Decarbonizing Minnesota’s Natural Gas End Uses

Meeting 8

July 17th, 2020

Via Zoom

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Agenda

8:30	Welcome and Introductions
8:45	Presentation Q&A: Renewable Natural Gas and Biogas
10:00	BREAK
10:15	Discussion: Renewable Natural Gas and Biogas
11:00	Presentation and Q&A: Hydrogen
12:00	LUNCH
1:00	Discussion: Hydrogen
2:00	Final Discussion
2:30	ADJOURN

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DRAFT SCENARIOS

		Natural Gas Prices	
		Low	High
Policy Favorability to NG Decarb. Tech and Approaches	Unfavorable	A	B
	Favorable	C	D

Factors to Understand and Evaluate Strategies

	Efficiency	Electrification	RNG	Hydrogen	Geothermal (District Systems)
Cost (upfront, ongoing, factors of influence)					
Scalability, Best End Uses, Opp. Cost					
Decarb. Potential & Co-benefits					
Equity (to be better defined)					
Economy & Workforce					
Risk					
Potential Overlaps/ Interdependency					

Presentation and Q&A: Renewable Natural Gas and Biogas

Tom Cyrs,

World Resources Institute

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ROLE OF BIOGAS AND RNG IN DECARBONIZATION – OPPORTUNITIES AND DRIVERS

WRI RNG INITIATIVE OVERVIEW

WRI Renewable Natural Gas (RNG) initiative milestones:

2018 – WRI launched initial paper on RNG as a climate strategy

2019 – Reconvened and broadened working group to develop follow-on state guidance document and conducted preliminary scoping research

2020 – Drafting, expert consultations, peer review, and publication launch

Rationale – why state level guidance?

States have a **wide array of options to drive resource development**
number of private fleet owners, utilities, and other businesses are interested in RNG as a decarbonization solution.

Yet uncertainty remains on the role that RNG can play in decarbonization

promote greater awareness and understanding

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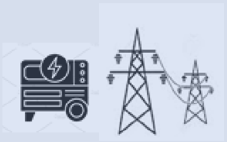
RESOURCE POTENTIAL AND GHG IMPLICATIONS BY FEEDSTOCK

OVERVIEW OF BIOGAS AND RNG

Cleaned / conditioned biogas	Upgraded biomethane / RNG
Treatment required	
Initial cleaning and conditioning (moisture, siloxane, and H_2S removal). Medium-btu gas (>50% CH_4).	Additional upgrading to increase purity (removal of nearly all non-methane trace gases such as CO_2, O_2, and N_2. High-btu gas (>95% CH_4).
Common end-uses & markets	
 Boiler or process heat  On-site electricity generation	 Compressed RNG to vehicle fuel  Gas pipeline and delivery to multiple end-use markets

Project-specific considerations:

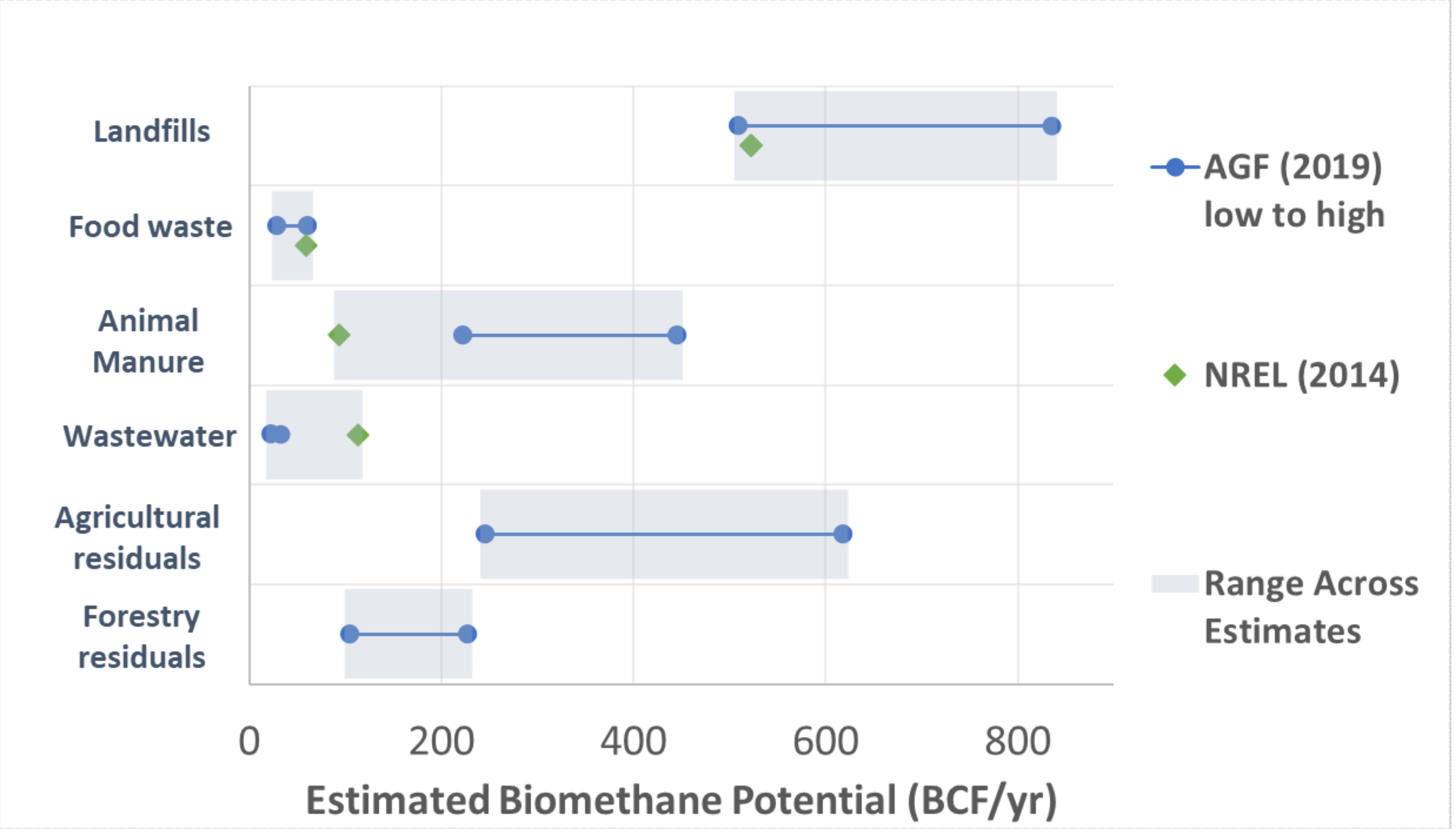
- **Fuel specification** – higher gas purity required for pipeline injection
- **Pipeline vs. non-pipeline options** – interconnection and injection provides largest market opportunity if economically viable, however virtual pipelining and on-site applications also merit consideration
- **Stand-alone vs. clustered projects** – clustering may be a vital strategy to reduce capital costs and utilize shared infrastructure, particularly for distributed resources such as dairies

RESOURCE POTENTIAL BY FEEDSTOCK

National assessments:

State assessments:

Figure | **National Resource Potential by Feedstock**



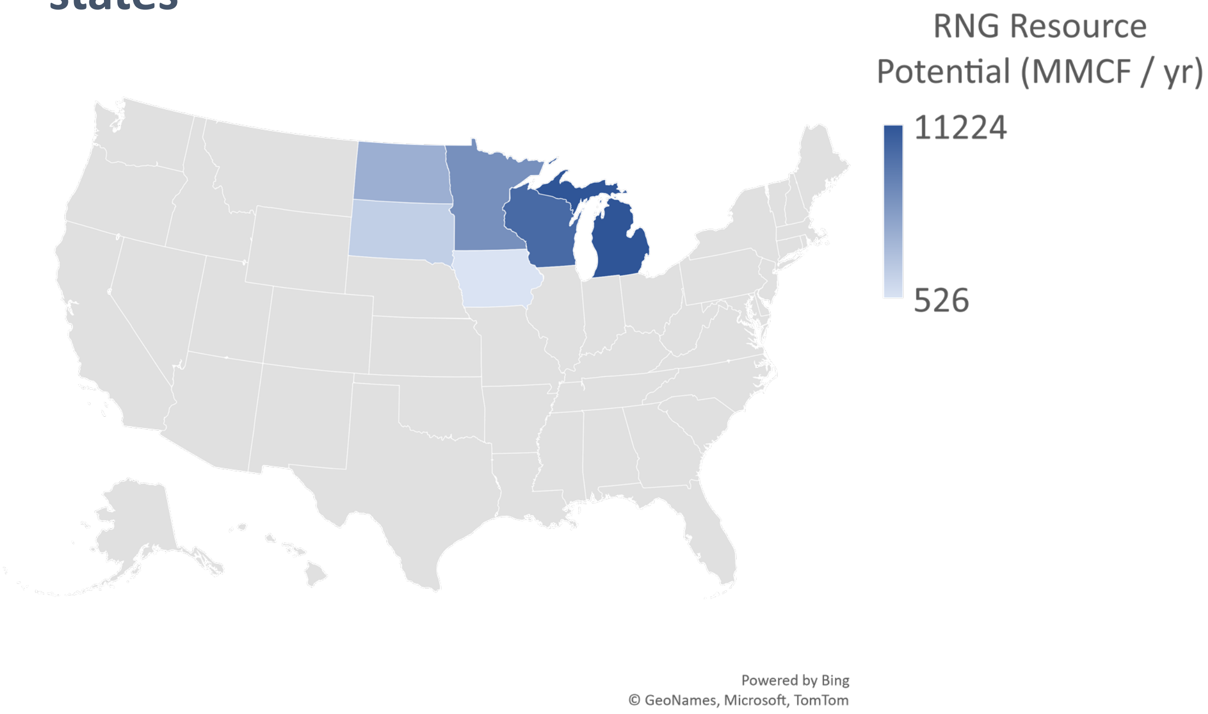
Note: National studies find annual biomethane potential of 780-2,200 BCF.

CURRENT MIDWEST RESOURCE POTENTIAL

Table| **Current RNG Projects in upper Midwest Region (Coalition for RNG)**

Feedstock Type	Number of Projects Online	Current Annual Production (MMCF / yr)
Animal Waste	11	9.1
Food Waste	0	0
Landfill	8	12.8
Wastewater	2	200

Figure | **Total RNG potential for upper Midwest states**

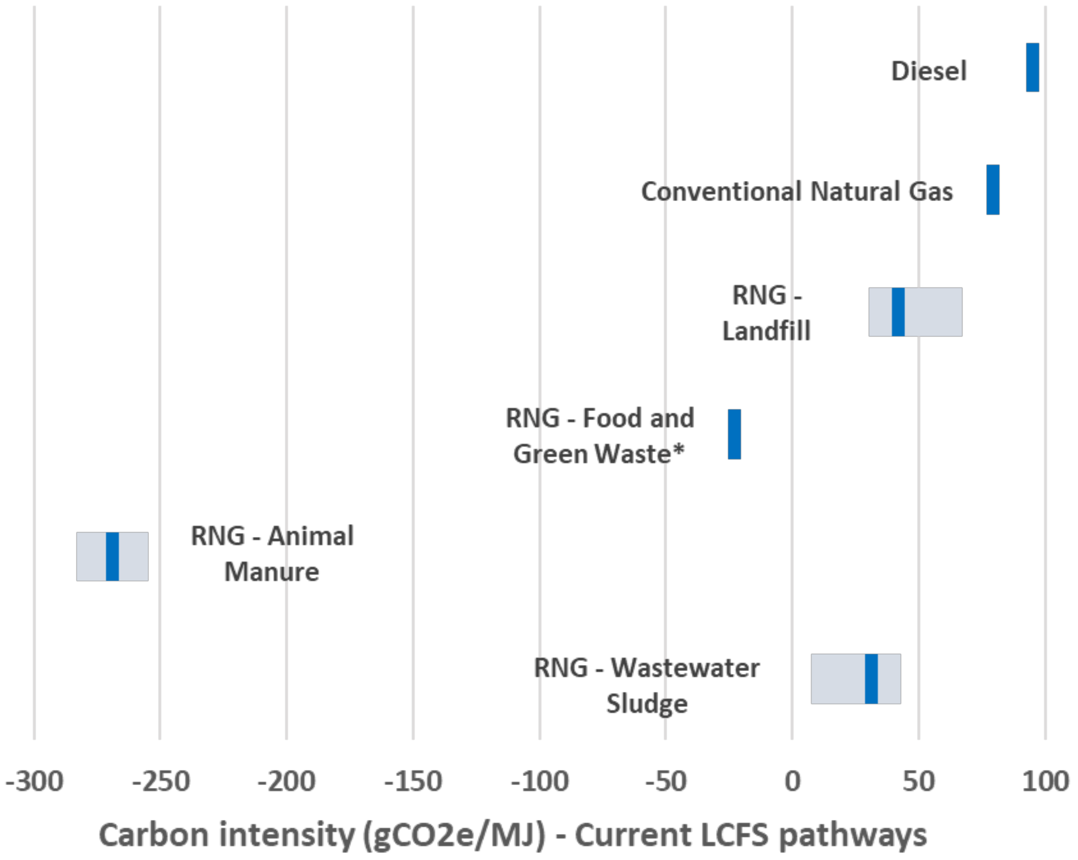


Takeaways:

- Total regional resource potential = ~5.5% of residential natural gas sales (wet waste feedstocks only) (NREL)
- Estimated output of currently online projects: 222 million cubic feet per year (or ~2.3% of potential)
- Wide diversity of projects in the region

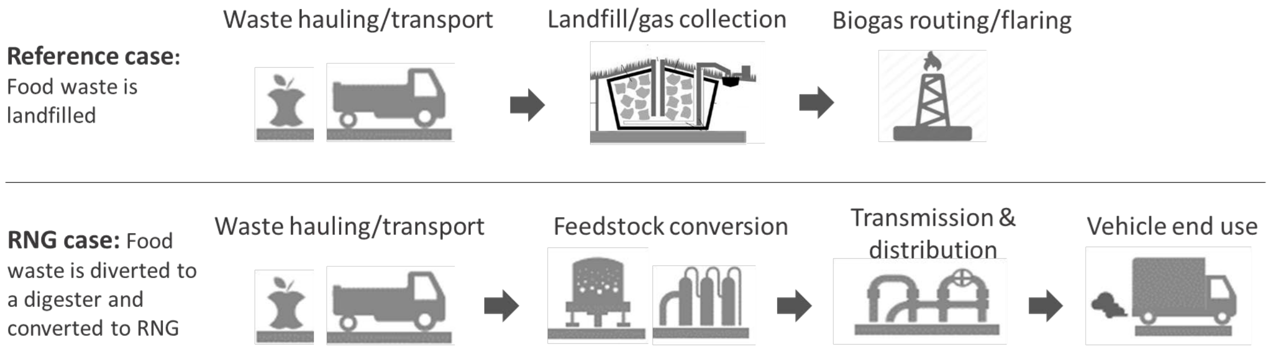
EVALUATING EMISSIONS IMPACTS

Figure | **Lifecycle carbon intensity by feedstock**



Note: RNG climate impacts vary considerably from feedstock to feedstock.

