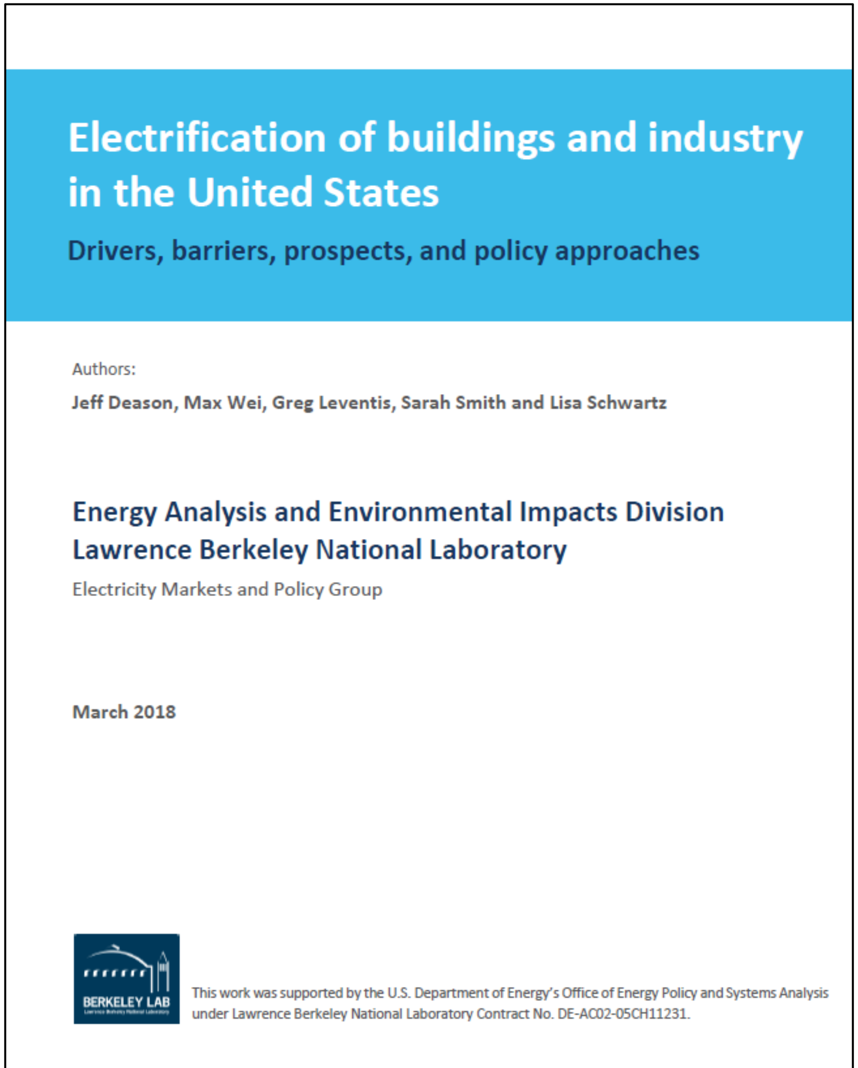


Sample results: 2025 netload with 1.5 million FCEVS

The technical potential for centralized electrolysis to provide grid peak shaving and valley filling support for California in 2025 has been modeled for the first time.

Paper submitted Journal of Power Sources February 2018

New LBNL Report: Electrification drivers, barriers, prospects, and policy approaches



Electrification of buildings and industry in the United States

Drivers, barriers, prospects, and policy approaches

Authors:

Jeff Deason, Max Wei, Greg Leventis, Sarah Smith and Lisa Schwartz

Energy Analysis and Environmental Impacts Division
Lawrence Berkeley National Laboratory
Electricity Markets and Policy Group

March 2018

BERKELEY LAB

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https://emp.lbl.gov/publications/electrification-buildings-and

For buildings: electrification is generally more cost-effective:

- in new buildings (as opposed to alterations of existing buildings);
- in residential buildings (as opposed to commercial);
- when a single electric heat pump can provide both heating and cooling;
- for all-electric buildings, where some gas infrastructure costs can be avoided; and
- in locations with mild winters.

In industry, electrification is most viable in processes:

- with relatively low energy costs;
- where the degree of process complexity and process integration is more limited and extensive process re-engineering would not be required;
- where combined heat and power is not used;
- where induction heating technologies are viable; and
- where process heating temperatures are lower.

