INCREASE YOUR H2IQ

The #H2IQ Hour

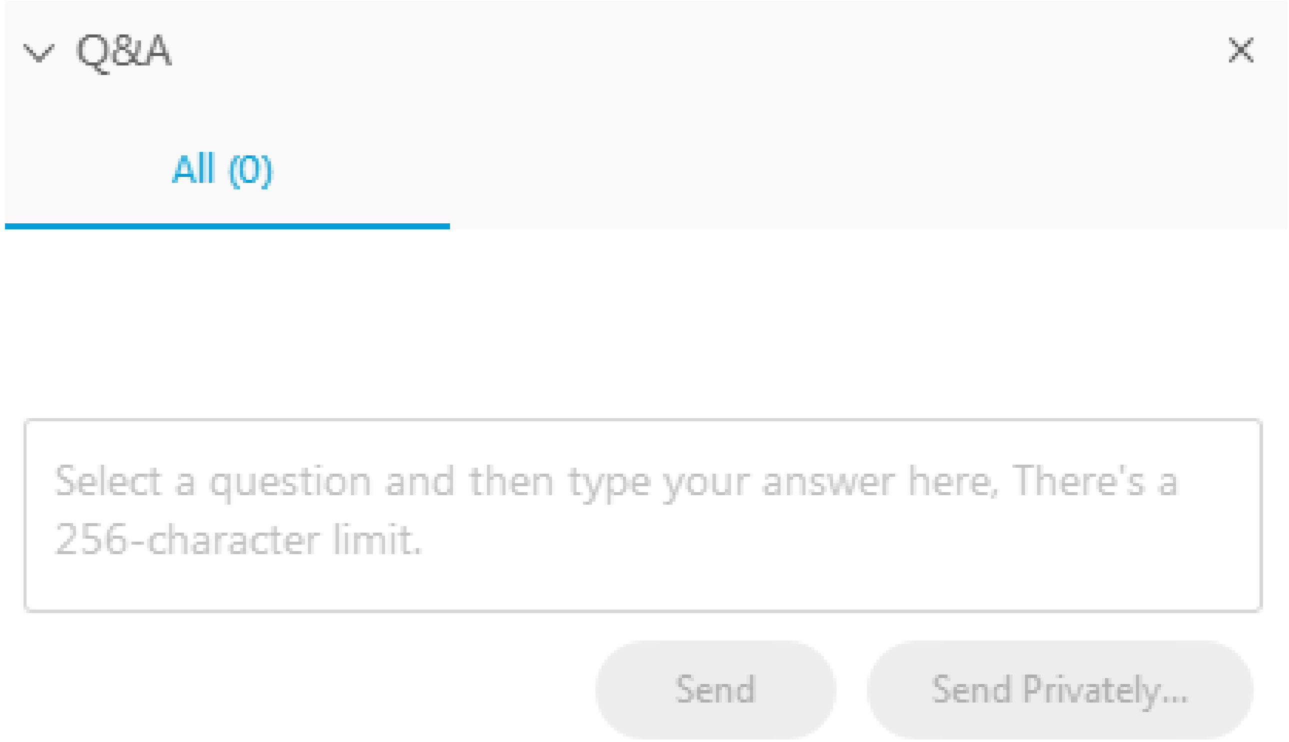
Today's Topic:

A Special National Hydrogen and Fuel Cell Day H2IQ Hour - Highlighting H2@Scale Demonstration Projects

This presentation is part of the monthly H2IQ hour to highlight research and development activities funded by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE).

The #H2IQ Hour Q&A

Please type your questions into the **Q&A Box**



Hydrogen and Fuel Cell Day – A weeklong celebration of progress

HYDROGEN & FUEL CELL WEEK

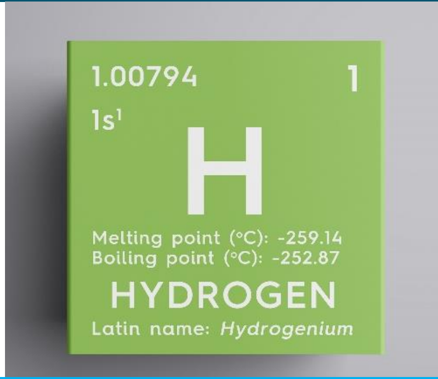
October 5–9, 2020

#HydrogenNow

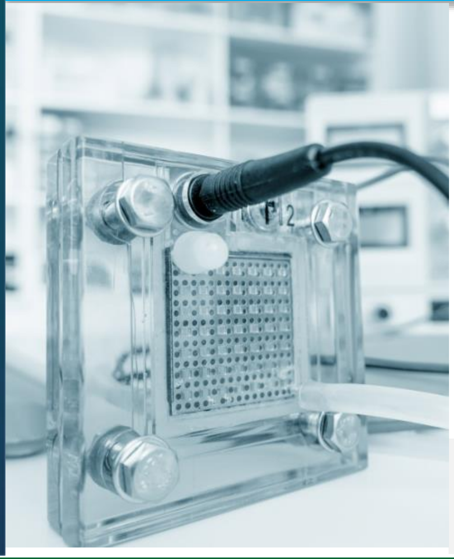
#FuelCellsNow

Hydrogen and Fuel Cell Day October 8 (10.08)

- Represents hydrogen's atomic weight of 1.008
- Celebrated in the U.S. since 2015 with weeklong activities
  - Blogs, announcements
  - Ride and drives, presentations at schools, tech demos
  - Interactive online resources (i.e. 101 quiz, career map)



What can you do?