Example | **Food waste RNG lifecycle:**



- Sources of emissions in RNG pathway may include energy for gas cleaning and upgrading, fuel combustion, and methane leakage along the pathway
- "Credits" in RNG pathway can include avoided methane emissions / flaring from landfill
- LCA accounting captures these nuances, but is complex, data intensive, and reliant on counterfactuals

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DEPLOYMENT TRENDS AND ROLE IN DECARBONIZATION

RNG MARKET TRENDS: TRANSPORTATION SECTOR

Figure | **RNG Use in NG Vehicles**

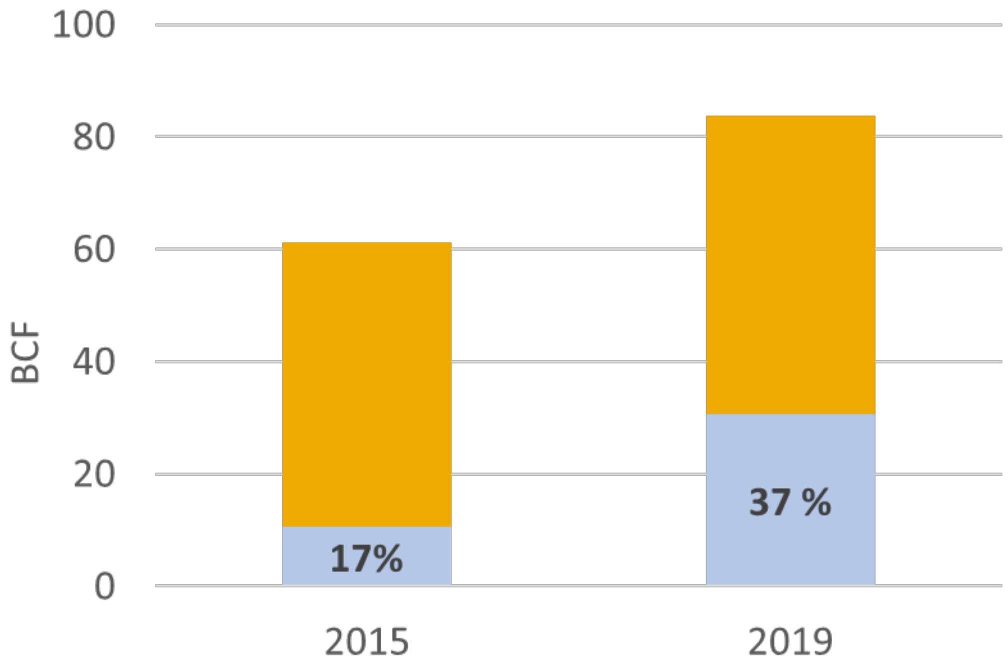
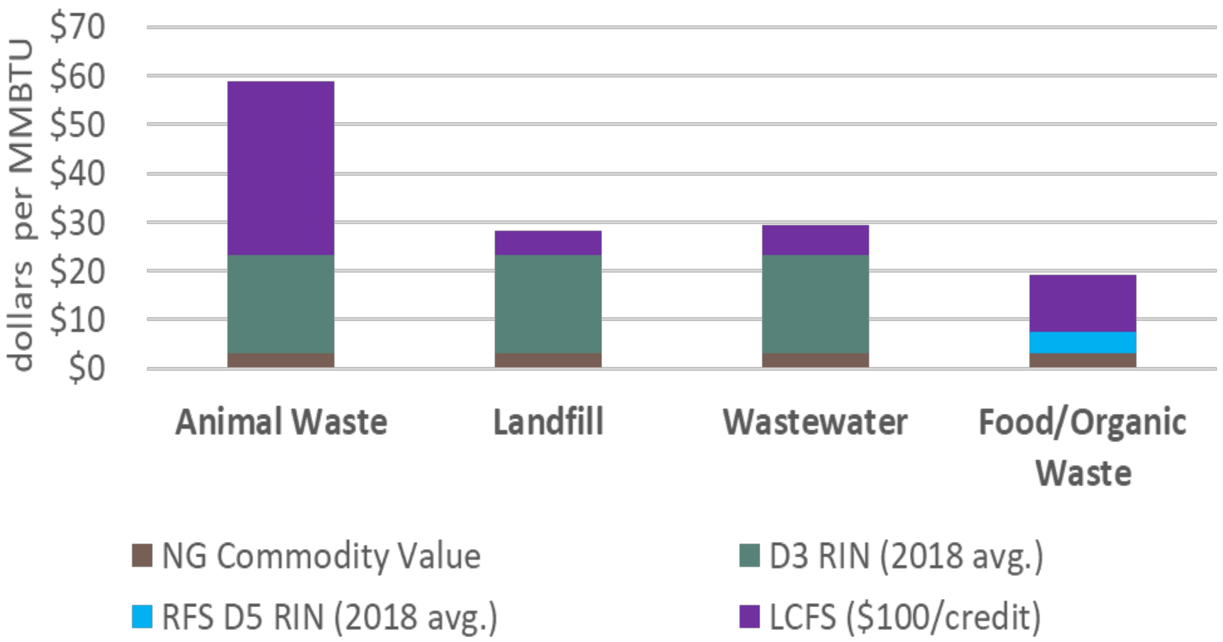


Figure | **RNG value by feedstock**



Current trends:

- 85 of 99 operational RNG projects supplied fuel for transportation use in 2019
- Development has been driven largely by policy incentives

Value of policy incentives:

- Large share of RNG supply can be brought online at $15/mmbtu threshold
- Current transportation sector incentives can offer nearly 4x this value, but market involves risk

RNG MARKET TRENDS: BUILDINGS SECTOR

Current trends:

- Utilities are increasingly seeing RNG as a way to decarbonize supply
- Market now in a phase of development similar to where power sector RECs were decades ago
- Momentum toward more robust market:
    - **CRS / Green-e** – Now developing renewable fuels standard
    - **M-RETS** – to begin validating RNG attributes for voluntary and compliance markets

Challenges

- Incentives still nowhere near those in transportation sector, however as market matures may allow developers to hedge their risks against LCFS/RFS prices or obtain more stable, long-term offtake
- RNG still costs 5x (or higher) price of natural gas, lack of financial incentives and regulatory support

Table **| Current utility rate cases and programs**

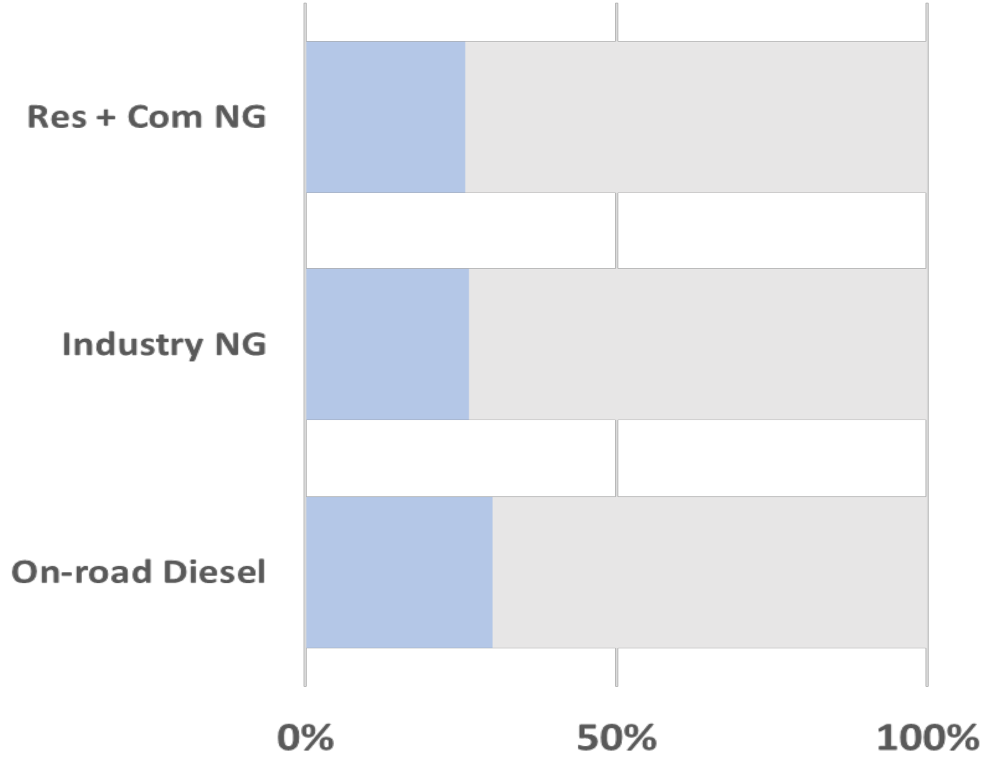
State	Utility	Details	Current Status
Vermont	Vermont Gas	Voluntary opt-in program using "RNG adder"	Active – approved 2017
Michigan	DTE Energy	Voluntary opt-in "BioGreenGas" program – flat rate surcharge of $2.50/month.	Active - first approved in 2015 – extended inl 2019.
Utah / Idaho	Dominion Energy	Voluntary opt-in "GreenTherm" program – customers purchase "blocks" of RNG at $5 monthly	Active - Approved 2019
New Hampshire	Liberty Utilities	Contract with large buyers, with option to market excess supply to additional customer in service territory.	Dismissed by PUC in 2020. Re-file pending
Minnesota	Centerpoint	Voluntary, five year pilot program	Dismissed by PUC in 2019. Re-file pending

ROLE OF RNG IN DEEP DECARBONIZATION

Table | **deep decarbonization studies incorporating RNG in energy system modeling**

Region	Study
California	*Deep Decarbonization in a High Renewables Future* (Mahone, et al. 2018)
California	*Getting to Neutral: Options for Negative Emissions in California* (Baker, et al. 2020)
Oregon/ Washington	*Pacific Northwest Pathways to 2050* (Energy+Environmental Economics 2018)
Northeast	*Northeast 80x50 Pathway* (National Grid 2018)
Northeast	The Role of Renewable Biofuels in a Low Carbon Economy (Lowell 2019)

Figure | **Illustrative RNG Resource Potential at $21 / MMBtu (in 2040)**



Key takeaways from deep decarb studies and modeling:

- In transportation sector, RNG contributes to emissions reductions for medium- and heavy-duty vehicle fleets
- In buildings / thermal end-use sector, deployment of RNG in existing infrastructure displaces fossil gas
- On its own, RNG is insufficient to decarbonize any one sector, but contributes as a complementary strategy

BARRIERS AND POLICY DRIVERS

UNDERSTANDING BARRIERS TO RNG DEPLOYMENT

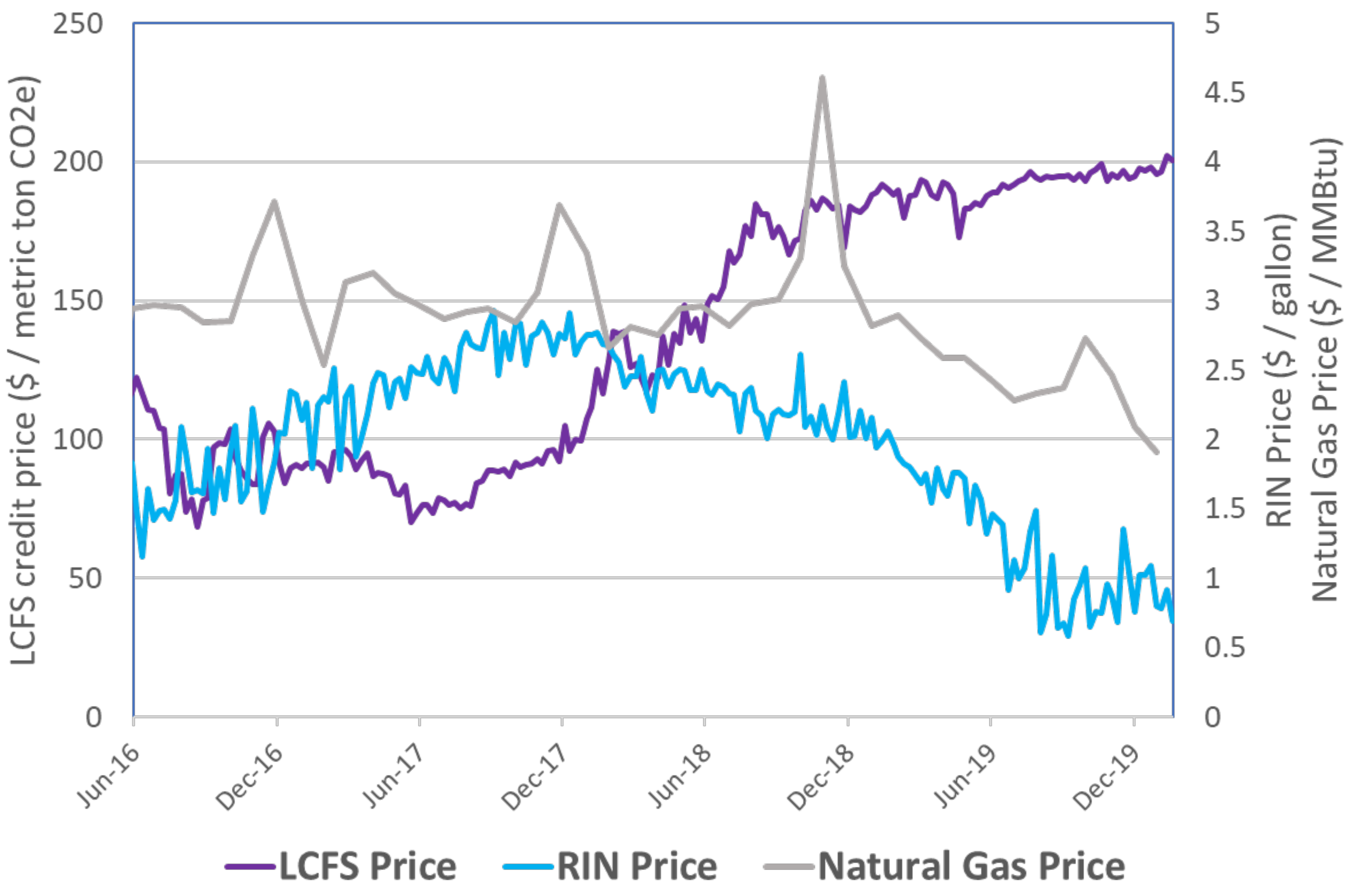
Feedstock availability
- Variable waste production cycles
- Effects of storage, environment
- Demand for competing uses

Regulatory Risk
- Shifting political forces
- Reliance on extensions
- Conditional sunsetting

Operational Risk
- Feedstock consistency
- Equipment failure

Project Economics
- Large upfront costs
- Operational and maintenance costs

Market Risk
- Uncertainty in gas prices, credit prices



RNG SUPPORTING POLICY CATEGORIES

Climate and energy mandates

- Policies that set explicit requirements for emissions reductions and/or the share of energy derived from clean and renewable sources.
- Typically enacted through binding regulatory authority and achieved through tradeable performance standards.

Public financial support

- Policies that promote project development through public financing.
- May include grant programs or tax incentives to offset capital expenditures or establishing preferential purchasing standards for publicly funded institutions.

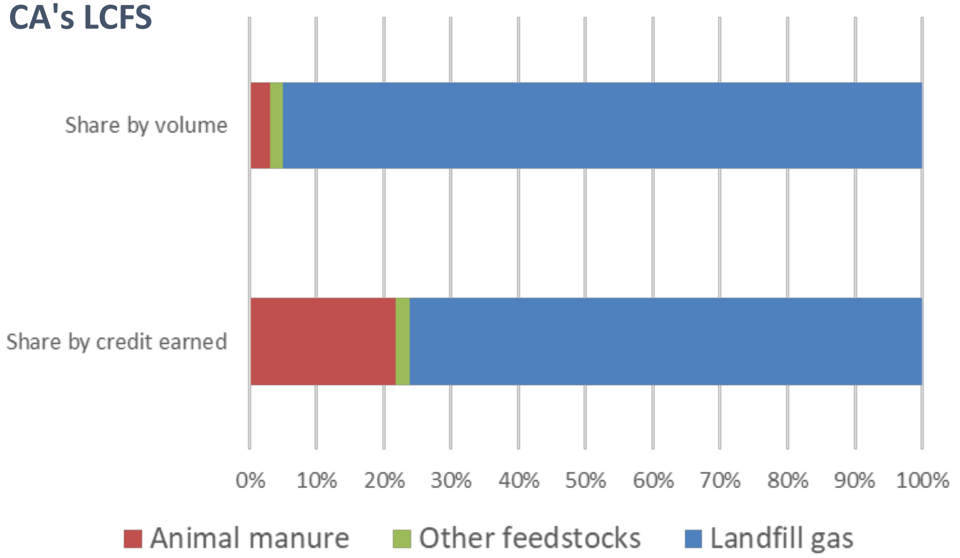
Additional enabling policy options

- Other regulatory policies that may have important effects—either directly or indirectly—on RNG deployment.
- For example, an organic waste recycling mandates or updates to local siting and permitting rules may provide greater regulatory certainty for producers.

KEY POLICY CONSIDERATIONS – CLIMATE AND ENERGY MANDATES

Types of mandates:

Figure | **RNG feedstocks by volume and by credits generated in CA's LCFS**



Key elements and considerations:

- **Eligibility -** How does RNG production satisfy overarching program objectives, fill in compliance gaps, or complement other technology options?
- **Credit value -** How are different RNG feedstocks treated and what level of administrative complexity is feasible / appropriate?
- **Technology neutrality vs. carve-outs -** Which technologies and/or feedstocks have a current cost advantage? Are there options that merit direct support?
- **Additionality -** Are potential overlapping mandates, credit stacking, or eligibility for pre-existing projects mutually reinforcing or do they raise additionality concerns?

KEY POLICY CONSIDERATIONS – DEVELOPING CLEARER PUC GUIDELINES

Key considerations as rules develop:

- **Cost** - How to balance priorities of protecting ratepayers and promoting decarbonization efforts through RNG?
- **Integrity** - How to ensure additionality, certification of environmental attributes, and transparency for consumers?
- **Investment and fair competition** – How and where can utilities invest along RNG supply chain?

Table | **example state-level enabling legislation**

State	Legislation facilitating LDC investment in RNG	Specific actions
California	SB 1383 (2016): Short-lived Climate Pollutants	PUC to implement no less than five dairy biomethane pilot projects to demonstrate interconnection.
California	AB 3187 (2018): Biomethane: gas corporations: rates: interconnection	PUC to consider standards for investment and rate-based cost recovery for RNG interconnection infrastructure, including gathering lines for clustered diary digesters.
Oregon	SB 98 (2019): Relating to renewable natural gas; prescribing an effective date.	PUC to adopt rules for qualified rate-based recovery. Sets progressive cap on RNG percentage in gas distribution mix that increases over time, starting at 5% through 2024.
Utah	HB 107 (2019): Sustainable Transportation and Energy Plan Act Amendments	Establishes “Innovative utility programs” whereby commission may authorize large-scale natural gas utility to up to $10 million per year on natural gas clean air programs, including renewable natural gas, that the commission determines are in the public interest and spread across rate base.