Policies, regulatory changes, and programs to improve economics of electrification:

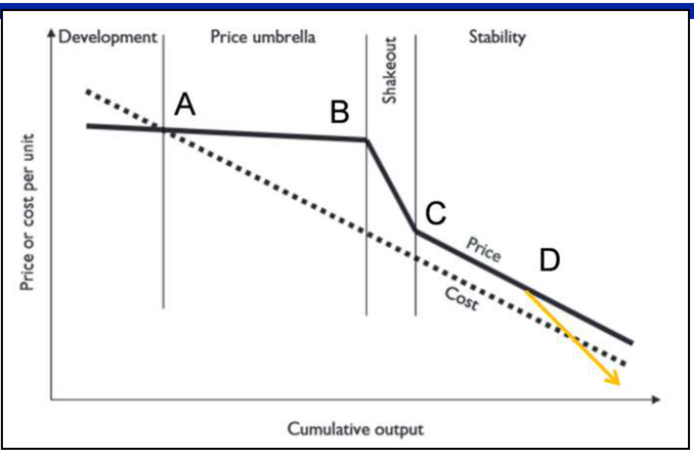
- Make it less expensive to use electricity off-peak, including time-varying rates,
- Zero net energy building codes,
- Demand response programs, and
- Payments for flexible loads

Deployment programs are critical

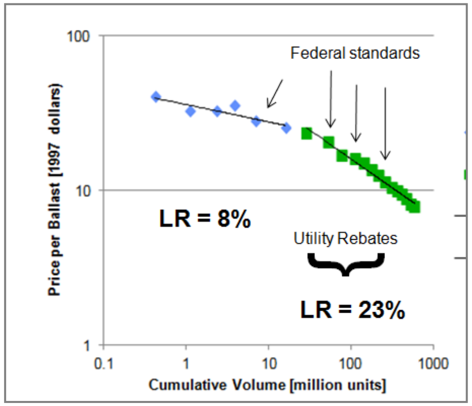
Key Finding: Deployment programs are correlated to downward bends in the experience curve (i.e., higher learning rates for several energy-related technologies)

Policy Impact: Expanding deployment programs such as multi-state ZEV alliance to other end use sectors such as multi-state ZEV trucking should be encouraged.

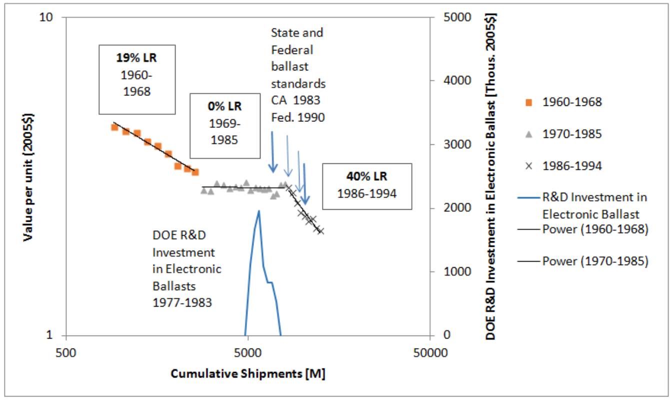
Deployment programs (e.g., EE standards, incentives, procurement) --
Experience curves are empirically observed to bend down to higher learning rates in several technologies in many cases and correlated to deployment programs



