Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicles, and Grid Resources

Department of Energy Annual Merit Review
for Fuel Cell Research

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Project ID #
TV043

Overview

Timeline

- Project Start Date: June 1, 2016
- Project End Date: May 30, 2019
- Percent complete: 30%

Budget

- **Total funding: 1.65 Million (DOE)**
- **Funding received in FY16: 500,000 (new start)**
- **Planned funding in FY17: 550,000**

Barriers Addressed

- The extent to which **hydrogen** can simultaneously provide **sustainable mobility solutions and support the electric grid** remains unclear.
- The role of **hydrogen production plants** in **favoring renewable energy integration** remain unclear.
- **The value proposition to enable FECVs to export power for emergency backup and/or grid support** remains unclear.

Partners

NREL NATIONAL RENEWABLE ENERGY LABORATORY

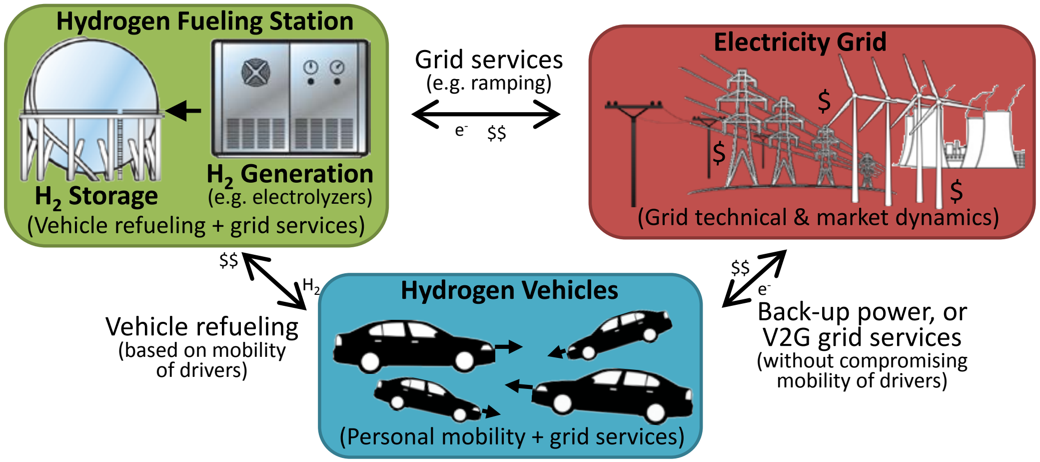
INL Idaho National Laboratory

Relevance & Objectives – H2 Vehicle to Grid Integration Model

- Hydrogen technologies offer the unique ability to simultaneously support the electricity and transportation sectors.
- Electrolytic hydrogen production can provide grid services, increase load flexibility, and favor the integration of renewables, including exploiting otherwise-curtailed renewable generation
- The ability for vehicle or station owners to more intelligently integrate with the electric grid may enable new revenue streams and support more rapid deployment

Project Objectives

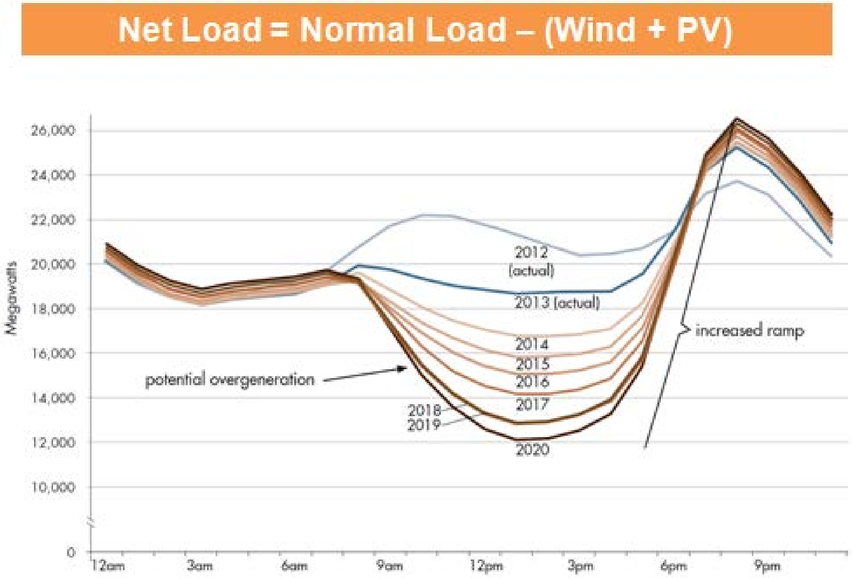
- **Provide an integrated modeling capability ("H2VGI Model")** to quantify the interactions between stationary hydrogen generation, fuel cell vehicles, and grid support resources.
- Quantify potential grid support and balancing resources from flexible hydrogen systems (e.g., dispatchable production of hydrogen by electrolysis).
- Develop methods to optimize the systems configuration and operating strategy for grid-integrated hydrogen systems.