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THANK YOU!

Contact: tom.cyrs@wri.org

Decarbonizing Minnesota's Natural Gas End Uses

BREAK

RETURN AT 10:00

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Discussion:

Renewable Natural Gas and Biogas

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Presentation and Q&A: Hydrogen

Dr. Jennifer Kurtz and Michael Peters,

National Renewable Energy Laboratory

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NATIONAL RENEWABLE ENERGY LABORATORY

Hydrogen Research at NREL

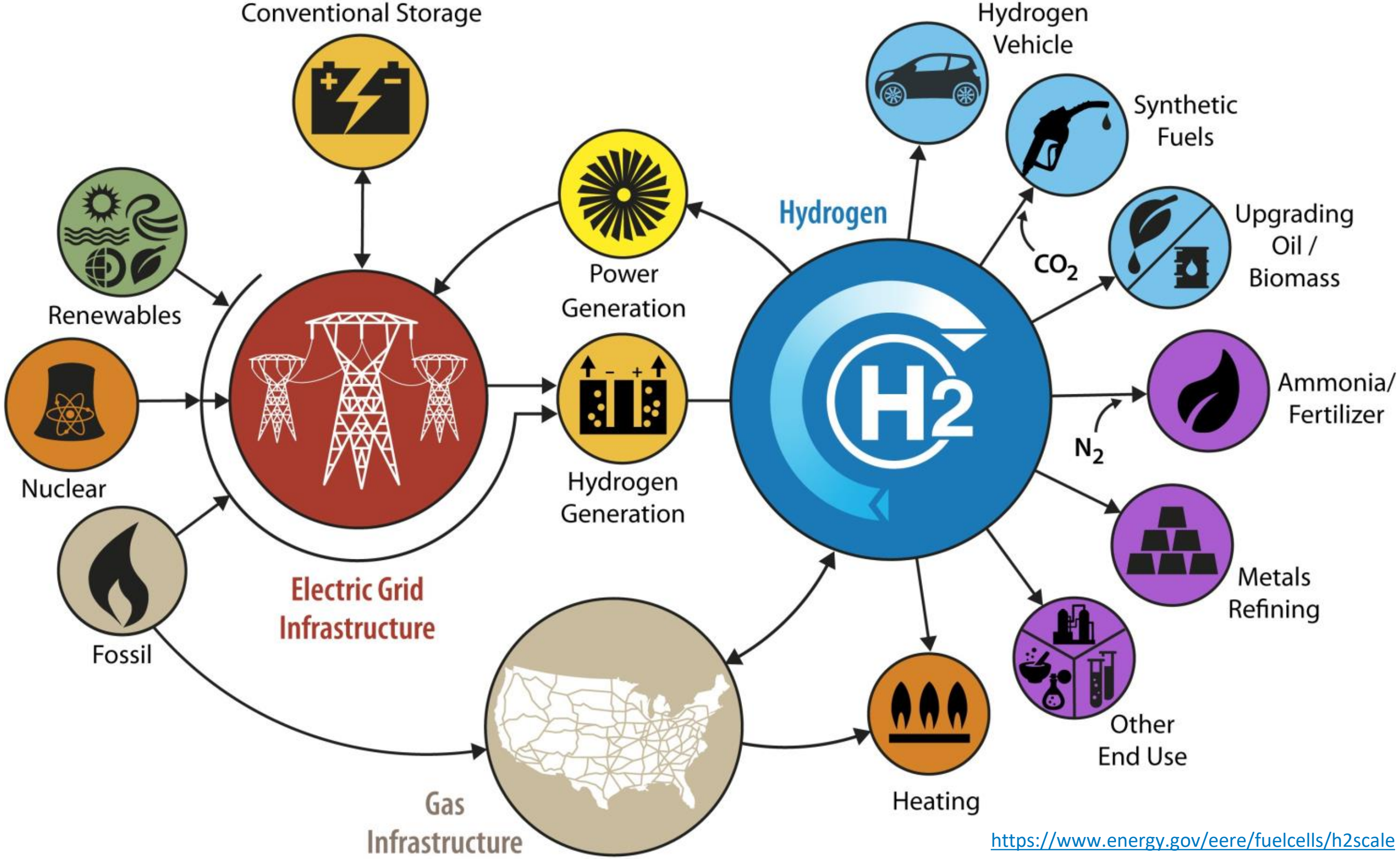
Dr. Jennifer Kurtz
Mike Peters

7/17/2020

Hydrogen Production and Grid Integration

NREL Hydrogen Research Presentation

Grid-Integrated Electrolysis Plays an Important Role in the H2@Scale Vision



https://www.energy.gov/eere/fuelcells/h2scale

NREL’s H_2 & Fuel Cell R&D

Make

- Electrochemical
- Photoelectrochemical
- Biological
- Thermochemical
- Grid integration
- Power electronics
- Direct connect renewable integration

Move

- Pressure
- Form
- Quantity
- Mode

Store

- On-board
- Carriers
- Bulk

Use

- Fuel cells
- Electrons to Molecules
- Fuel upgrading
- Combustion
- Metal reductant

Crosscuts

- Foundational decision science
- Manufacturing
- Safety
- People

Vision: *Hydrogen will be a ubiquitous means of transporting, storing, and transforming energy at the scale necessary to enable a clean and vibrant economy*

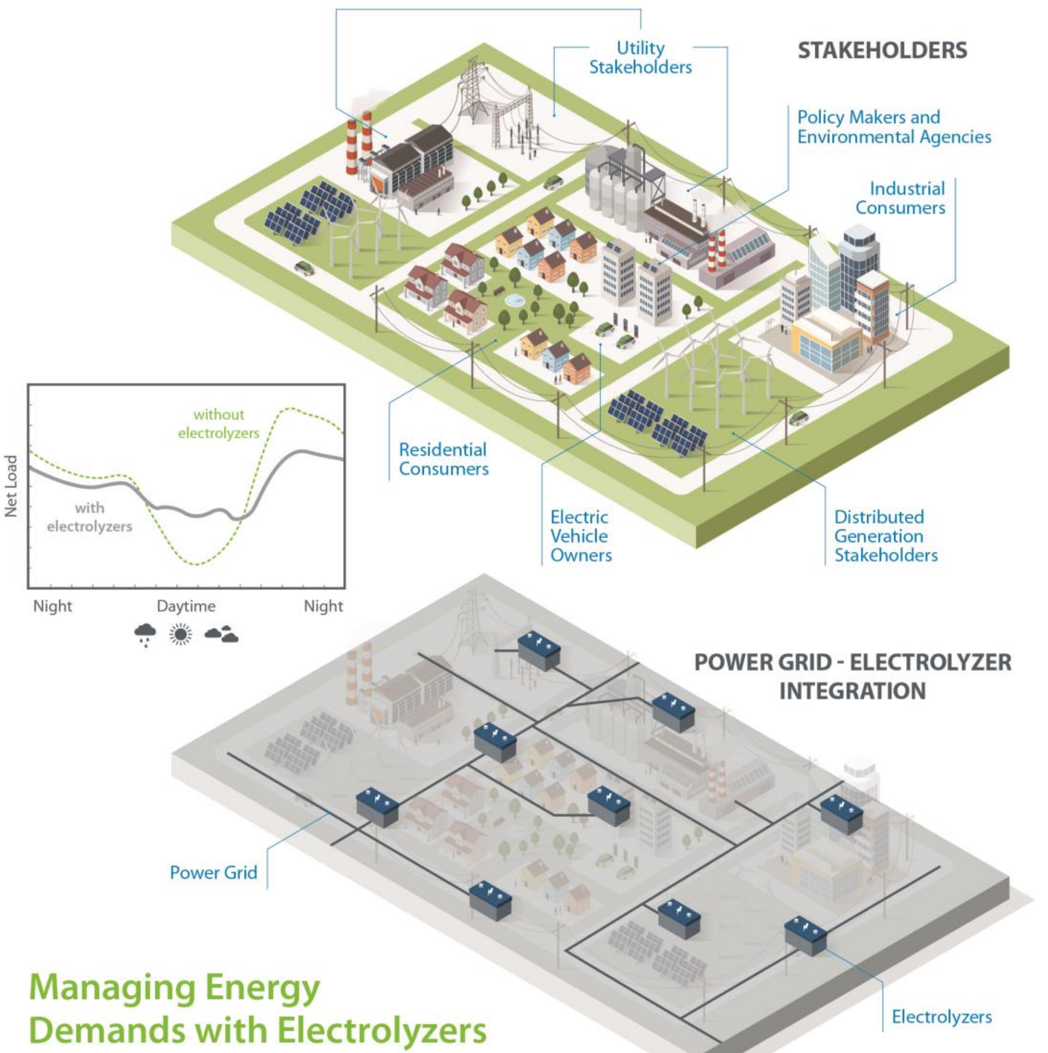
Potential Benefits of Electrolyzer Grid Integration

Reduce energy usage and emissions in end-use applications

- Petroleum displacement
- Chemical processes (metals refining, fertilizer production)
- Natural gas supplementation
- Combined heat and power with fuel cell systems

Improve grid performance, reliability, and resiliency

- Avoid curtailment of renewables
- Mitigate voltage/frequency disturbances



M. Koleva, K. Nagasawa, J. Kurtz, "California Hydrogen Integration Report," 2020

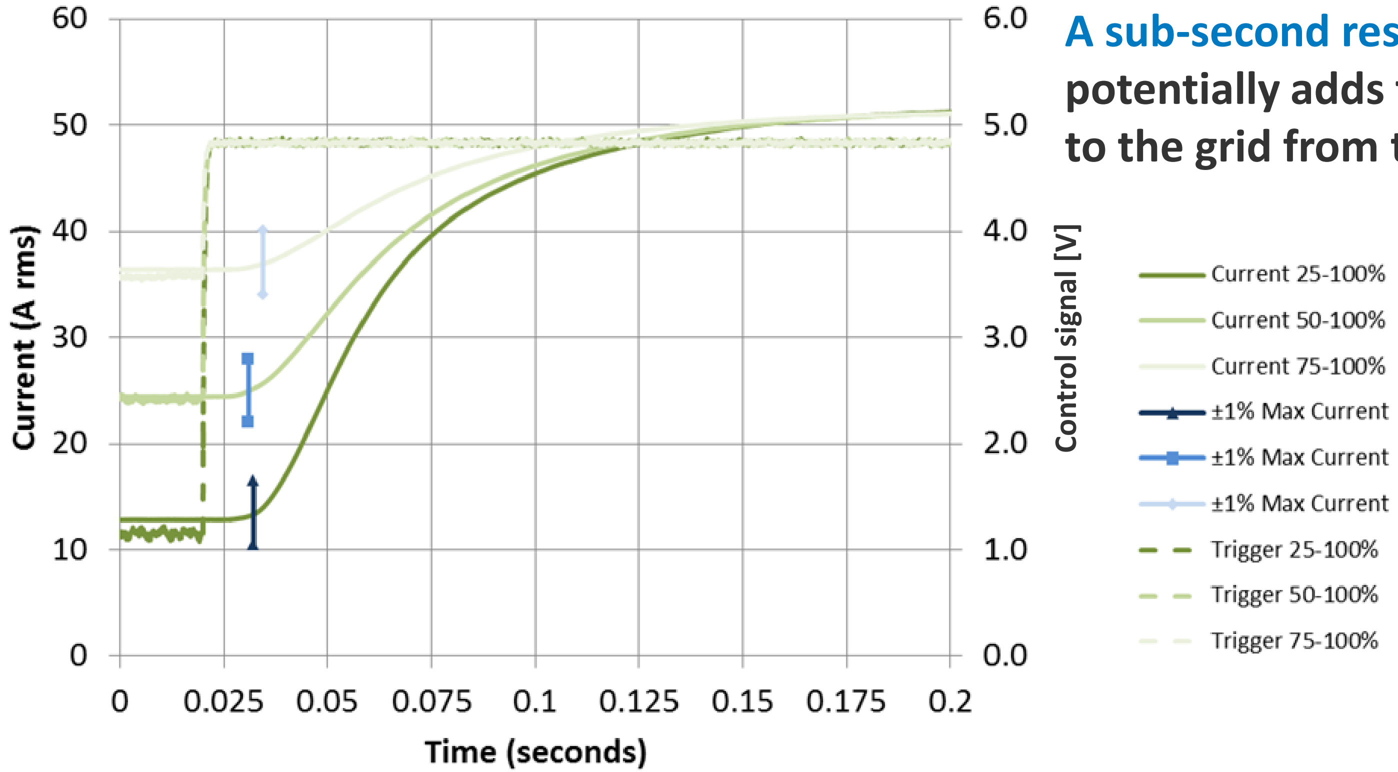
Electrolyzer Grid Integration R&D Timeline

	FY15–FY16	FY17	FY18	FY19	FY20
Objective	Identify highest potential integration opportunities and build HIL capabilities with remote control	Develop communication and controls and demonstrate fast-acting electrolyzer response			
Modeling	Utility distribution grid, electrolyzer characterization, economic potential	Front-end control			
Systems Analysis	Demand response, ancillary services, reverse power flow, grid fault transient dampening with electrolyzer	Frequency and voltage support with grid faults, refined economic analysis			
ESIF	120 kW PEM electrolyzer via RTDS, verified sub-second response, and validated communication INL-NREL	500 hours of electrolyzer operation, validated response time for grid faults, and characterized electrolyzer efficiency			

ESIF: Energy Systems Integration Facility

System-Level Response Time for the PEM Electrolyzer

PEM: Proton Exchange Membrane



A sub-second response time potentially adds flexibility and stability to the grid from the demand side.

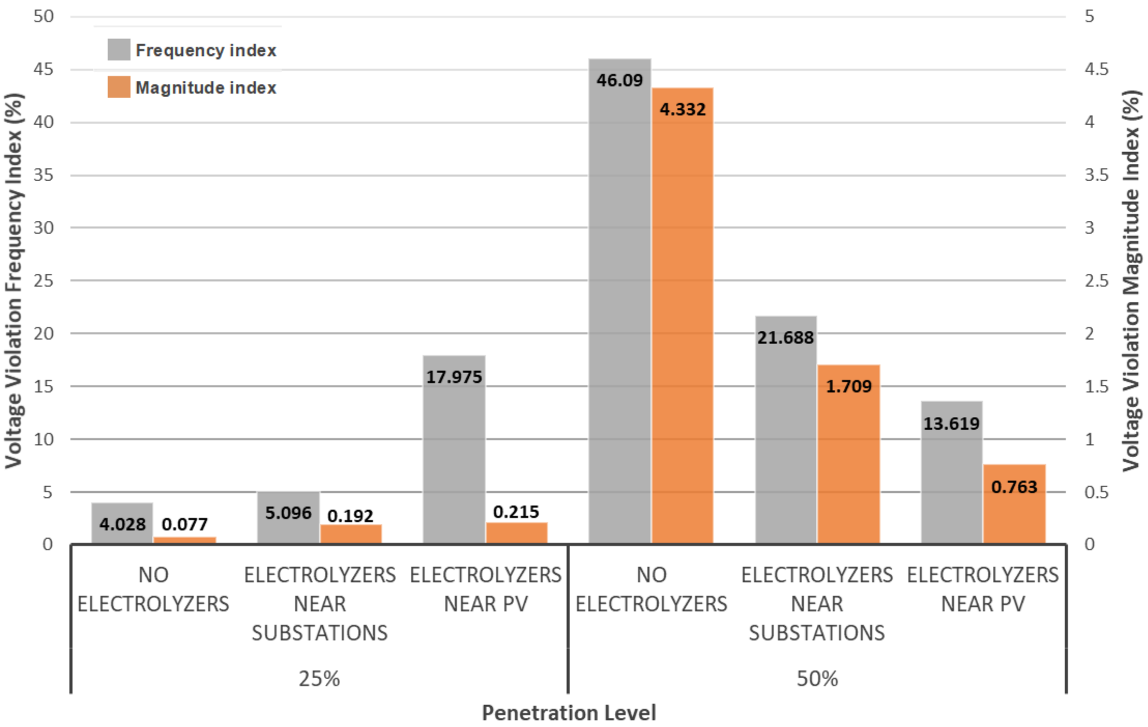
J. Eichman, K. Harrison, M. Peters, "Novel Electrolyzer Applications: Providing More Than Just Hydrogen," NREL Technical Report, 2014

Electrolyzer Grid Integration R&D Timeline

	FY15–FY16	FY17	FY18	FY19	FY20
Objective	Identify highest potential integration opportunities and build HIL capabilities with remote control	Develop communication and controls and demonstrate fast-acting electrolyzer response	Verify communication and controls with traditional grid and high renewable penetration	Validate grid modeling with renewables and nuclear and validate mitigated disturbances	
Modeling	Utility distribution grid, electrolyzer characterization, economic potential	Front-end control	Multiple distribution grid networks with renewables	Bulk and distribution grids with renewables, nuclear generation	
Systems Analysis	Demand response, ancillary services, reverse power flow, grid fault transient dampening with electrolyzer	Frequency and voltage support with grid faults, refined economic analysis	Different renewable penetrations, rate structures for electrolyzer production costs	Validated bulk and distribution models, improved hydrogen production model	
ESIF	120 kW PEM electrolyzer via RTDS, verified sub-second response, and validated communication INL-NREL	500 hours of electrolyzer operation, validated response time for grid faults, and characterized electrolyzer efficiency	225 kW PEM electrolzyer, operated with multiple PV production profiles, validated avoidance of curtailed renewable energy	Validated electrolyzer control with bulk and distribution grids, refined power set-point control	

ESIF: Energy Systems Integration Facility

Mitigated Voltage Disturbances in Count & Magnitude

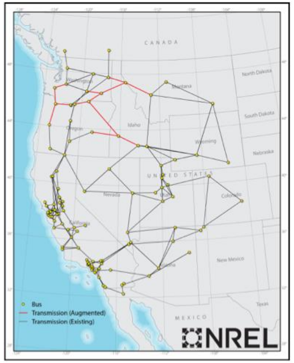


In the high renewable penetration scenario, locating electrolyzers near the renewable generation source mitigates voltage disturbances more effectively.