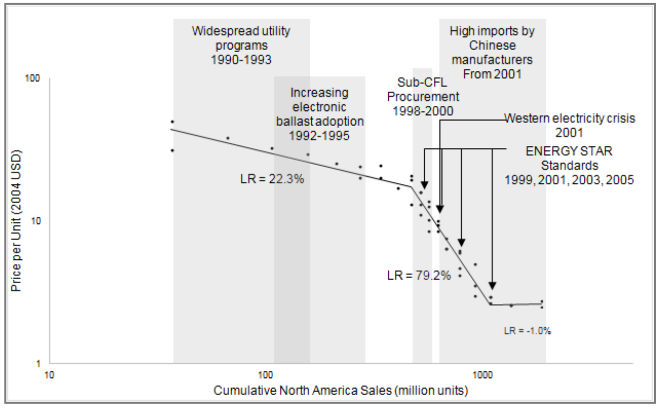
Canonical Bending down then up



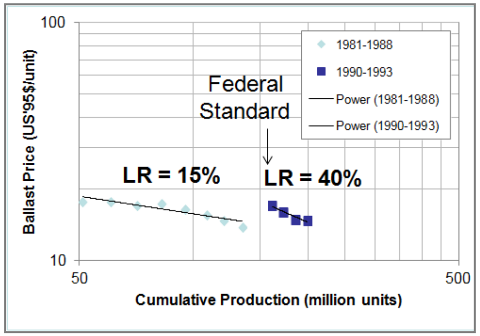
Electronic Ballasts



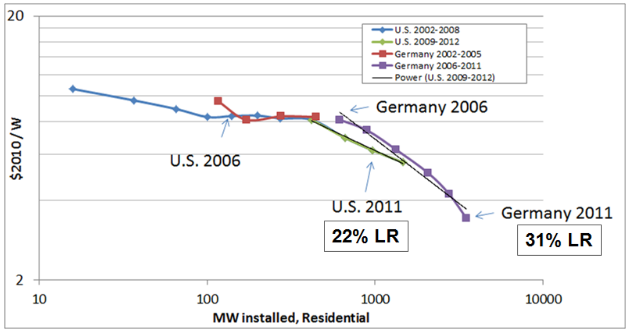
General Service Fluorescent Lighting



CFLs, North America



Magnetic Ballasts



Installed Cost of Solar PV

Multi-state deployment programs can be critical

Wei, et al. Non-Constant Learning Rates in Retrospective Experience Curve Analyses and their Correlation to Deployment Programs, Energy Policy, 2017; Buskirk et al ERL 2014

Acknowledgments

Funding and support of this work by the California Energy Commission is gratefully acknowledged (for SWITCH, Buildings, and Industry slides)