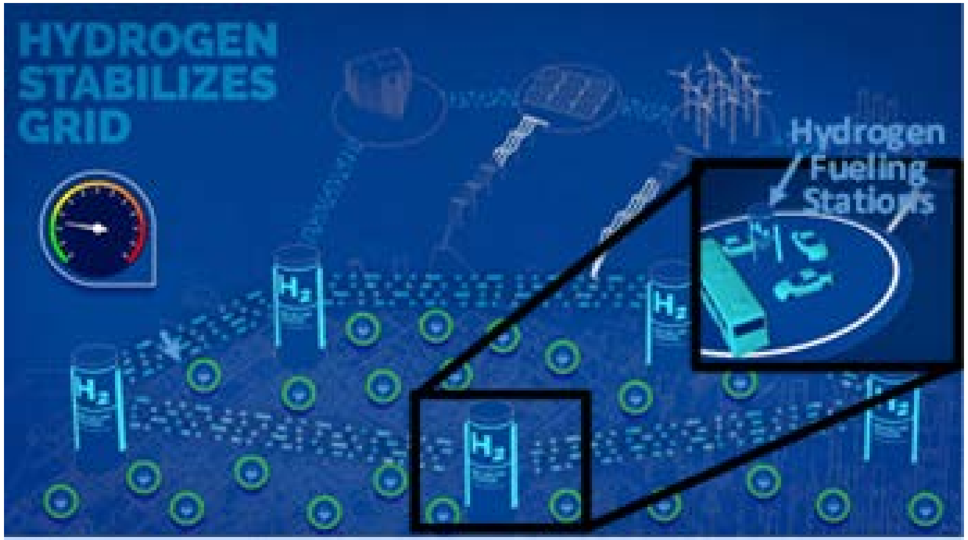


Relevance – Quantification of Grid Support and Potential Value Streams

H_2 resources can provide grid support through greater utilization of grid assets, enhanced reliability, and integration of renewable generation (e.g., mitigating the California net load curve below)

The H2VGI toolset quantifies the co-benefits and value streams for hydrogen resources to provide grid support



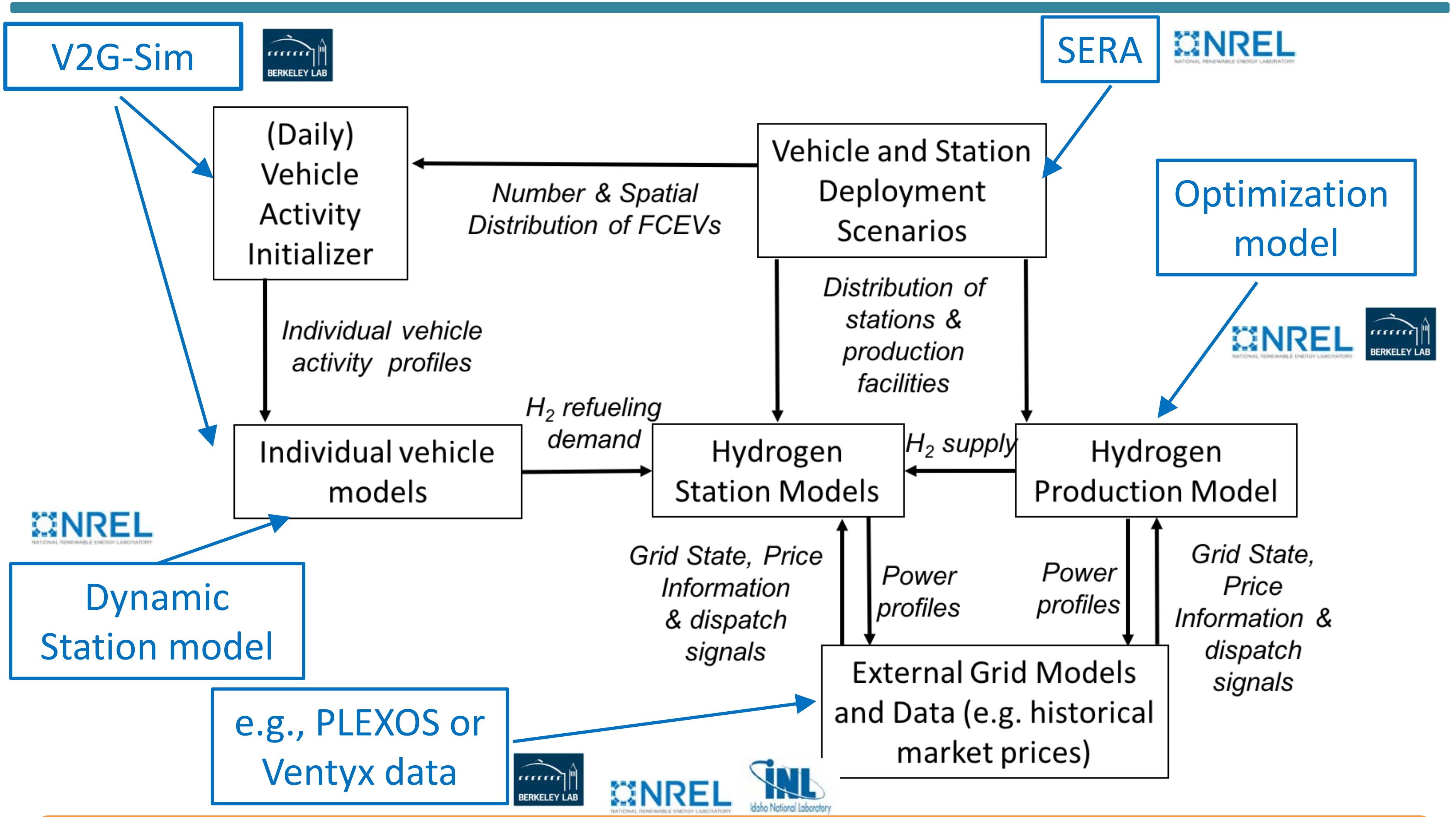


Relevance – Stakeholders Benefits of the Proposed H2VGI Model

Stakeholder	Benefits of H2VGI Model	Case studies
Policy makers	Understand co-benefits of investment in H_2 fueling infrastructure	Support decision making in deployment
Automotive	Design of grid-integrated FCEVs	Support value proposition
Researchers	Open-source toolset	Foundation for future R&D
H_2 station owners	Justify investment in H_2 stations	Quantify value of H_2 to grid support

The proposed H2VGI model provides economic analysis and decision-making support that benefits multiple industry groups and policymaking stakeholders

Approach – H2VGI Model Structure



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

Key planned case studies

- Determine the flexible capacity that is available from hydrogen-mobility-grid systems under various scenarios of FCEV/station deployment and renewables deployment.
- Determine how the use of H2 production and dispensing to provide grid services affects the cost competitiveness of hydrogen.
- Quantify the capacity that hydrogen vehicles can support provision of grid services or backup power for a building under different penetrations of FCEVs.
- What is the value of station configuration/storage sizing in reducing electricity costs (includes over-sizing and over-powering electrolyzer)?
- Examine the tradeoffs for centralized production and distribution/transportation to fueling stations vs. stations with distributed production.
- Assess the overall capability of the hydrogen refueling network to provide short term storage and long-term storage.