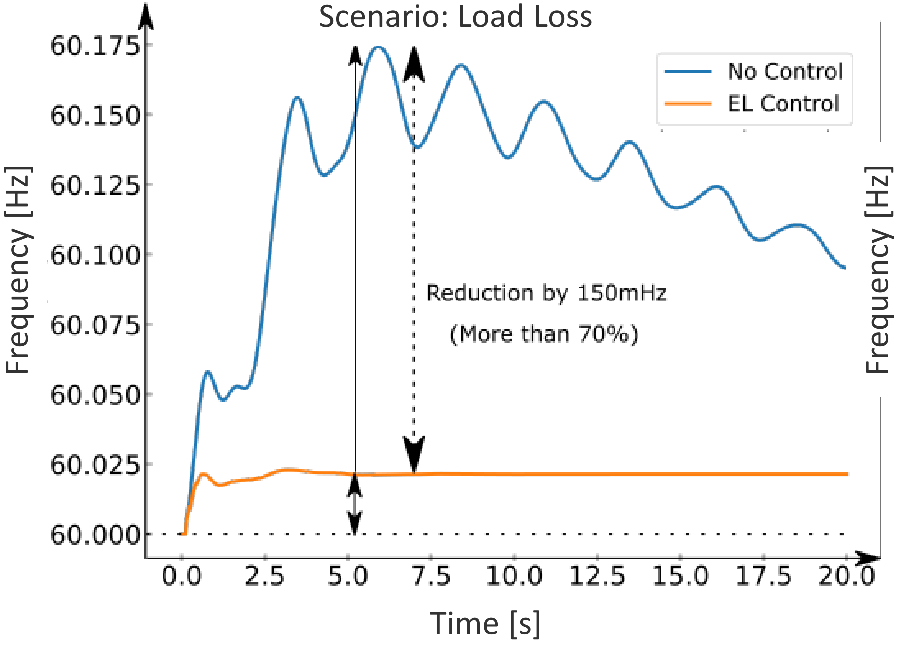
Electrolyzer location was not optimized.

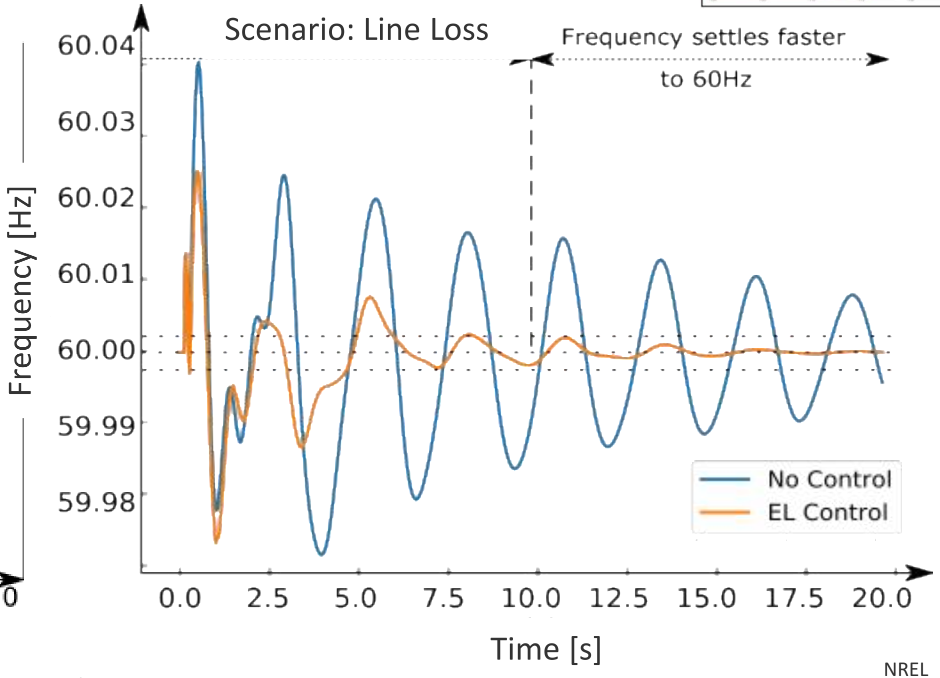
R. Jain, K. Nagasawa, S. Veda, J. Kurtz, Grid Ancillary Services using Electrolyzer based Power-to-Grid Systems with Increasing Renewable Penetration - Journal Manuscript under internal review

Impacts of Electrolyzers on the Bulk Grid



The electrolyzers dispersed on the bulk grid reduced frequency deviations, and the frequency settling time was about ~50% less compared to the case without the electrolyzer network.



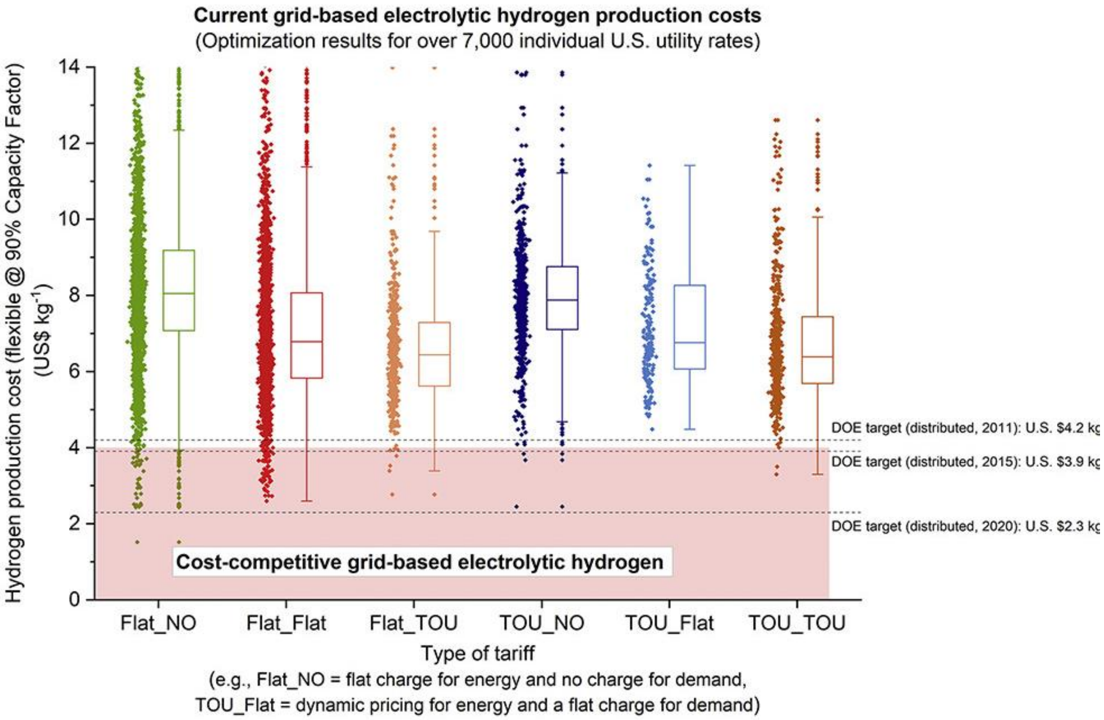


B. Guha, R. Jain, S. Veda, Bulk Grid Frequency Support Using Electrolyzers, IEEE IAS Annual Meeting, 2020

Hydrogen Production Costs

- **Some locations already have tariffs that would lower the cost of grid-integrated electrolysis today[1]**

- Other locations may inherently have lower electricity prices, however prices may be more *volatile*



[1]Omar J. Guerra, Joshua Eichman, Jennifer Kurtz, and Bri-Mathias Hodge. 2019. "Cost Competitiveness of Electrolytic Hydrogen." *Joule*, July. https://doi.org/10.1016/j.joule.2019.07.006.

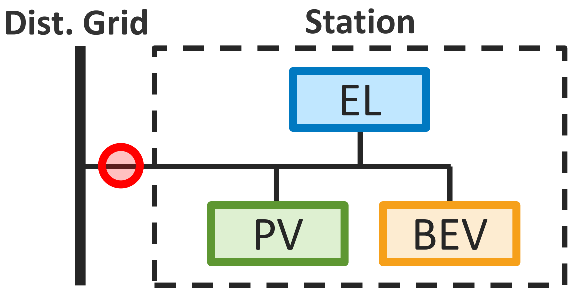
Electrolyzer Grid Integration R&D Timeline

	FY15–FY16	FY17	FY18	FY19	FY20
Objective	Identify highest potential integration opportunities and build HIL capabilities with remote control	Develop communication and controls and demonstrate fast-acting electrolyzer response	Verify communication and controls with traditional grid and high renewable penetration	Validate grid modeling with renewables and nuclear and validate mitigated disturbances	Evaluate the ability of electolyzers to stabilize integrated station power demands
Modeling	Utility distribution grid, electrolyzer characterization, economic potential	Front-end control	Multiple distribution grid networks with renewables	Bulk and distribution grids with renewables, nuclear generation	Integrated station with multiple demands (and renewables)
Systems Analysis	Demand response, ancillary services, reverse power flow, grid fault transient dampening with electrolyzer	Frequency and voltage support with grid faults, refined economic analysis	Different renewable penetrations, rate structures for electrolyzer production costs	Validated bulk and distribution models, improved hydrogen production model	Geographical effects on economic trade-offs for demand and energy charges
ESIF	120 kW PEM electrolyzer via RTDS, verified sub-second response, and validated communication INL-NREL	500 hours of electrolyzer operation, validated response time for grid faults, and characterized electrolyzer efficiency	225 kW PEM electrolzyer, operated with multiple PV production profiles, validated avoidance of curtailed renewable energy	Validated electrolyzer control with bulk and distribution grids, refined power set-point control	750 kW PEM electrolyzer*, integrated station control

ESIF: Energy Systems Integration Facility

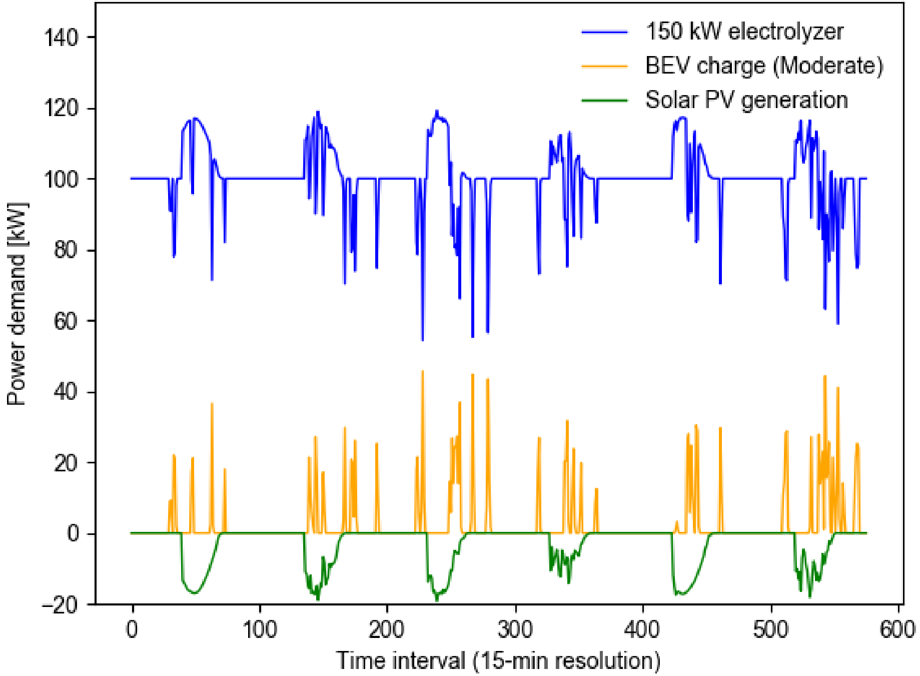
* To be confirmed with the electrolyzer industry partner

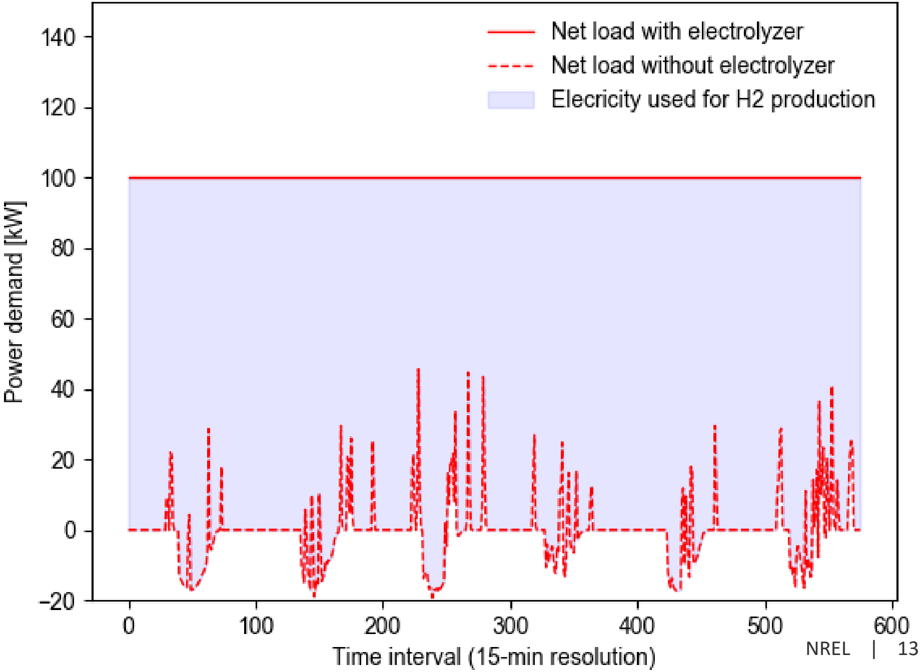
Effect of Electrolzyer Control on Net Load

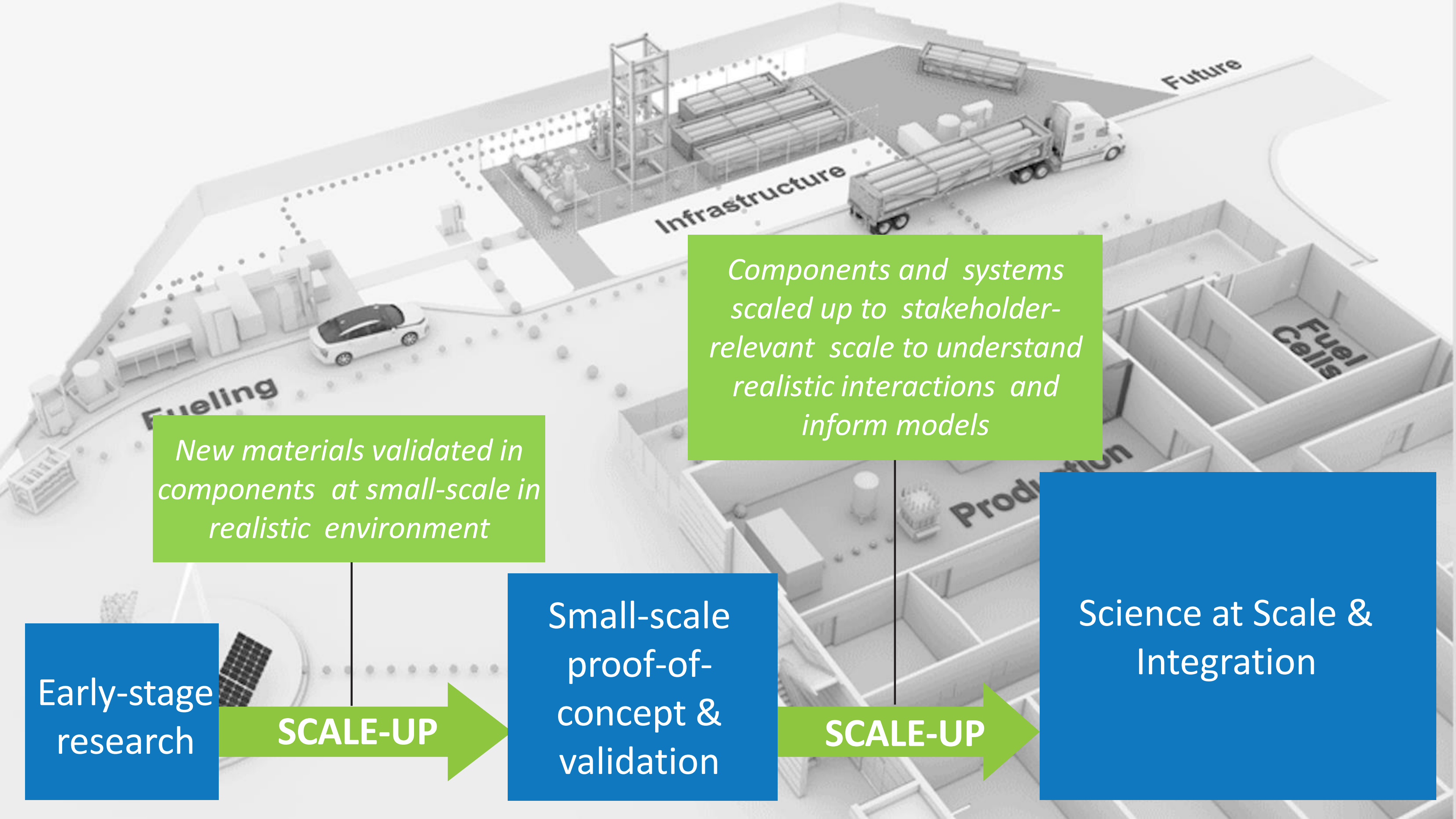


The integrated station with the electrolyzer stabilizes demand fluctuations while producing valuable hydrogen, and the utility just sees the constant power demand.