Thank you

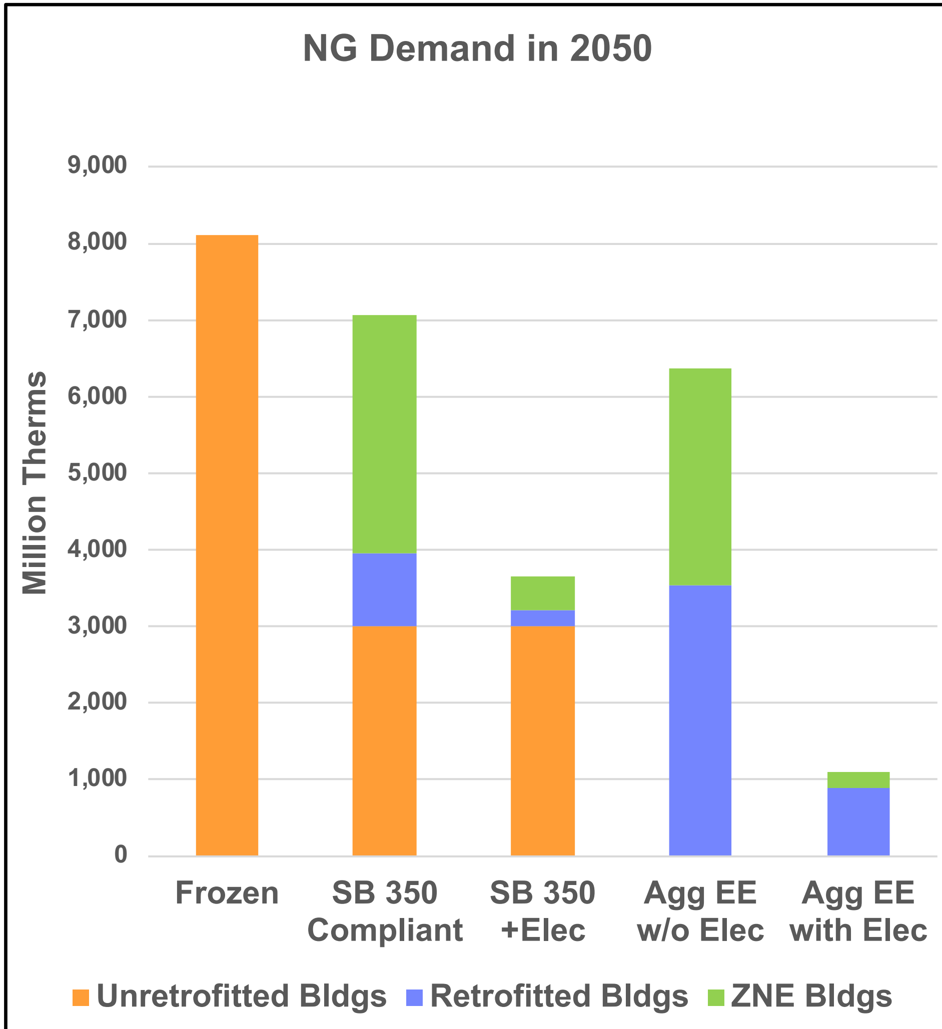
Max Wei

mwei@lbl.gov

510-486-5220

Backup slides

Annual retrofit rates have to be high along with high electrification rates for the sector to meet emission goals



Key Findings:
Aggressive retrofit rates along with switch to electricity for heating accompanied by the adoption of high efficiency electric appliances for this sector to meet 40% GHG Emissions reduction by 2030 relative to 1990 levels.

Policy Impact:

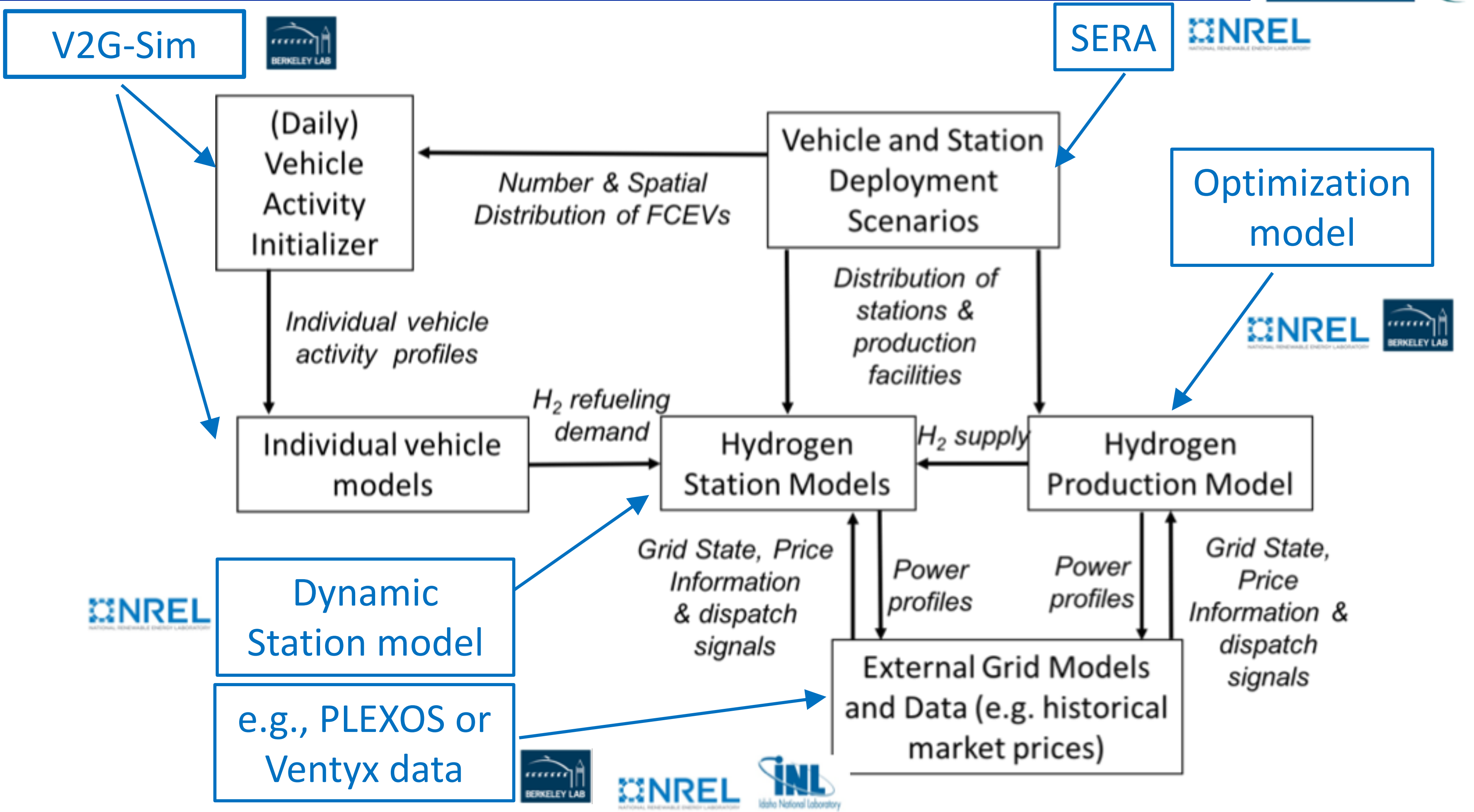
A. To increase retrofit update in the residential sector, several barriers must be overcome, for example:

(i) first cost and financing challenges,
(ii) the cost of home energy assessments,
(iii) lack of experienced whole-house performance sales personnel
(iv) Trained plumbers and electricians in retrofitting high efficiency appliances

B. Sustained policies necessary to help market dynamics and bulk procurement to bring the costs down through economics of scale.

Hydrogen Vehicle to Grid Integration Project (DOE)

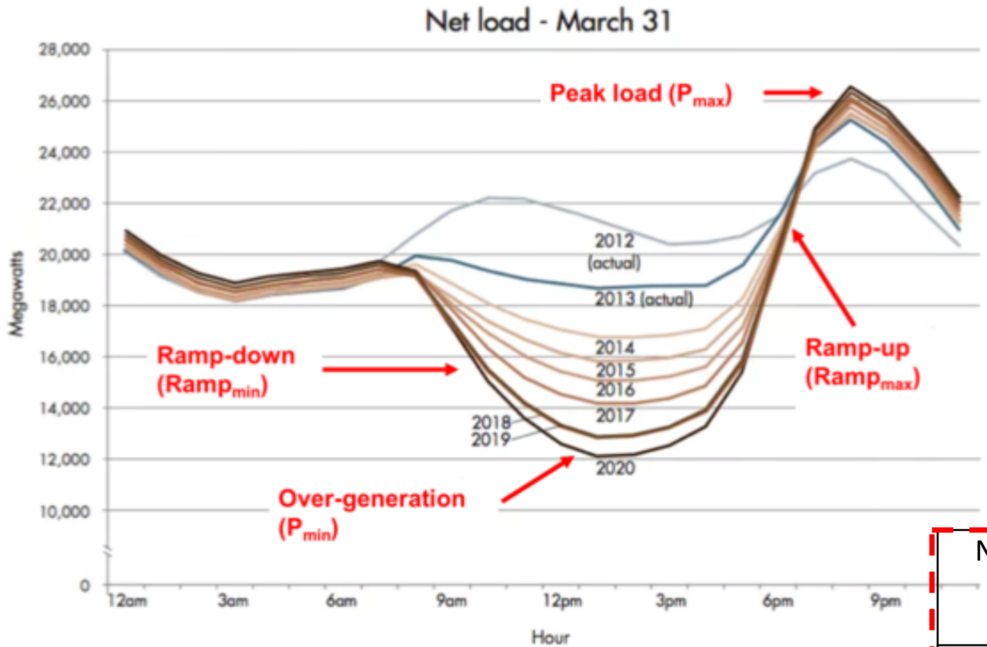
Technical Approach - H2VGI Model Structure
(Saxena, Wei, Greenblatt)



The H2VGI model integrates multiple operational and deployment models for FCEVs and H2 generation resources with external grid models across various time scales

3. Support for High Renewables and "Duck Curve": H2 Resources for Renewable Integration in California

(Saxena, Wei)



Calculated storage capacity: <8 hours

Four important problems indicated by "Duck Curve":

- Over-generation
- High evening peak load
- Sharp mid-morning down-ramps
- Substantial evening up-ramps

2025 Scenarios:

Number of FCEVs	Million Metric Tons H2/year	Number of Fueling Stations	Pct of Calif. refinery H2 production
200,000	0.04	350	4%
800,000	0.14	700	15%
1,500,000	0.27	1000	29%

Objective functions to tackle problem:

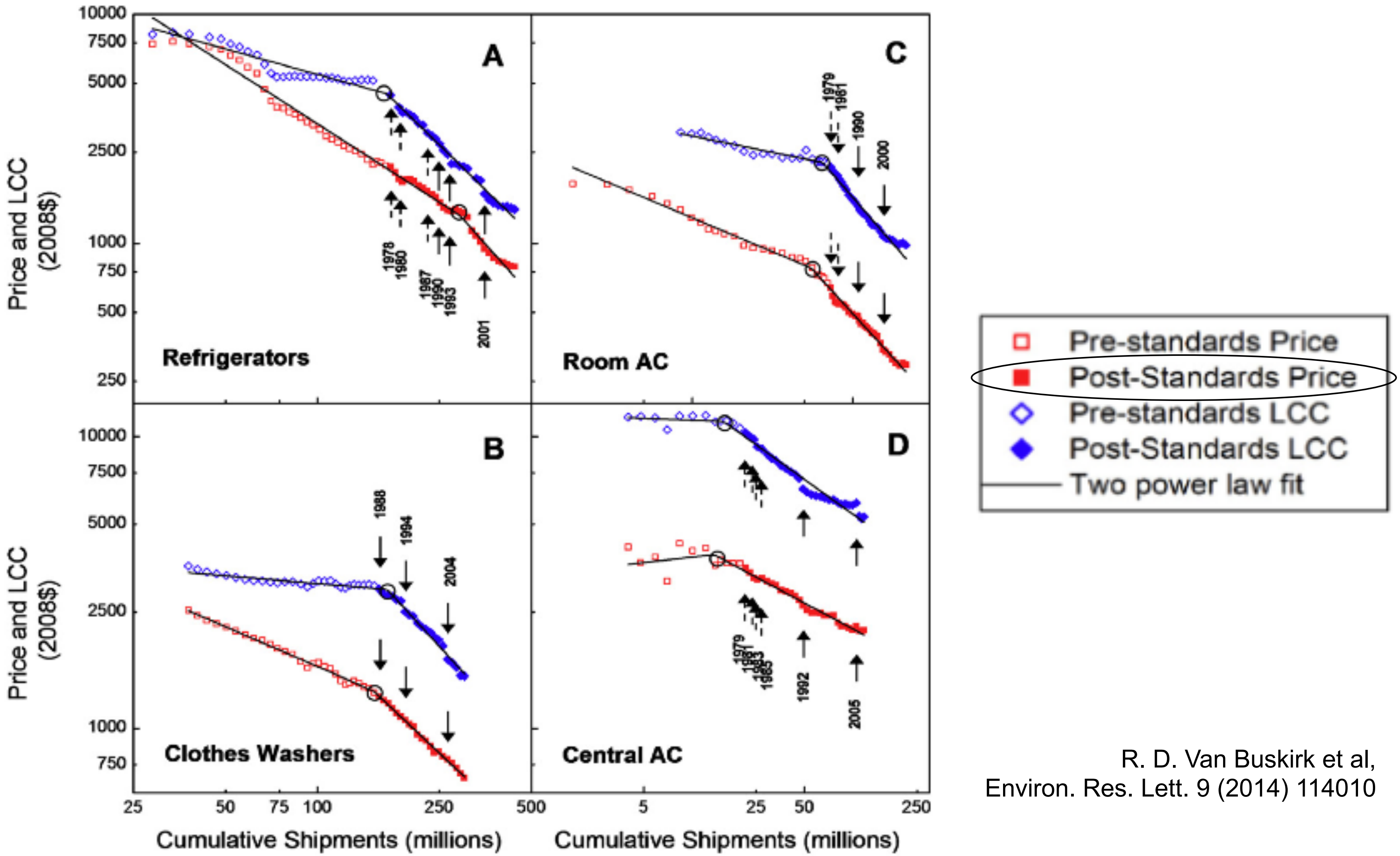
N(t): net load at time t;
P(t): electrolyzer power at time t.
(decision variable)

Peak-valley control: $\min \sum_{t=0}^{T} (N(t) + P(t))^2$

Ramp control: $\min \sum_{t=1}^{T} (N(t) + P(t) - N(t-1) - P(t-1))^2$

Subject to: Aggregate power and energy constraints

Additional data from LBNL Energy Efficiency Standards group: more downward bends in experience curve



R. D. Van Buskirk et al, Environ. Res. Lett. 9 (2014) 114010