Approach: Project Phases and Selected Milestones

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Literature review and sub-model development

(FY17 Q1)

- **Survey prior studies on hydrogen-vehicle-grid integration and in existing simulation tools**
- **H2VGI model structure methodology outlined and code developed including sub-model data-exchange formats.**
- **Sub-models for vehicle activity initializer, and individual vehicle models ready for integration into overall H2VGI model.**

Model integration and use case definition

(FY17 Q2)

- **Integration of FCEV H2 consumption sub-models** with hydrogen station models developed by NREL.
- **Definition of case studies** for hydrogen vehicle-station-grid integration.
- **Quantify the value of hydrogen production for FCEVs** in California to support renewable supply integration

Model Validation

(FY17 Q3)

- **Testing and input-output validation of fully integrated H2 sub-models** within H2VGI model to confirm the directions of model results change as expected with inputs that have well understood sensitivities.
- Demonstration that H2VGI model produces results that are directionally correct based on input-output validation. (Go/No-go criteria)

Model Implementation

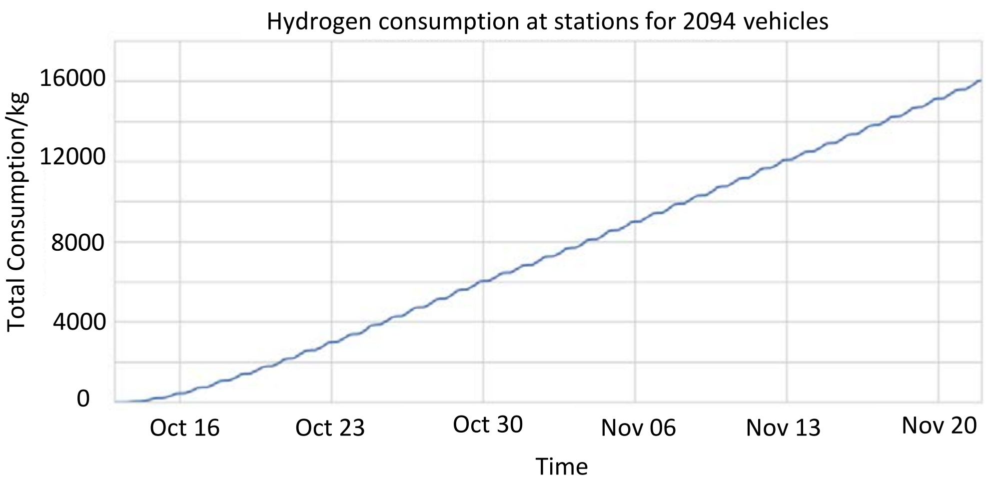
(FY17 Q4)

- **Initial results on first case study** to quantify the scale of opportunity for hydrogen-vehicle-grid integration.
- **Write a short report** with key graphs and figures summarizing findings.

Accomplishments and Progress: Sub-models for vehicle activity initializer and individual vehicle models

Development of **preliminary** mobility hydrogen demand sub-models

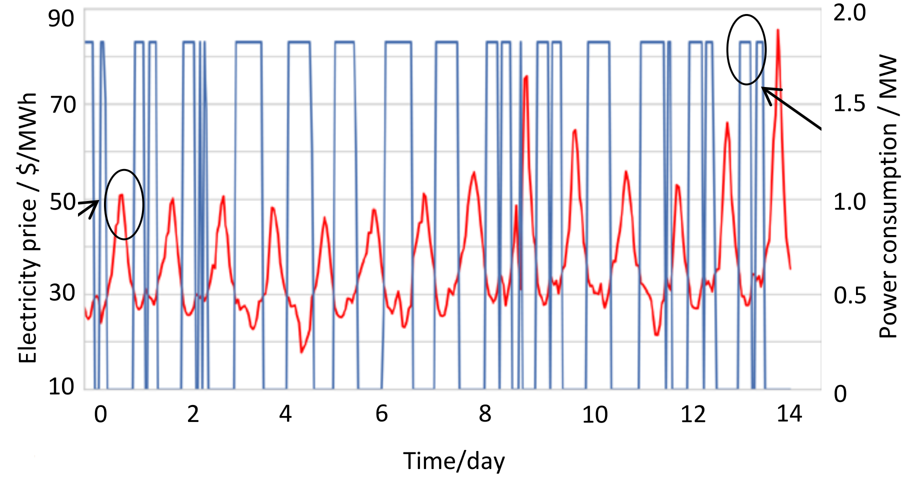
- Calibrated fuel cell vehicle models
- A preliminary refueling sub-model, which governs when individual vehicles are refueled within their travel itineraries
- Initialization data for travel itineraries for large collections of vehicles, using national household travel survey data as a first step.