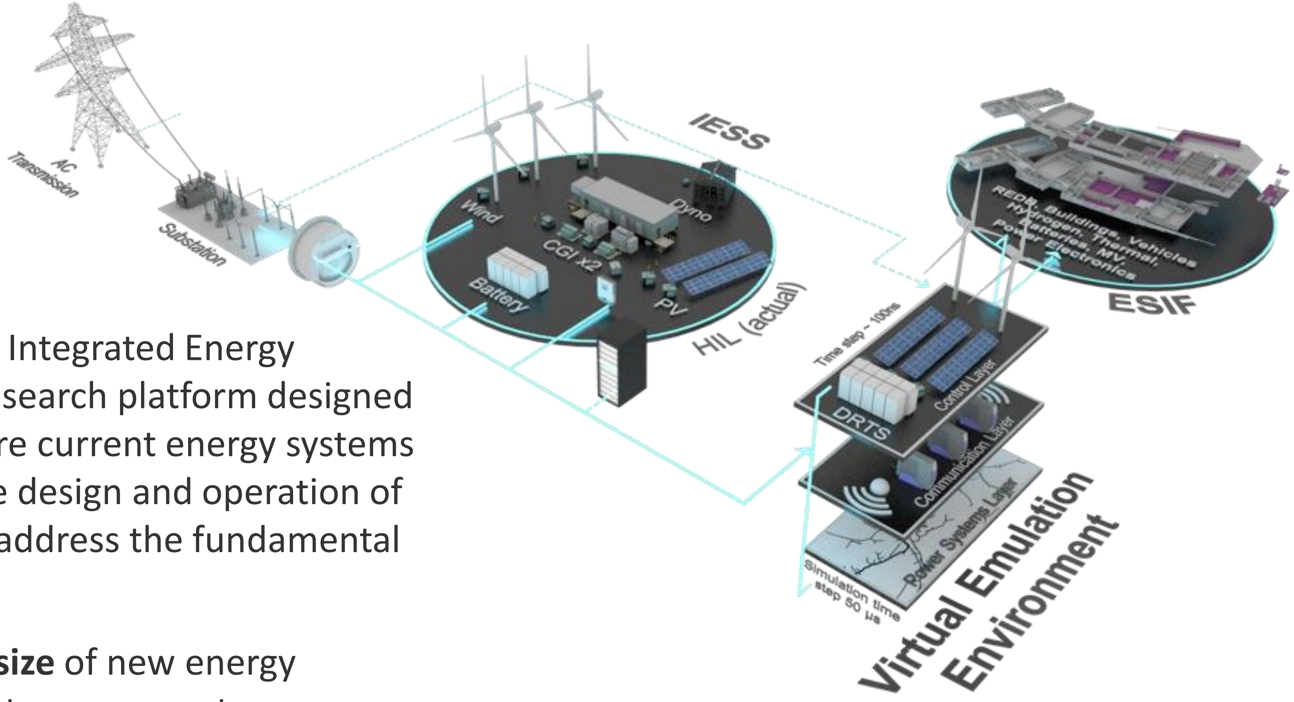
Simplified scenario; Electrolyzer size and operation were not optimized.






Future
Infrastructure
Fueling
Fuel Cells
Components and systems scaled up to stakeholder-relevant scale to understand realistic interactions and inform models
New materials validated in components at small-scale in realistic environment
Early-stage research
SCALE-UP
Small-scale proof-of-concept & validation
SCALE-UP
Science at Scale & Integration

ARIES

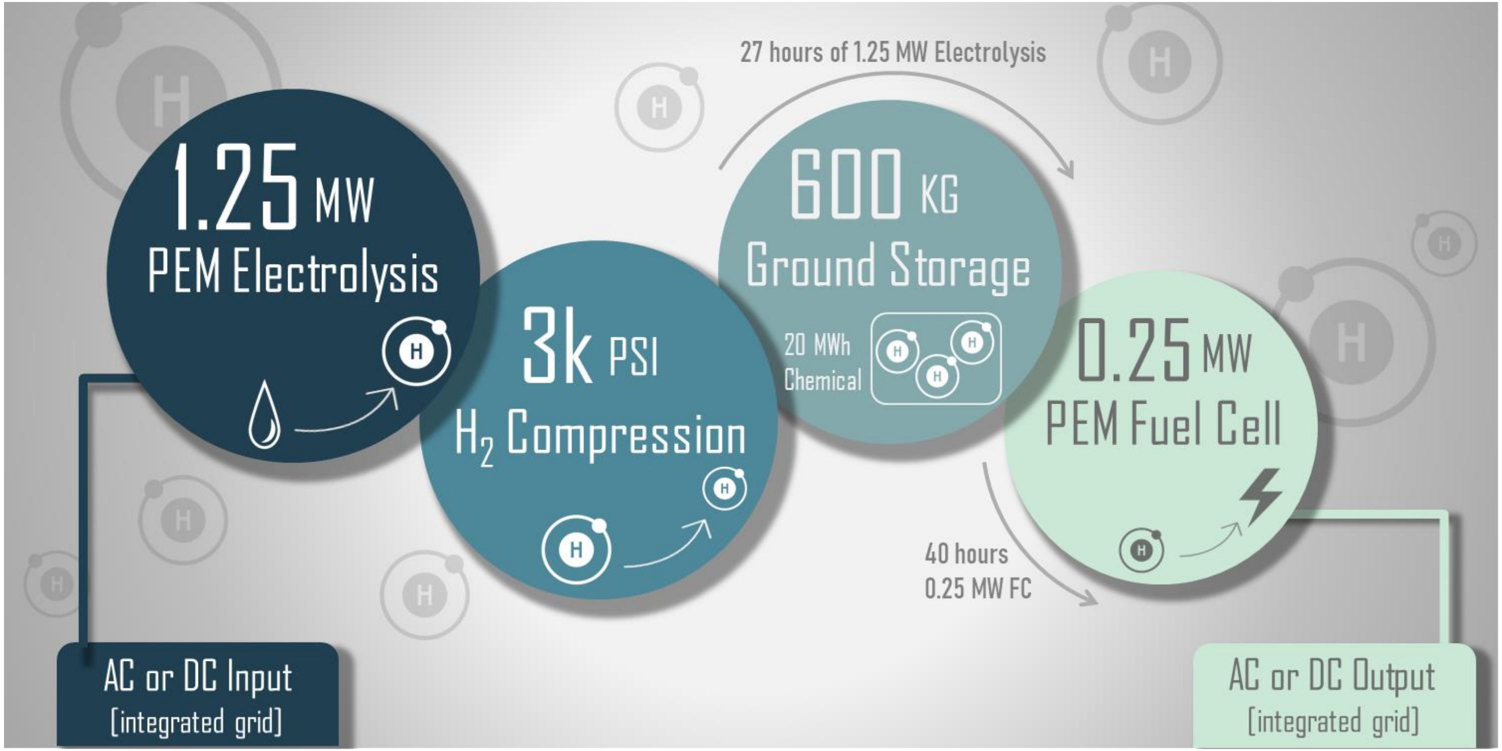


NREL's Advanced Research on Integrated Energy Systems (ARIES) is a unique research platform designed to de-risk, optimize, and secure current energy systems and to provide insight into the design and operation of future energy systems. It will address the fundamental challenges of:

- Variability in the **physical size** of new energy technologies being added to energy systems
- Controlling **large numbers** (millions to tens of millions) of interconnected devices
- Integrating **multiple diverse technologies** that have not previously worked together

One Research Platform
Developing and Using Assets at ESIF, IESS, and Virtual Emulation Environment and Remote Connections

In-Progress Capability Expansion



Key hydrogen system components and associated capacities that will be procured and implemented at NREL's Flatirons Campus as part of the ARIES.

Our goal is to improve the economic viability of transforming, transporting, and storing hydrogen technologies in conjunction with key government and industry partners who will accelerate their adoption.

Hydrogen End-Use

NREL Hydrogen Research Presentation

Connecting renewables & mobility

Renewables

Curtailed renewable electricity

Production

Hydrogen production via electrolysis

Distribution

Hydrogen storage & distribution via liquid, truck, pipeline

Fueling

Hydrogen fueling cars, trucks, buses, and forklifts

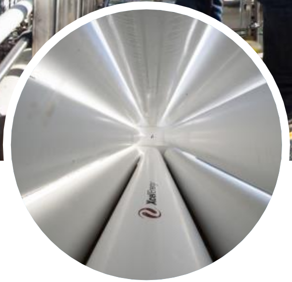
Mobility

Zero emission mobility for people and goods

Hydrogen Safety R&D

Integration

Integrate safety research into codes and standards



Components

Study component performance and failures from the field and in the lab

Sensors

Verify, validate, and develop prototype sensors with high accuracy and low cost

Monitoring

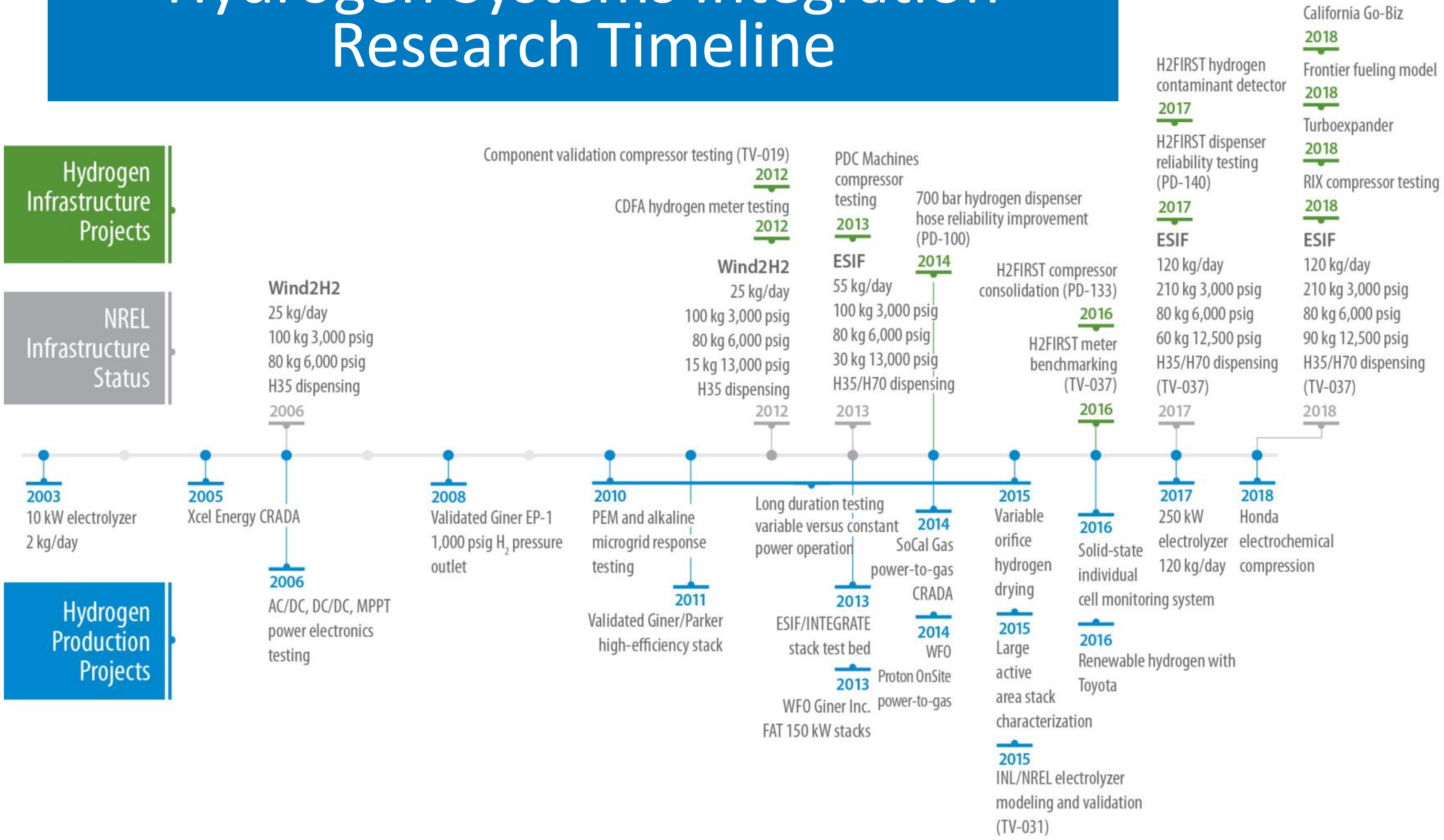
Study requirements for safe operation, handling, and use of hydrogen

Outreach

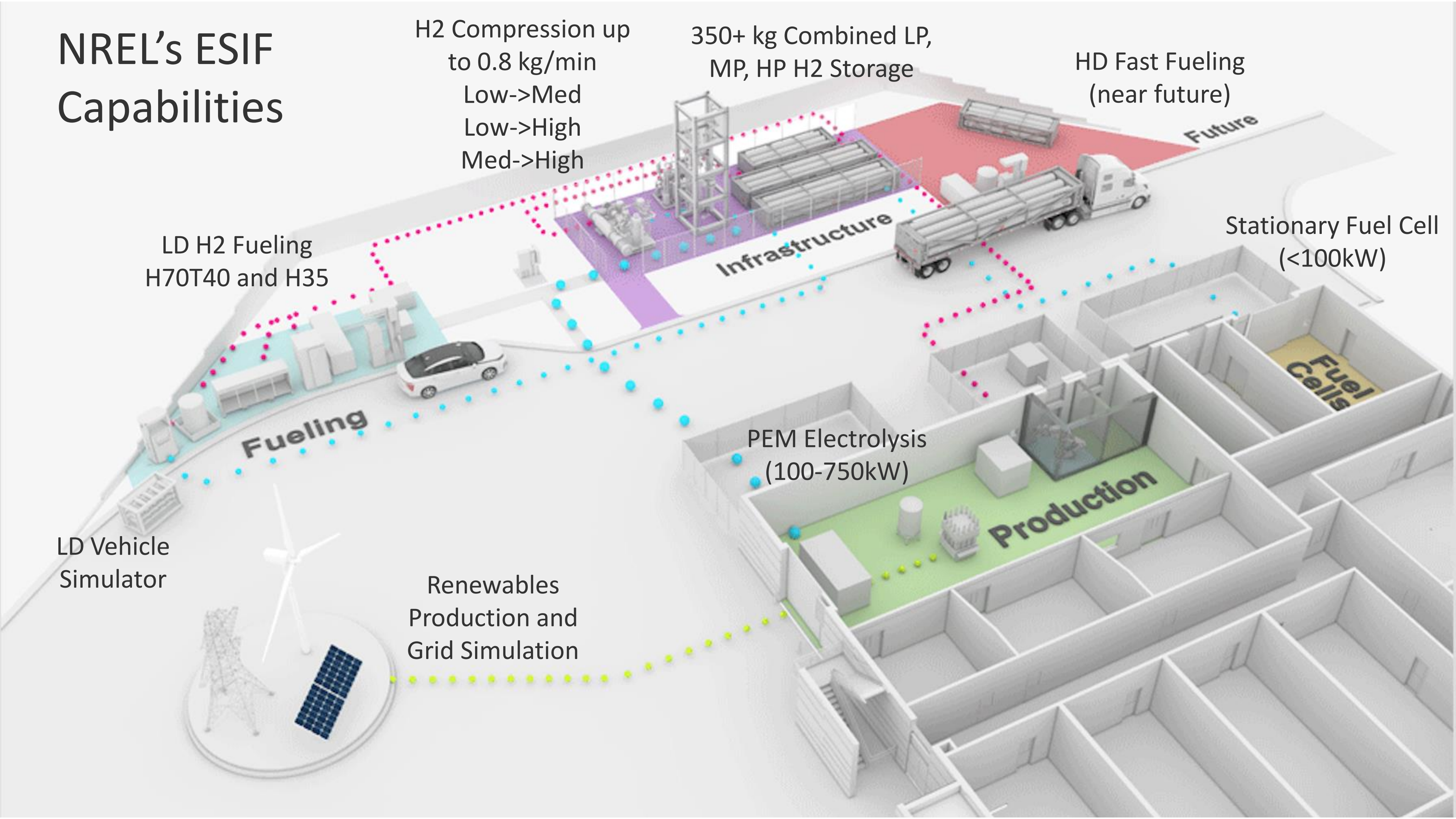
Connect users to safety requirements to advance safe deployment

Images: NREL

Hydrogen Systems Integration Research Timeline

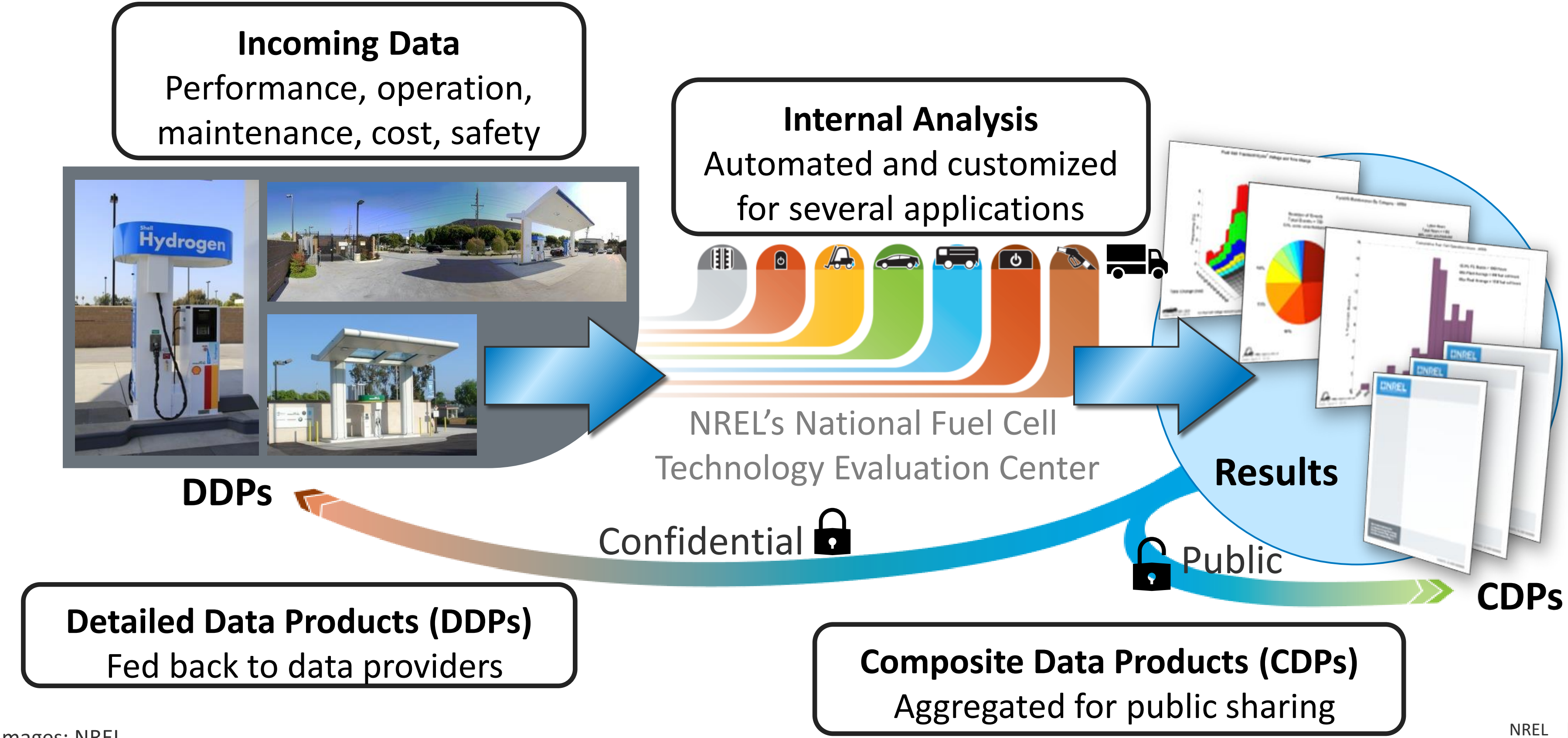


NREL's ESIF Capabilities



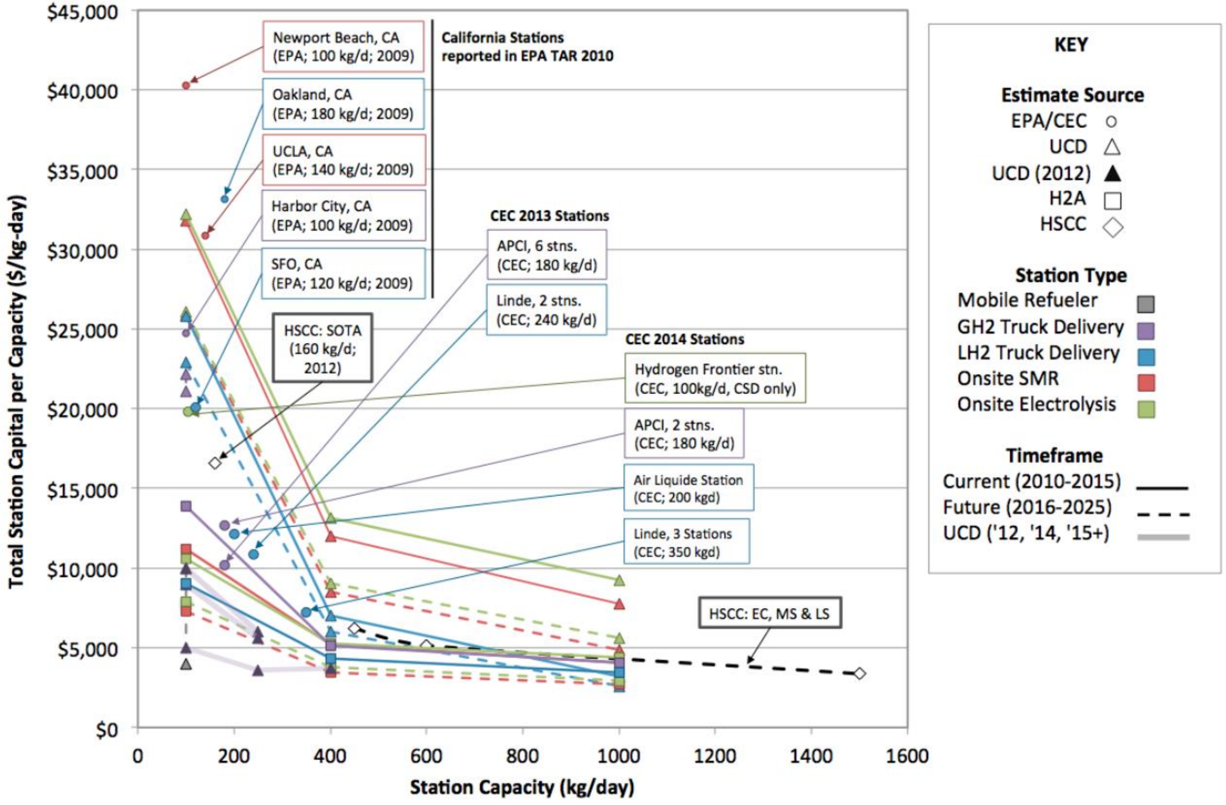
Hydrogen Systems
Experimental Capabilities

NFCTEC Data, Analysis, and Results Sharing



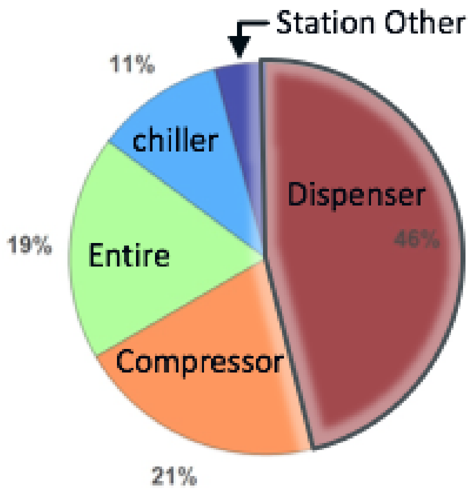
Images: NREL

Capital Cost - H2 Retail Stations



- Progress – 2009 100 kg/day stations >$20,000 kg/day
- <$3,000/kg for 1,000 kg/day station = $3 million

Benchmarking Dispenser Reliability

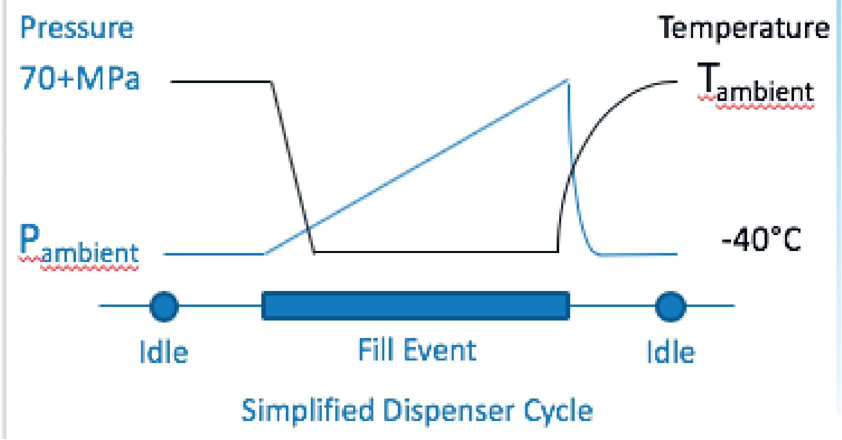


Maintenance by Equipment Type
Retail Stations
Total Events: 4,663
Dispenser: 46% of Events

NREL cdpRETAIL_infr_21

Major Dispenser Components:

Breakaway
Hose
Nozzle
Block/Bleed Valves
Filters

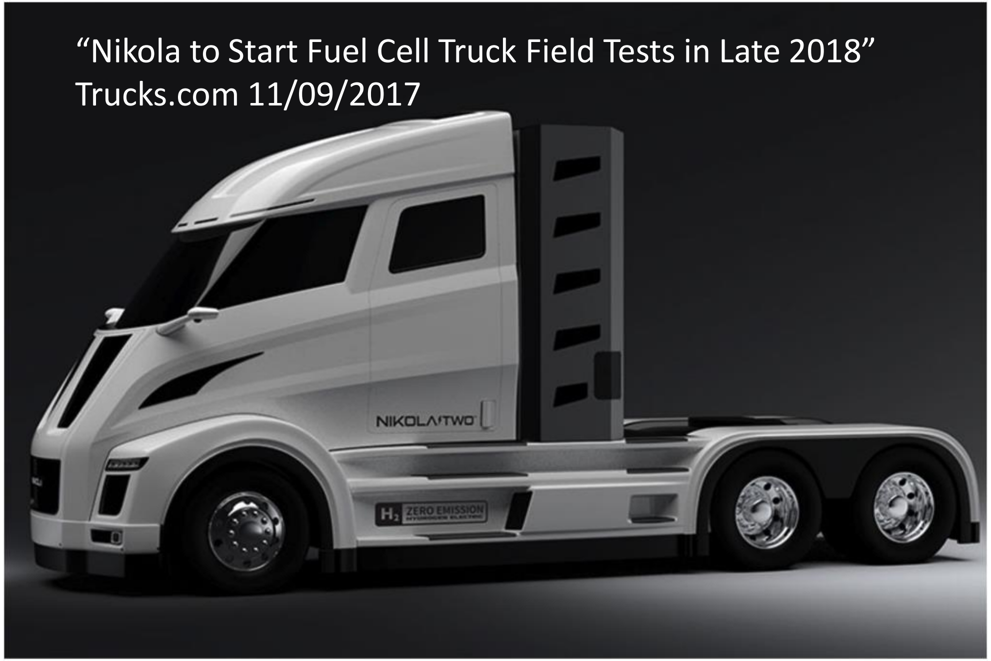


Hydrogen Infrastructure Research Projects

- Dispenser reliability: Improving low-temperature (-40) operation and components for pre-cooled fueling of FCEVs (DR)
- Medium- and heavy-duty fueling
- Fueling dispenser hose reliability validation
- Pressure relief device (PRD) validation
- "Reference Station" analysis and dissemination
- Storage "consolidation" validation at station
- Hydrogen compressor validation and reliability improvements
- Novel hydrogen pre-cooling through turbo-expander

Fuel Cell Bus & Heavy Duty

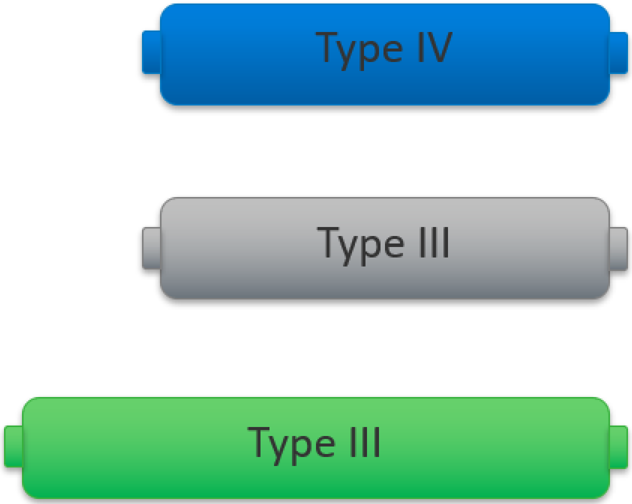
Toyota's Project Portal hydrogen fuel cell Class 8 truck. (Photo: Toyota)

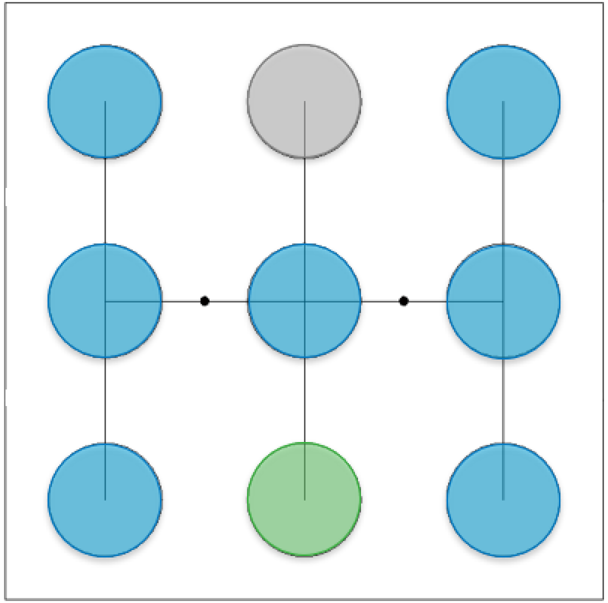


Nikola Two electric fuel cell truck. (Photo: Nikola Motor)