Cumulative hydrogen consumption over 40 days for ~2,000 vehicles

Implementation of the **hydrogen mobility demand sub-models**

- Preliminary results for daily hydrogen demand have been generated



Example of cost-optimized operation of hydrogen electrolyzer that accounts for the dynamic price of electricity (using time-of-use electricity prices)

Accomplishments and Progress: Scenario definition sub-model: FCEV adoption and hydrogen refueling station deployment

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*SERA: Scenario Evaluation, Regionalization & Analysis

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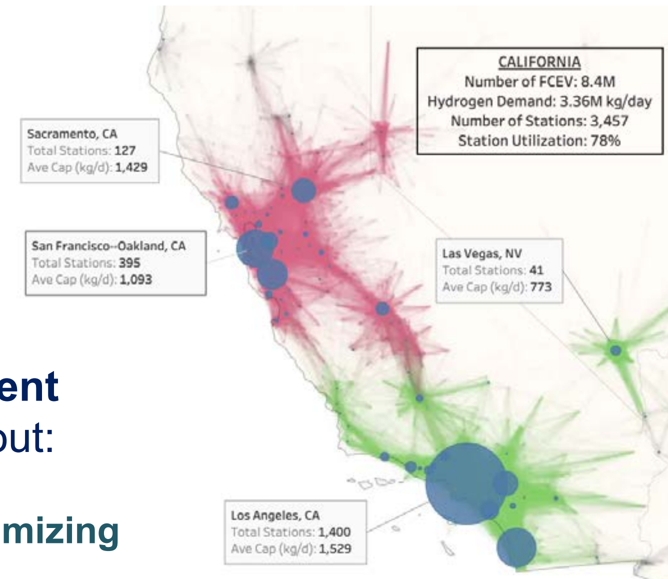
The SERA* model has been used to generate **self-consistent FCEV adoption and hydrogen demand scenarios** relevant to early market transition, considering:

- **Geospatially and temporally resolved vehicle adoption in each Urban Area in California based on demographics and early adopters metrics**
- **Annual vehicle mileage based on empirical evidence**
- **FCEV fuel economy improvement over time**
- **Vehicle stock turnover**

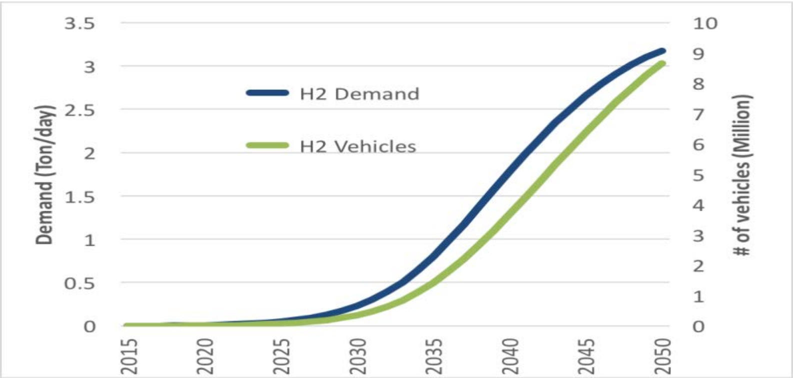


SERA determines optimal **regional infrastructure development patterns** focusing on detailed hydrogen refueling stations rollout:

- **Stations are sized and geographically placed strategically, maximizing overall coverage**
- **The distribution of fueling stations (in both capacity and space) will evolve over time as the demand for hydrogen increases**

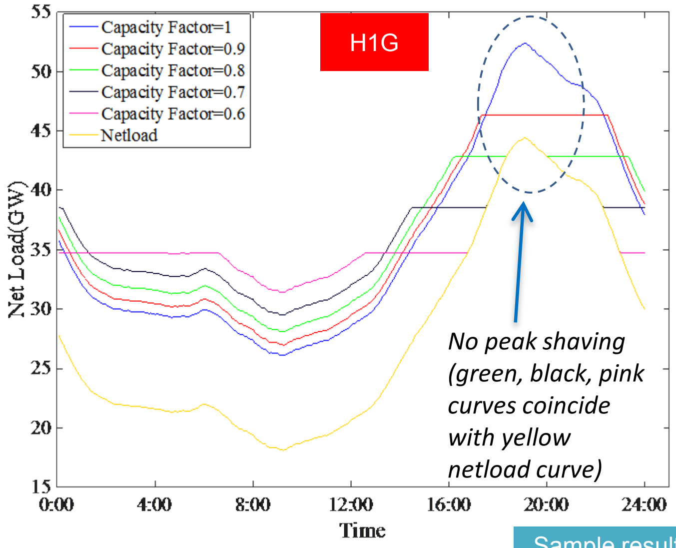
SERA provides annual FCEV adoption and H2 demand scenarios and strategic placement of fueling stations

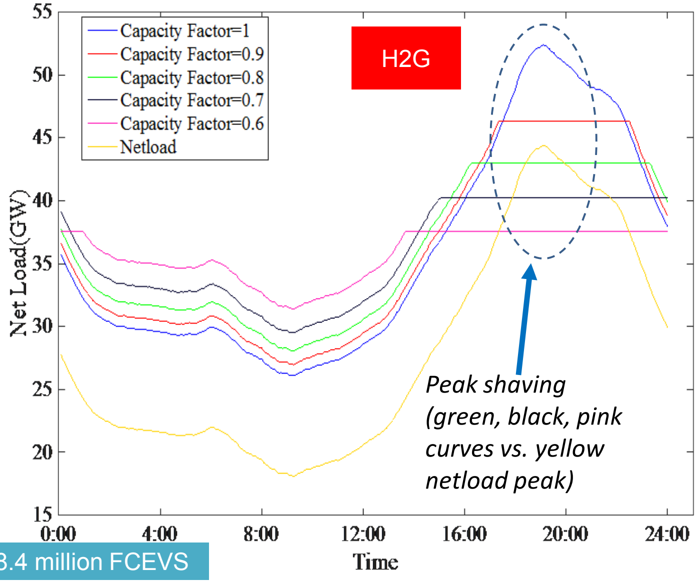
Accomplishments and Progress: Quantifying the value of hydrogen production facilities to help the integration of renewable energy in California – *Peak shaving and valley filling*