- Target market for FCEV technology
- Range, performance, and efficiency

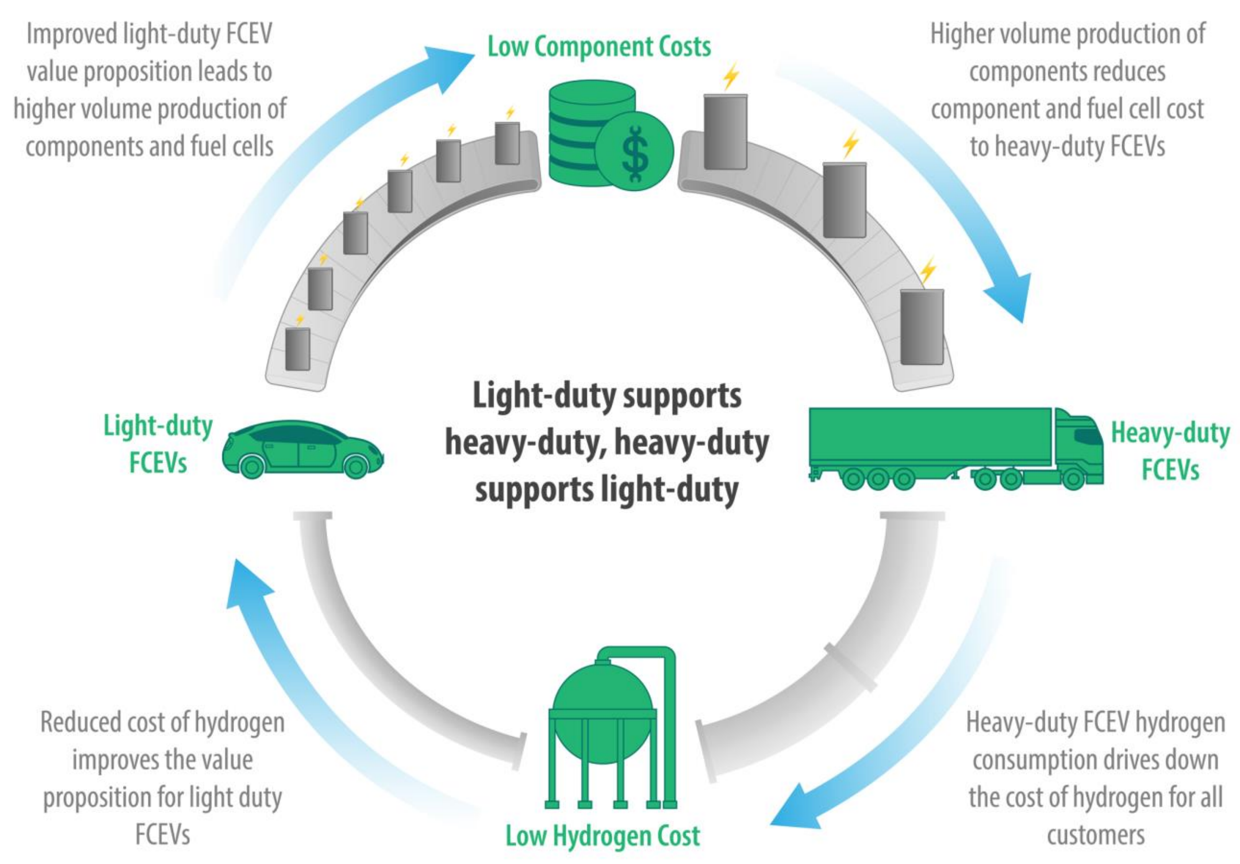
Heavy-duty Hardware Testing





- 60 kg+ fills at an average flow rate of 10 kg/min, 70 MPa, -40°C pre-cooling
- Provides validation data for transient 3D CFD modeling
- Type IV is current standard, Type III for “warmer” fills

The Mutually Beneficial Relationship with Light-Duty and Heavy-Duty FCEVs



2020 Fuel Cell Seminar

Hydrogen Blending

- Started discussions with a small industry group with monthly meetings to discuss potential research topic areas ~October 2019

- Effort spearheaded by Stony Brook University, Southern Company, and NREL

Hydrogen Blending

- Near the end of 2019 the group informed DOE of momentum building in the blending research space

- DOE began active participation in group updates and brought in other national laboratories to compliment core capabilities of NREL

Laboratory Core Competencies

ANL

Life Cycle Analysis

PNNL

Polymeric Material Testing

NREL

Technoeconomic Analysis Project Lead

SNL

Metallic Material Testing

ORNL

Building Appliances

Blending Webinar

Part 1

- Introduction – DOE
- Overview of Activities & Value Proposition of Blending – NREL
- Materials Compatibility Considerations of Blending – SNL/PNNL
- Case Study on Life Cycle Analysis of Hydrogen Use Using GREET Model – ANL

Part 2

- Gas and Electric Utility Transformation with Hydrogen – National Grid U.S.
- Hydrogen Blending and Generation Programs – GTI
- The Impact of H2 on Gas Turbine and Associated Power Plant Systems – GE Gas Power
- Hydrogen Pipeline Infrastructure – Praxair/Linde
- Hydrogen Blending: Gaps, Opportunities, and Fueling the Future – Southern Company

Link: https://register.gotowebinar.com/recording/7618332856547865867

Ranking Exercise

Instructions

- Leverage research interest's activity and discussion over webinar to compile a list of 10 – 15 research ideas
- Create pairwise comparison table and send to group
- Submit results back to NREL

Pairwise Comparison Example

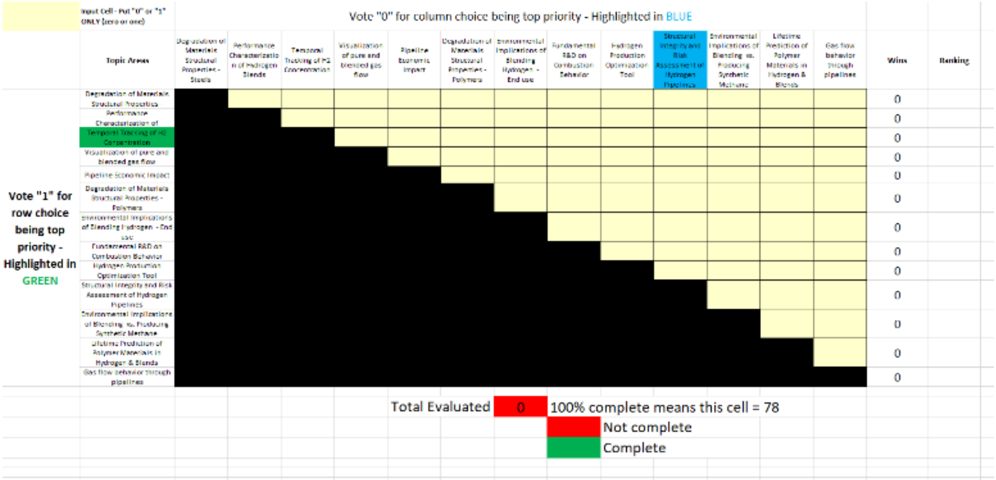
Mark "1" for this topic more important than Row topic

Mark "0" for this topic more important than Column topic

	Research Topic 1	Research Topic 2	Research Topic 3	Research Topic 4	Research Topic 5	Research Topic 6	Research Topic 7	Research Topic 8	Research Topic 9	Research Topic 10
Research Topic 1		0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
Research Topic 2			0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
Research Topic 3				0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
Research Topic 4					0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
Research Topic 5						0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
Research Topic 6							0 or 1	0 or 1	0 or 1	0 or 1
Research Topic 7								0 or 1	0 or 1	0 or 1
Research Topic 8									0 or 1	0 or 1
Research Topic 9										0 or 1
Research Topic 10										
Rank score	***0 - 100%***	***0 - 100%***	***0 - 100%***	***0 - 100%***	***0 - 100%***	***0 - 100%***	***0 - 100%***	***0 - 100%***	***0 - 100%***	***0 - 100%***

Ranking Exercise

- Randomized the order the topic areas were arranged
- Received 19 individual responses from 14 different companies*



ID	Topic	Title
Research Topic 1	Materials - Metal	Degradation of Materials Structural Properties - Steels
Research Topic 2	End-Use	Performance Characterization of Hydrogen Blends
Research Topic 3	System Integration	Temporal Tracking of H2 Concentration
Research Topic 4	Virtual Visualization	Visualization of pure and blended gas flow
Research Topic 5	Techno-economic analysis	Pipeline Economic Impact
Research Topic 6	Materials - Polymer	Degradation of Materials Structural Properties - Polymers
Research Topic 7	Environmental Life Cycle Analysis	Environmental Implications of Blending Hydrogen - End use
Research Topic 8	End-Use	Fundamental R&D on Combustion Behavior
Research Topic 9	Techno-economic analysis	Hydrogen Production Optimization Tool
Research Topic 10	Materials - Metal	Structural Integrity and Risk Assessment of Hydrogen Pipelines
Research Topic 11	Environmental Life Cycle Analysis	Environmental Implications of Blending vs. Producing Synthetic Methane
Research Topic 12	Materials - Polymer	Lifetime Prediction of Polymer Materials in Hydrogen & Blends
Research Topic 13	Gas Flow through Pipelines	Gas flow behavior through pipelines

Industry only – national laboratory and DOE responses were not counted towards these results

Ranking Exercise

- Top 4 responses were related to materials compatibility:
  - Metals/steel top 2
  - Polymers 3rd and 4th rank
- Economic impact, performance characterizations on end-use equipment, and environmental impacts rounded out 5th – 8th spots on the ranking list

Title	Rank
Structural Integrity and Risk Assessment of Hydrogen Pipelines	1
Degradation of Materials Structural Properties - Steels	2
Lifetime Prediction of Polymer Materials in Hydrogen & Blends	3
Degradation of Materials Structural Properties - Polymers	4
Pipeline Economic Impact	5
Performance Characterization of Hydrogen Blends	6
Environmental Implications of Blending Hydrogen - End use	7
Environmental Implications of Blending vs. Producing Synthetic Methane	8
Temporal Tracking of H2 Concentration	9
Visualization of pure and blended gas flow	10
Fundamental R&D on Combustion Behavior	11
Gas flow behavior through pipelines	12
Hydrogen Production Optimization Tool	13

DOE Releases a CRADA Call

Two topic areas:

- Hydrogen blending and medium- and heavy-duty FC vehicles

Details of HyBlend

- \$5 - \$7M/year available from DOE
- Working with the core national laboratory team on a single cohesive proposal
- Gaining lots of interest in this space!

Dispensing, compression and storage, safety, control/operational strategies, production and delivery, outreach

Thank you

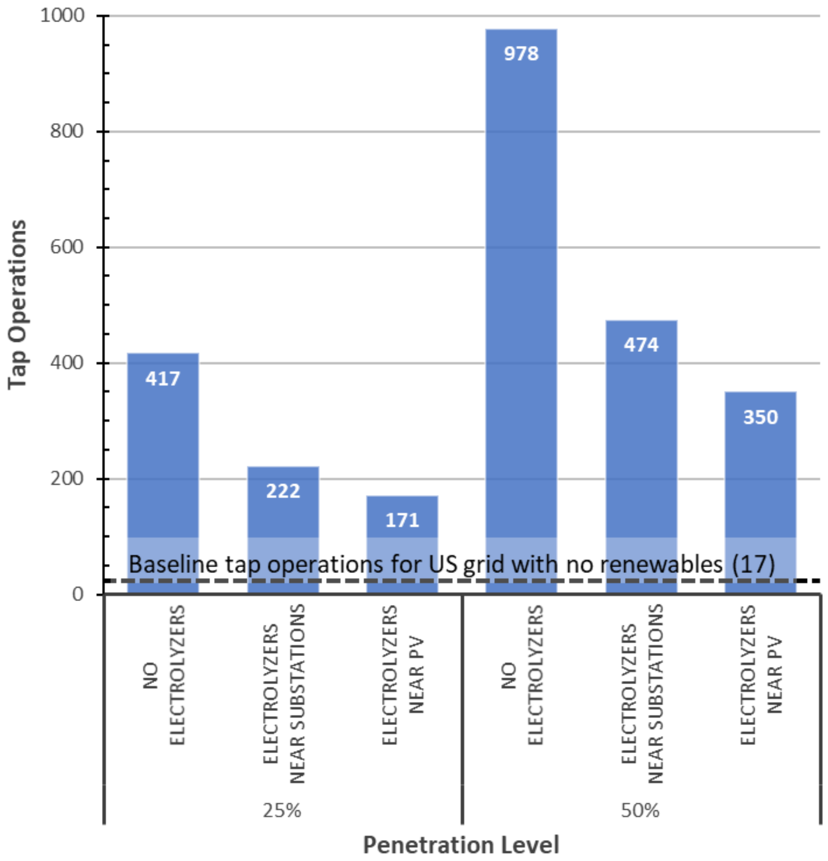
www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NATIONAL RENEWABLE ENERGY LABORATORY

Backup

Reduced Tap Operations



Adding electrolyzers on the grid helps reduce wear and tear of tap changers and cost burdens of maintaining grid reliability.

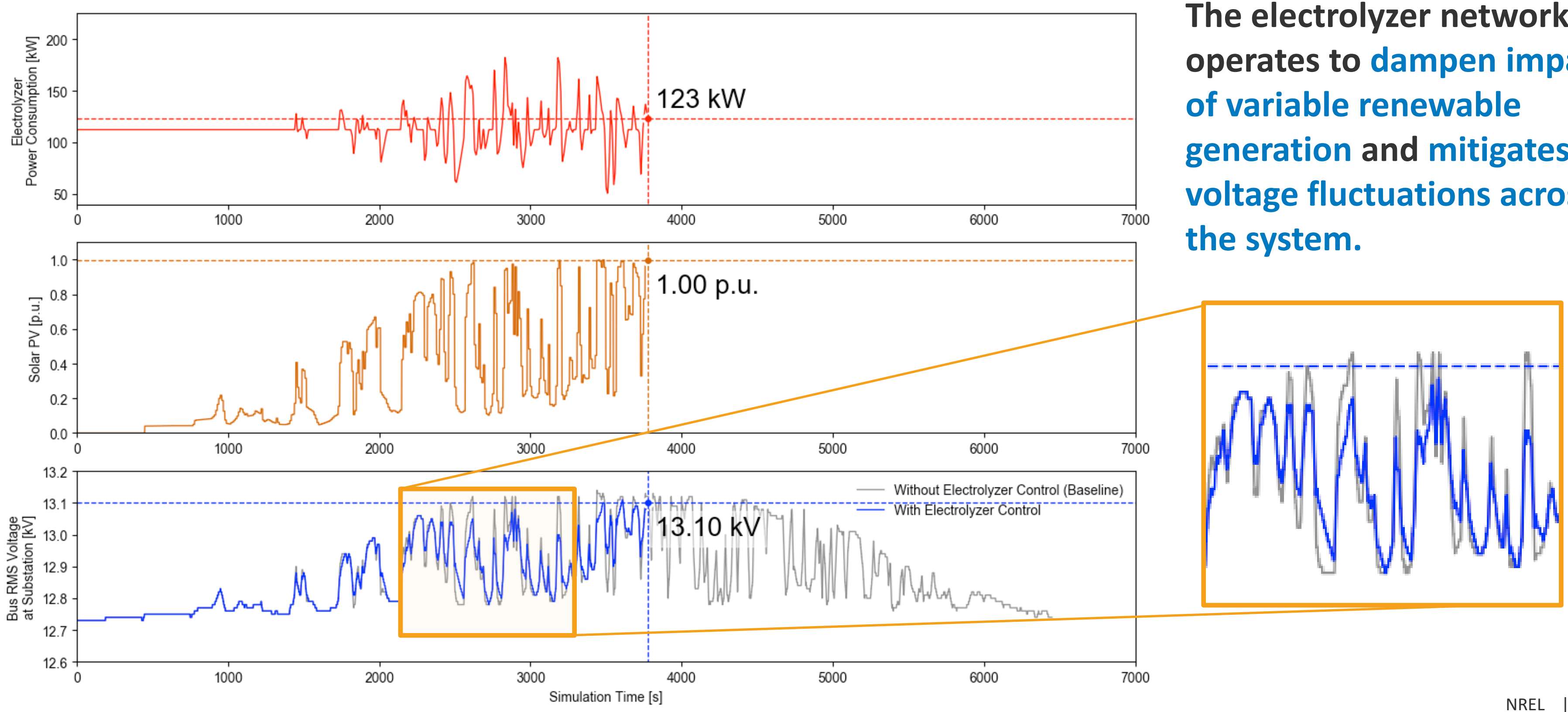
Renewable penetration levels

- 25%
- 50%

Electrolzyer deployment scenarios

- No electrolyzers
- Electrolyzers near substations
- Electrolyzers near PV

Effects of Variable Renewables on Electrolyzer Operation



The electrolyzer network operates to dampen impacts of variable renewable generation and mitigates voltage fluctuations across the system.

Distribution Grid Application

DER: Distributed Energy Resource

High-level summary; Not captures all aspects.

Objectives

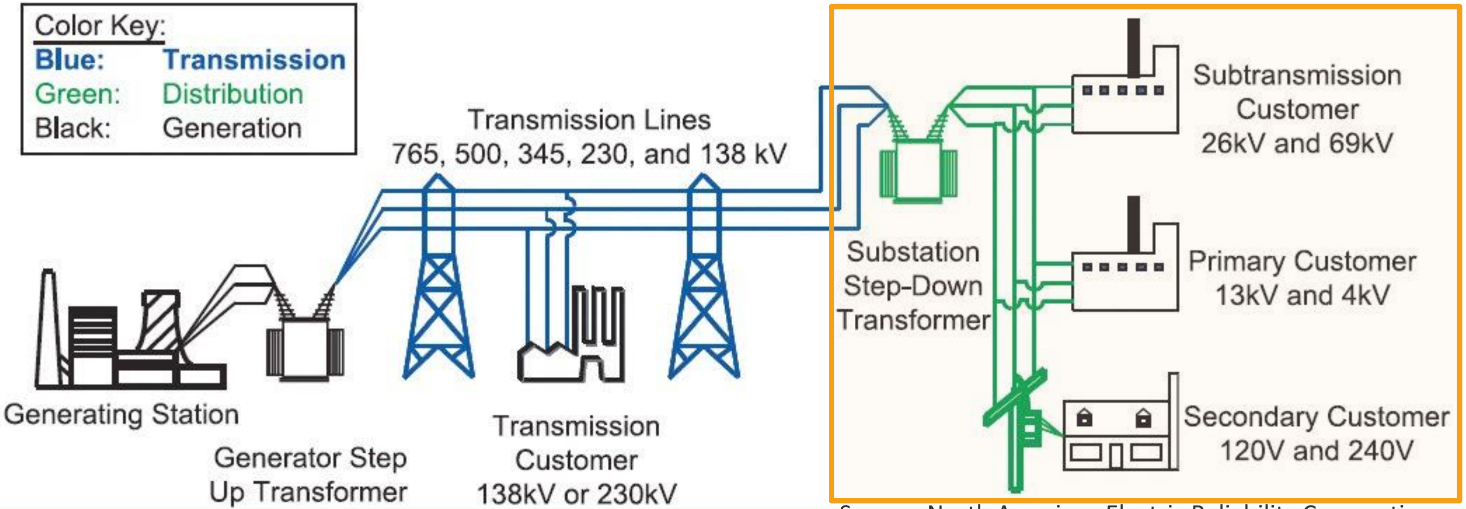
Maintain power quality

- Voltage regulation
- DER integration

Approaches

Regulate voltage and/or power ramps

- Tap changers (traditional)
- Network of electrolyzers



Source: North American Electric Reliability Corporation

Transmission Grid Application

High-level summary; Not captures all aspects.

Objectives

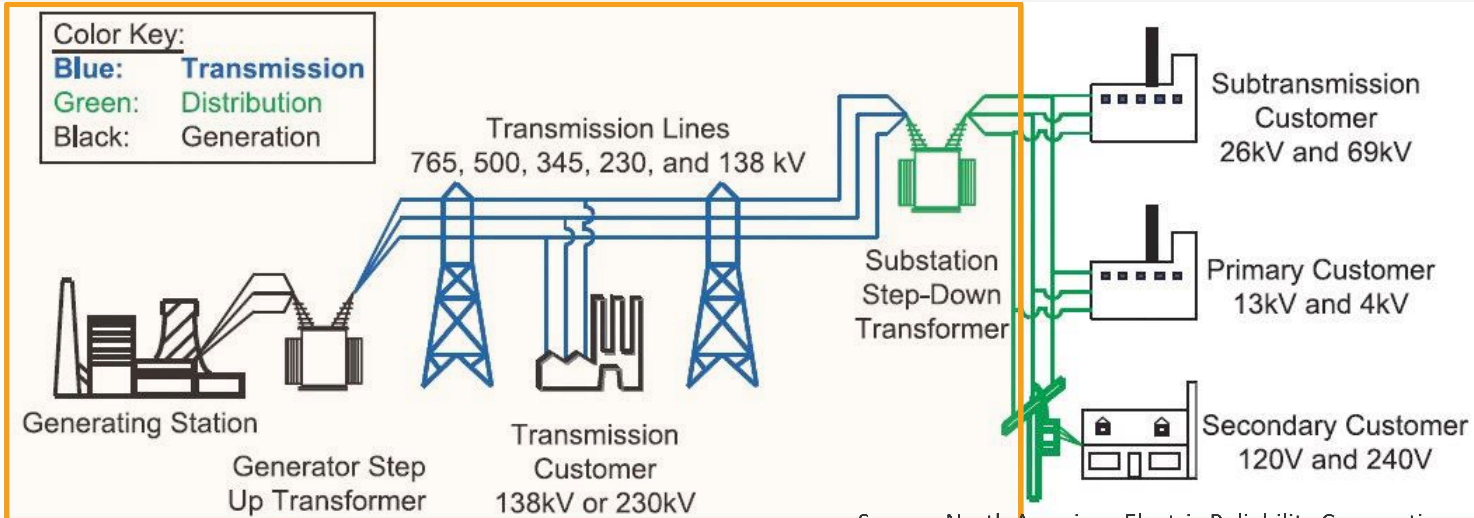
Maintain system balancing

- Frequency regulation
- System inertia support

Approaches

Regulate equipment power exchange

- Generation reserves (traditional)
- Network of electrolyzers



Source: North American Electric Reliability Corporation

Verifying Electrolyzer Value

Modeling

- Grid with traditional and renewable generation
- Electrolyzers
- Hydrogen infrastructure
- Demand

Experiments

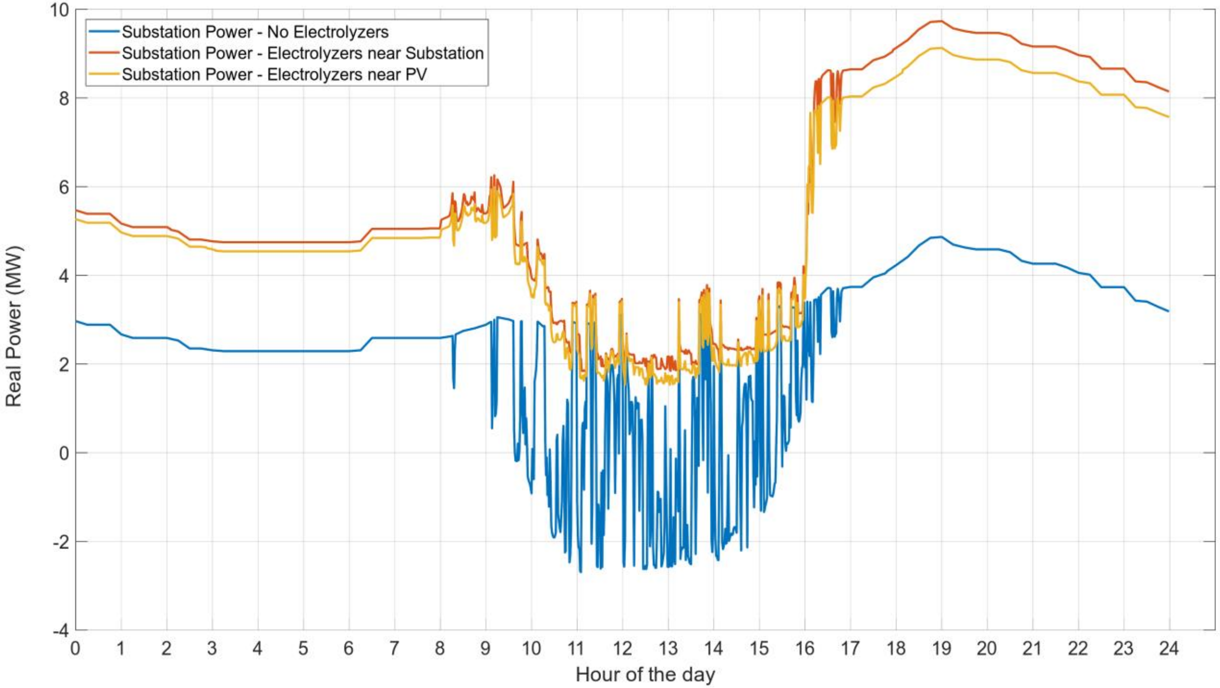
- Dynamic control
- Validate performance
- Evaluate use case scenarios

Analysis

- System characterization
- Optimization for cost, hydrogen production, services
- Iterations
- Markets

Electrolyzers avoid curtailed renewable generation with hydrogen production

Electrolyzers are operated at nearly steady state until PV generation, then the electrolyzer network operates during PV transients to dampen impacts of variable generation on a distribution feeder, utilize what would have been curtailed PV generation, and produce high-value hydrogen.



Ranking Exercise – Topic Descriptions

Topic 1 - Degradation of Materials Structural Properties – Steels

Description:

The basic structural properties of pipeline steels in gaseous hydrogen are well documented in the literature. Trends of properties with pressure have been established for a diverse range of loading conditions. This task will draw from the structural integrity activity to identify gaps in the available mechanical property database for transmission and distribution gas delivery systems (e.g., are their fatigue regimes that have not been adequately characterized, based on anticipated operational windows?). Additionally, this task will critically assess the role of gas impurities in blended H2/NG mixtures in controlled laboratory environments using input from the structural integrity task.

Topic 2 - Performance Characterization of Hydrogen Blends

Description

In this task, the team will conduct testing of building equipment to characterize the impact of hydrogen blends up to 15% on the performance, including:

a. flame stability and efficiency,

b. start-up leakage,

c. condensation impact on flue gas management, including acidity and equipment secondary heat exchanger performance under dry and wet conditions.

Ranking Exercise – Topic Descriptions

Topic 3 – Temporal Tracking of H2 Concentration

Description:

In this task, the team would obtain natural gas pipeline network layout and flows to complete hypothetical blending point simulations. The simulations would include hydrogen injection from renewable energy sources by combining electrolyzer operation profiles with regional PV or Wind sources. The team would perform a time impact of hydrogen concentrations to different nodes on the network. Results would bring about further understanding of the materials of construction needed for local pipelines by answering questions around varying H2 partial pressure, number of cycles, and other technical challenges that will adversely effect pipeline lifetime.

Topic 4 - Visualization of pure and blended gas flow

Description

Real-time advanced visualization of gas flow through a pipeline could provide early-warning gas management in a pipeline. We will specifically collect preliminary kinetic and material integrity data and develop machine learning and visualization tools for real-time monitoring and operations management of blended as well as pure hydrogen transport by using a cutting-edge, large-scale Strategic Machine-learning Acceleration and Ray Tracing (SMART) Cluster and world-class visualization facilities, such as the Reality Deck 2.0 (RD) and the Silo. This aspect will represent hydrogen transport in Artificial Intelligence (AI) controlled repurposed existing natural pipelines to safely move hydrogen while maintaining materials integrity. The complete data integration, modeling and visualization system for integration with a six-foot gas injection pipe fitted with pressure/temperature/flow measuring devices is being built at Stony Brook.

Ranking Exercise – Topic Descriptions

Topic 5 – Pipeline Economic Impact

Description:

In this task, the team would compare the economics of current natural gas pipelines (i.e., no H2 injection) versus different injection levels of hydrogen. The analysis would look at the economic impact of hydrogen blending on pipeline lifetime, differences in maintenance costs, having to change or upgrade sensors, and any changes to the pigging process or hardware. In addition, the task would look at the replacement strategy of current pipelines from an economic point of view.

Topic 6 - Degradation of Materials Structural Properties – Polymers

Description

The basic structural properties of distribution pipelines in gaseous natural gas are well documented in the literature, but there is limited data for hydrogen or hydrogen/NG blends on welds and other polymers, such as seals and gaskets. This task will identify gaps in the available mechanical property database for polymer distribution gas delivery systems. Additionally, this task will critically assess the role of gas impurities in blended H2/NG mixtures in controlled laboratory environments. This topic will provide insight into topic area 2 for input on lifetime-prediction model experiments.

Ranking Exercise – Topic Descriptions

Topic 7 – Environmental Implications of Blending Hydrogen - End use

Description:

This research topic can answer the following questions with respect to energy efficiency and life cycle greenhouse gas and criteria air pollutant emissions:

What are the impacts of hydrogen primary energy sources and production technology pathways?

What are the implications of hydrogen storage methods and associated energy use?

What are the impacts of hydrogen delivery methods and injection pressure?

What are the implications of various blending ratios and end use applications on NOx emissions?

What are the implications of leakage and fugitive emissions of hydrogen/natural gas blends?

Are there regional preferences or differences associated with hydrogen production, delivery and storage pathways?

What are the implications of new pipeline manufacturing, materials and installation?

Topic 8 - Fundamental R&D on Combustion Behavior

Description

In this task, the team will conduct fundamental R&D on the combustion behavior of hydrogen blends to inform the development of novel building equipment and subcomponents compatible with hydrogen blends (i.e. Heat exchangers and novel condensation management and venting methods). Key parameters that would be analyzed and visualized (e.g. using neutron source equipment) include flame behavior, flame speed, and flame temperature and characteristics of the flue gas associated with the subcomponent designs.

Ranking Exercise – Topic Descriptions

Topic 9 – Hydrogen Production Optimization Tool

Description:

The team would develop an economic focused modeling tool that would combine grid simulation, electrolyzer, and natural gas pipeline models. The tool would optimize the hydrogen production facility location, design, storage, and operations. The tool could be made available to the project partners so they can add in their own locations and scenarios as needs change over time.

Topic 10 - Structural Integrity and Risk Assessment of Hydrogen Pipelines

Description

Structural integrity assessment of gas delivery systems requires detailed to description of the systems and operating envelope for all elements of the systems. The intent of this activity is to develop general principles for operation of blended H2/NG delivery systems (transmission and distribution) in the context of structural integrity, including sensitivity to gas composition (if any). Necessarily, this task will identify operational conditions for these systems (such as pressure swings, gas composition, defect populations, etc). Additionally, sensitivity analysis will be used to assess structural integrity risk of blended H2/NG delivery systems. This task draws from and feeds into the task on evaluation of materials properties.

Ranking Exercise – Topic Descriptions

Topic 11 – Environmental Implications of Blending vs. Producing Synthetic Methane

Description:

This research topic will answer the following questions with respect to energy efficiency and life cycle greenhouse gas and criteria air pollutant emissions:

What are the impacts of hydrogen primary energy sources and production technology pathways?

What are the impacts of synthetic methane production from hydrogen and various CO2 sources?

What are the implications of various hydrogen-natural gas blending ratios and end use applications vs. those using pure hydrogen or synthetic methane with respect to pathway energy efficiency, greenhouse gas and criteria air pollutant emissions?

What are the implications of leakage and fugitive emissions of hydrogen/natural gas blends vs. those of synthetic methane?

Are there regional preferences or differences associated with hydrogen and synthetic methane production pathways?

Ranking Exercise – Topic Descriptions

Topic 12 – Lifetime Prediction of Polymer Materials in Hydrogen & Blends

Description:

Gas distribution pipelines have expected to lifetimes that exceed 50 years. Quasi-brittle failure is the critical failure mechanism in long-term applications. Stress rupture curves have been developed for NG polymer piping, however, the development of stress rupture curves to determine the long-term failure behavior under the H2/NG environmental stress conditions have not. Lifetime prediction curves for these polymeric materials subjected to H2/NG mixtures is needed to better understand the effects of the gas blend and their contaminants to compare against the baseline curves to evaluate long-term effects for 50 years and beyond.

Topic 13 - Gas flow behavior through pipelines

Description

Understanding the characteristics of flow of pure hydrogen and blended gas in pipelines is crucial for design, optimization and safe operation of gas pipelines. From hydrogen injection points, to intermediate pumping stations to transitions from transmission to distribution lines and in metering locations, there is a compelling need to better understand the extent of turbulence and compositional homogeneity in gas blends and their variations, as the utilization of blended gas swings from peak to off-peak conditions. Flow heterogeneities and discontinuities could potentially pose unexpected safety concerns and materials degradation issues at critical locations in the pipelines. We propose to develop models to predict blended gas flow behavior for a range of expected pipeline operating conditions and a framework for identifying change point detections associated with flow characteristics in real time. In addition to validating the models of flow with experiments on test pipeline sections, hydrogen induced compromised structural integrity aspects in critical locations of pipelines would also be assessed using 3-D nano-scale tomography and other techniques such as XPS and XRD.

Decarbonizing Minnesota's Natural Gas End Uses

LUNCH

RETURN AT 1:00

GREAT PLAINS INSTITUTE | Better Energy. Better World.

Discussion:

Hydrogen

GREAT PLAINS INSTITUTE
Better Energy.
Better World.

Final Discussion:

- What conclusions are you drawing about these technologies?
- What are your remaining questions?
- What do you think are the key challenges and opportunities?
- Are there decisions we could make today that would push us in a particular direction? In other words, what levers/drivers would advance the deployment of each technology?
- How do we ensure we don't prevent the development of a technology we may need in the future?
- Some of these fuels are deployed primarily for use in the transportation sector – how does or might that impact their use for heating?

Decarbonizing Minnesota’s Natural Gas End Uses

Next meeting:

Friday, August 14th

Via Zoom

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