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

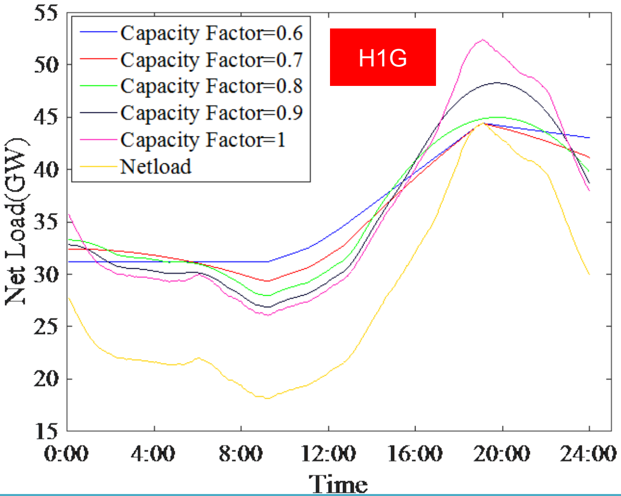




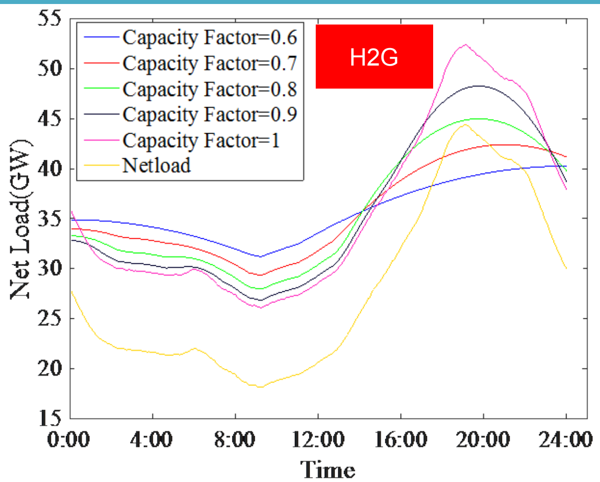
Sample results: 2025 netload with 8.4 million FCEVS

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.

Accomplishments and Progress: Quantifying the value of hydrogen production facilities to help the integration of renewable energy in California – *Ramping Mitigation*



Sample results: 2025 netload with 8.4 million FCEVS



Capacity Factor	Max ramp-up (MW/h)	Max ramp-down (MW/h)
1	7875	7047
0.9	3779	4336
0.8	3690	2446
0.7	2270	1295
0.6	1554	792

- Max ramp rate can be reduced by about 50% when the electrolyzer is slightly oversized (capacity factor from 1 to 0.9).
- H2G will not significantly increase the ramping mitigation capability compared to H1G.

Capacity Factor	Max ramp-up (MW/h)	Max ramp-down (MW/h)
1	7875	7047
0.9	3779	4336
0.8	3690	2446
0.7	2081	847
0.6	1159	281

The technical potential for centralized electrolysis to provide grid ramping support for California in 2025 has been modeled for the first time.

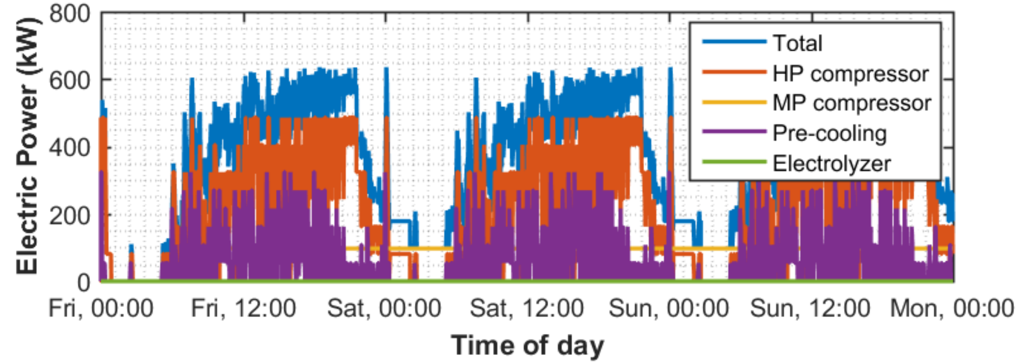
Accomplishments and Progress: Hydrogen station electricity consumption and grid support model

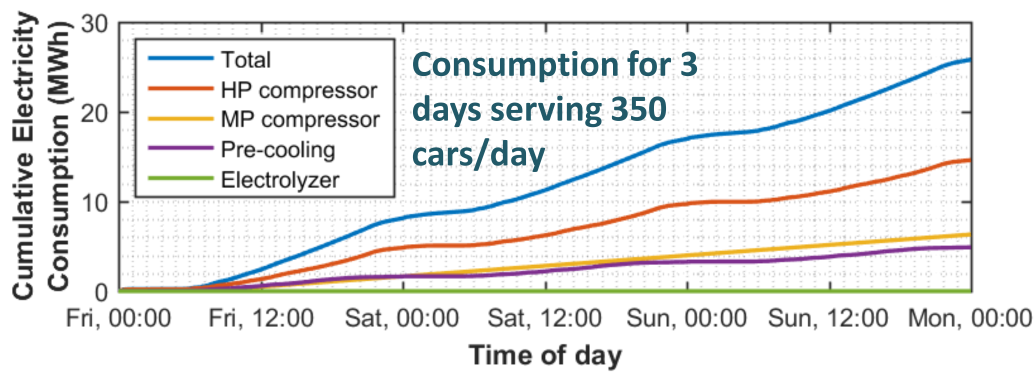
- Model is used to understand current electricity patterns and opportunity for grid integration
  - Energy management
  - Demand charge reduction
  - Demand response programs
  - Wholesale grid services

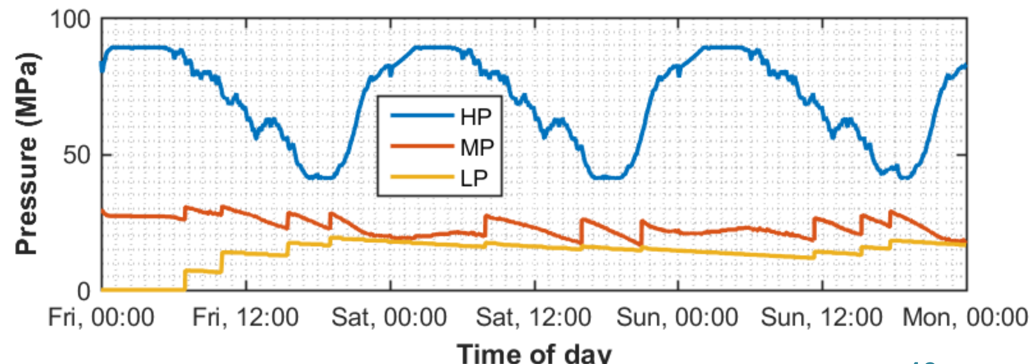
Hydrogen station modeling captures electricity consumption for various station configurations to understand the opportunity for grid support

LP: Low pressure
MP: Medium pressure
HP: High pressure

No electrolyzer operation here; H_2 delivery assumed







Accomplishments and Progress: Device Optimization for grid integration using RODeO

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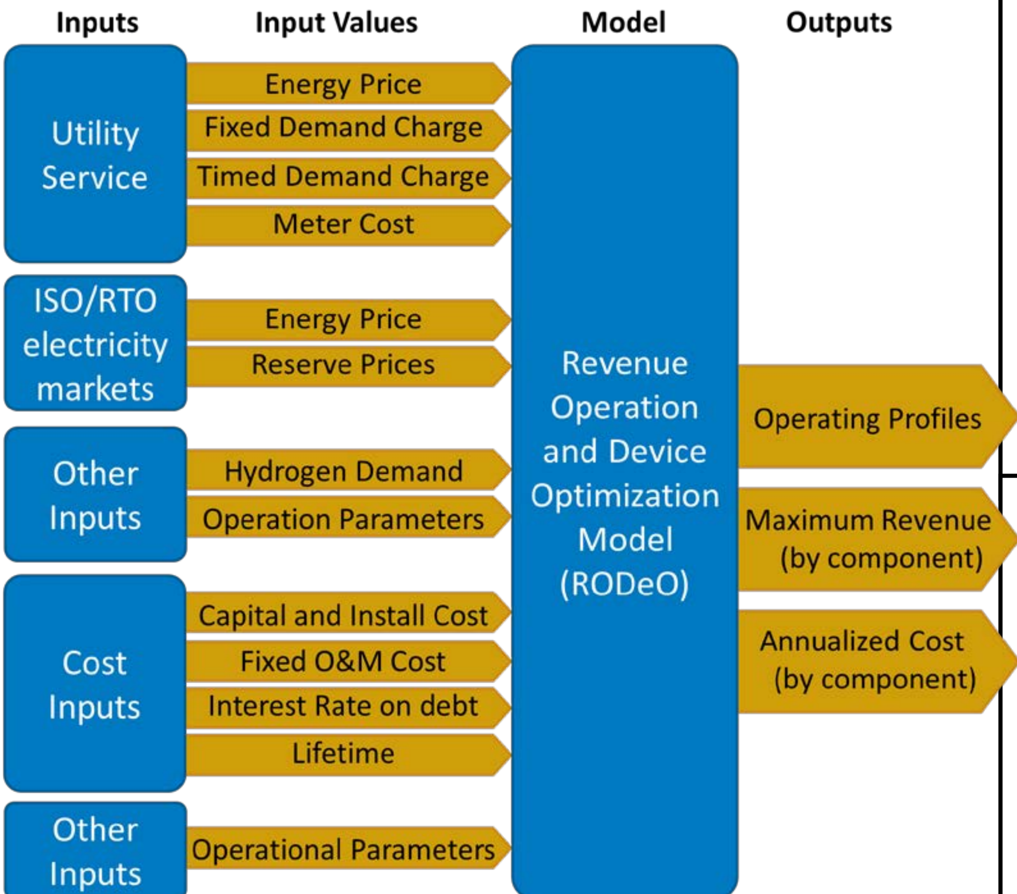
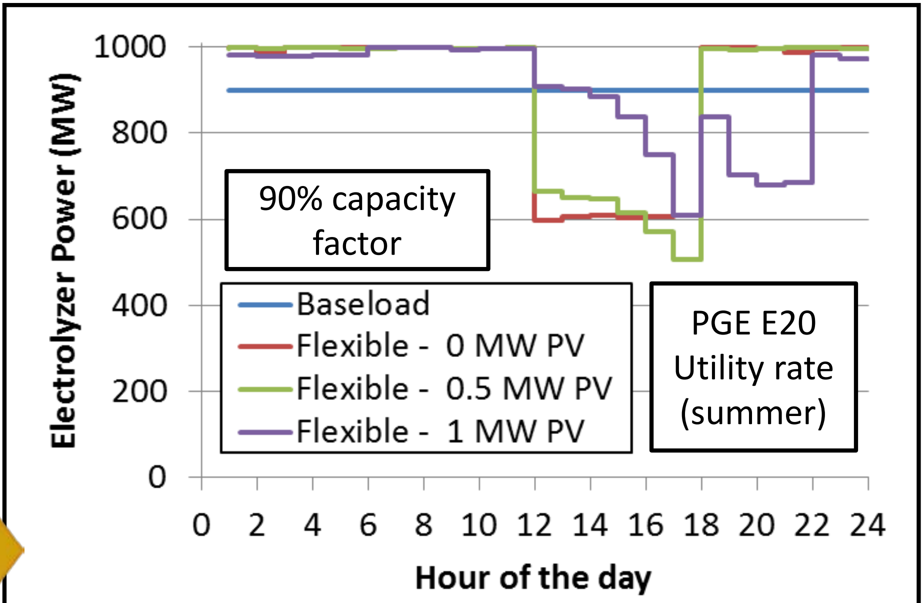
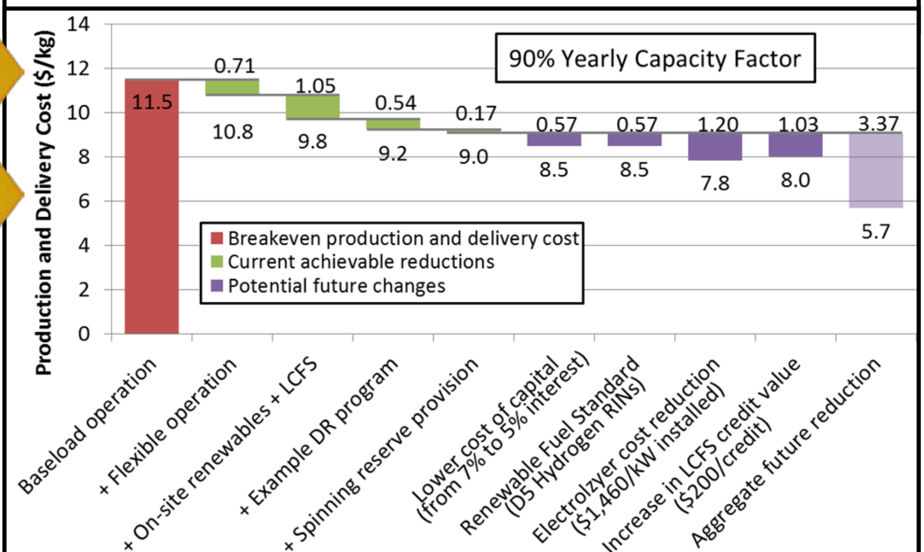
RODeO (Revenue Operation and Device Optimization Model) optimizes uses mixed-integer linear programming to maximize revenue and optimize equipment operation



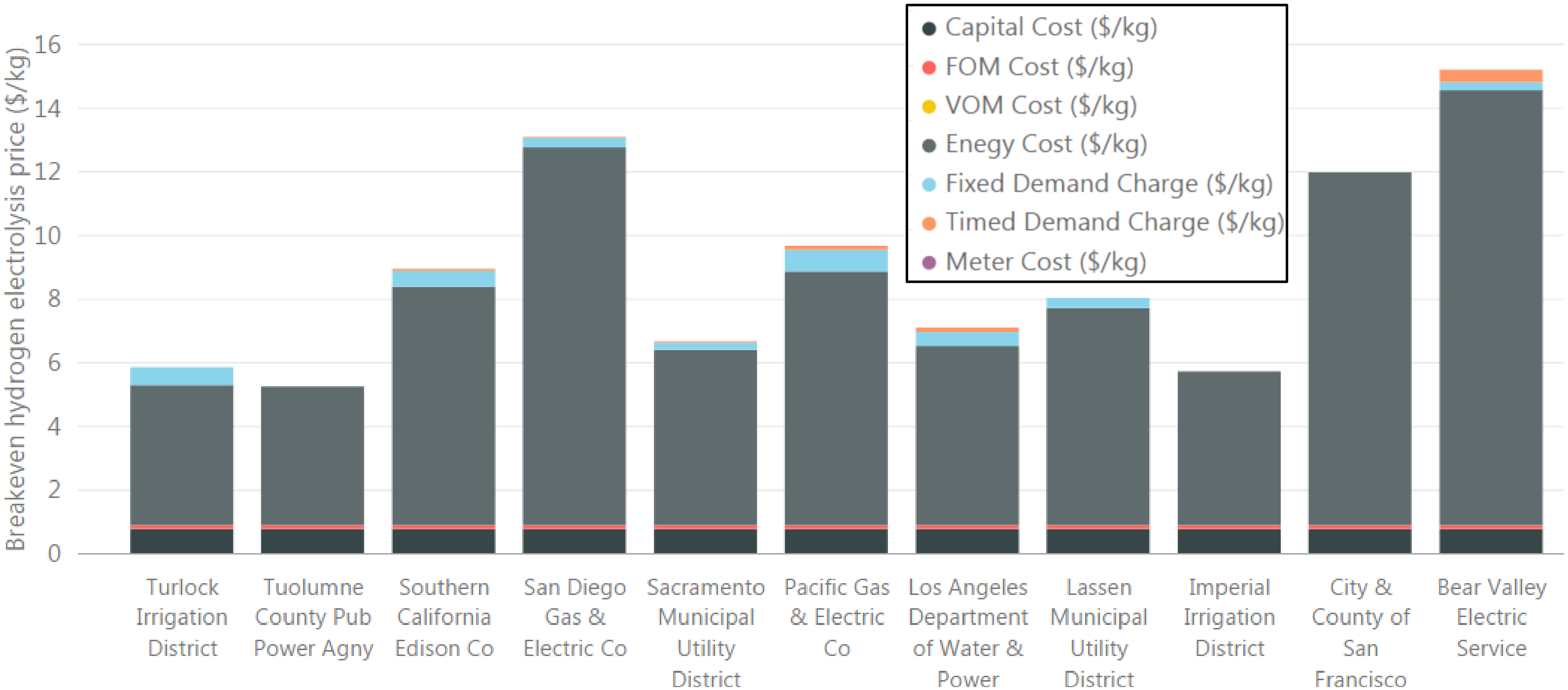


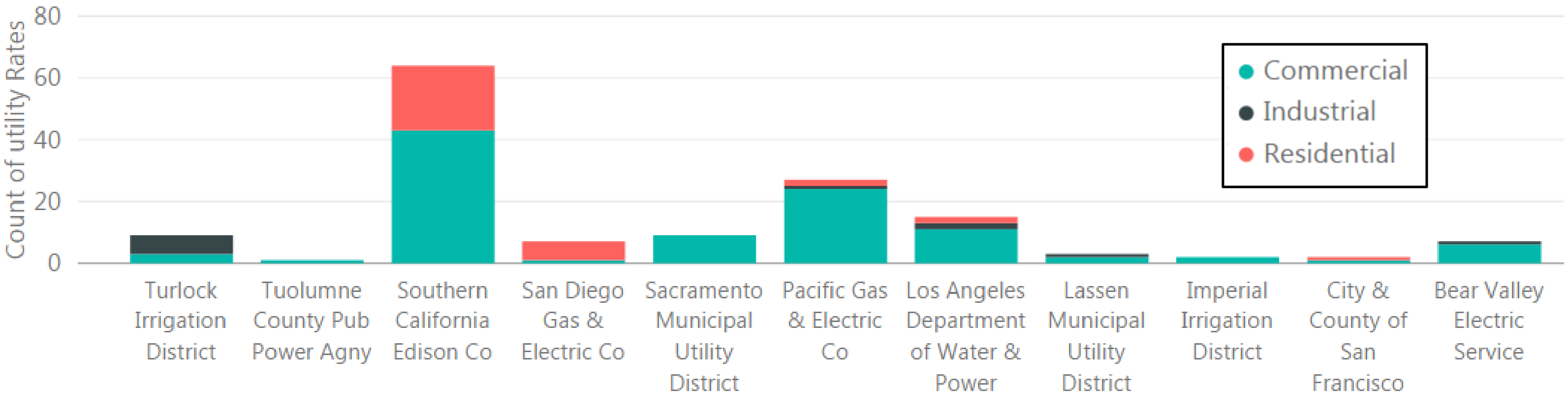


Example result (www.nrel.gov/docs/fy17osti/67384.pdf)

RODeO optimizes device operation and economic competitiveness

Accomplishments and Progress: Device Optimization for grid integration using RODeO





This example shows how RODeO can return the average costs by component for an electrolyzer system associated with each California utility rate

The RODeO tool has been integrated with the U.S. Utility Rate Database, which allows for competitiveness calculations of grid-integrated electrolysis across the U.S.

Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year.

Collaborations

Partner	Role	Project Roles
NREL NATIONAL RENEWABLE ENERGY LABORATORY	Sub (Within FCTO)	Lead hydrogen vehicle and station deployment scenarios and station modeling; co-lead model integration, dispatch controller development, and case study modeling; support grid services valuation
INL Idaho National Laboratory	Sub; (Within FCTO)	Co-lead dispatch controller development for grid services; and tie-in to FCTO-TV031 project (first project below)

Related Projects

1. Dynamic Modeling and Validation of Electrolyzers in Real Time Grid Simulation (FCTO-TV031, INL lead);
2. Modeling and Control Software Tools to Support V2G Integration (DOE VTO-GM0086, LBNL lead)

Remaining Challenges and Barriers

- Integration of external grid models into overall H2-VGI toolset e.g.,
  - Modeling H2 resources in grid models for potential benefits and revenue;
- Integration of economic models for H2 resources and H2-VGI scenarios e.g.,
  - Fuel cell vehicle, electrolyzer, and fueling station costs;
  - Cost evolution with higher adoption rates
- Develop outreach strategy and approaches to engage key stakeholder groups for their inputs and perspectives, e.g.
  - H2 infrastructure owners & investors, ISO/RTO system operators, utilities, regulators, etc.

Proposed Future Work

- Remainder of FY 2017
  - Testing and input-output validation of fully integrated mobility and hydrogen station sub-models within H2VGI model to confirm the directions of model results change as expected
  - Initial results on first case study to quantify the scale of opportunity for hydrogen-vehicle-grid integration
  - Develop a group of technical advisors for stakeholder inputs and technical reviews (FY17-18)
- FY 2018
  - Short report on testing and validation of H2VGI model.
  - Carry out case studies to quantify the scale of the opportunity from hydrogen-vehicle-grid integration and synthesize findings
  - Sensitivity analysis and optimization case study and synthesize findings

Any proposed future work is subject to change based on funding levels.

Summary

Objective

Provide an integrated modeling capability to quantify the interactions between stationary hydrogen generation, fuel cell vehicles, and grid support resources

Relevance

Hydrogen technologies can offer a unique ability to simultaneously support both electric and transportation sectors

Approach/Next Steps

H2VGI Model integration, validation, and release
Apply H2VGI towards targeted case studies

FY17 Technical Accomplishments

- **Sub-model development**
  - Vehicle activity initializer and individual vehicle models
  - Dynamic station model
  - FCEV adoption and hydrogen refueling station deployment
- **Integration of FCEV H2 consumption sub-models with hydrogen station models developed by NREL.**
- **Preliminary case study results:**
- H2 electrolysis driven by FCEV demands can play a substantial role in mitigating renewables integration challenges (case study for California ISO "duck curve" mitigation here)
- Hydrogen station electricity consumption and grid support model are used to understand current electricity patterns and opportunity for grid integration.

Thank you

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