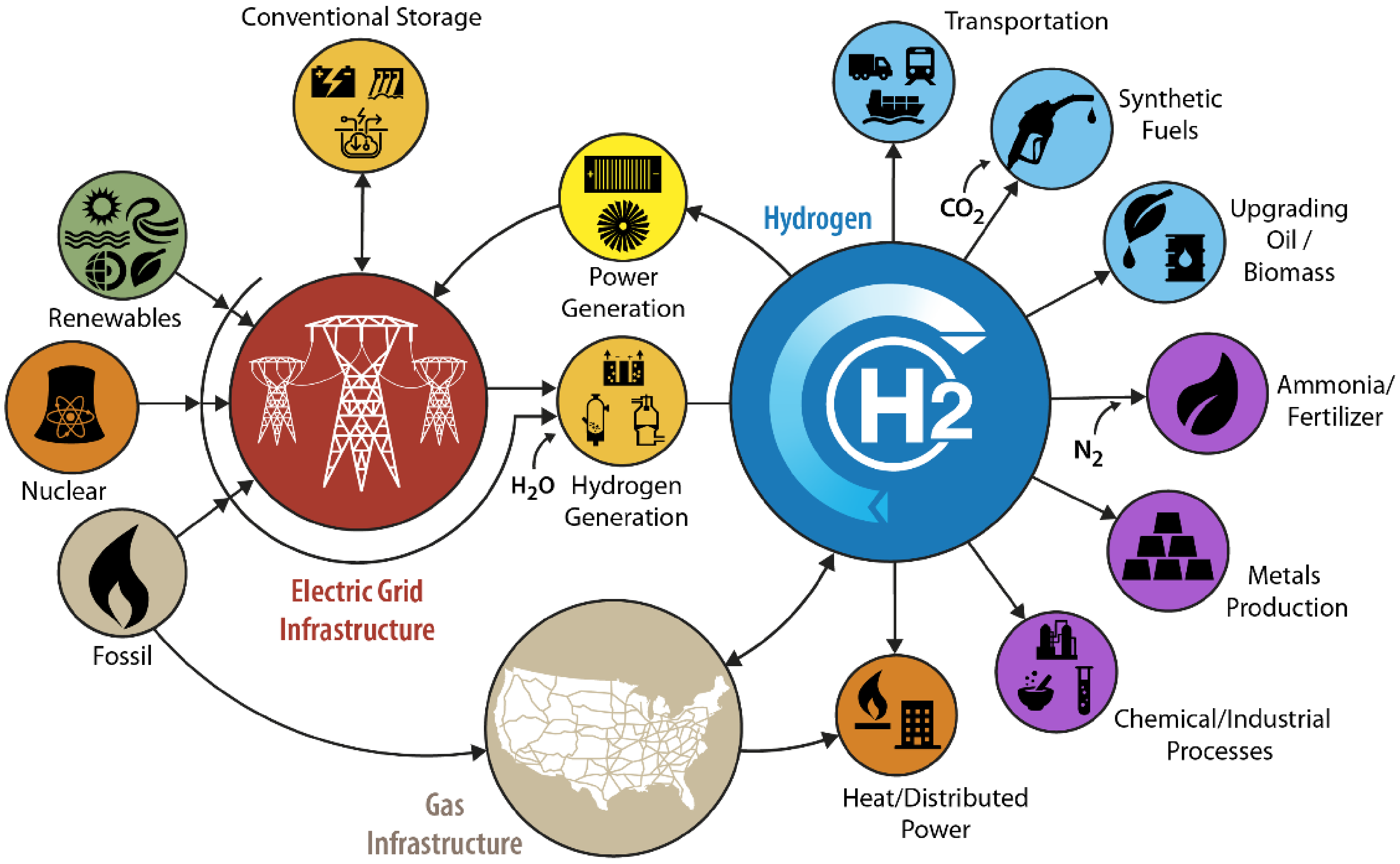


- **Post on social media** and share information, use hashtags!
- **Increase your H2IQ** by tuning in to the monthly H2IQ hours
- **Test your H2IQ** by taking the hydrogen and fuel cell quiz
- **Learn** about fuel cell and hydrogen jobs with the career map
- **Follow @The_IPHE** on twitter for global hydrogen updates

More info: **hydrogen.energy.gov**

Hydrogen is one part of a Comprehensive Energy Portfolio

H2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



Hydrogen can address specific applications across sectors

Today: 10MMT H_2 in the U.S.

Economic Potential: 2 to 4x more

H2@Scale Demonstration Projects

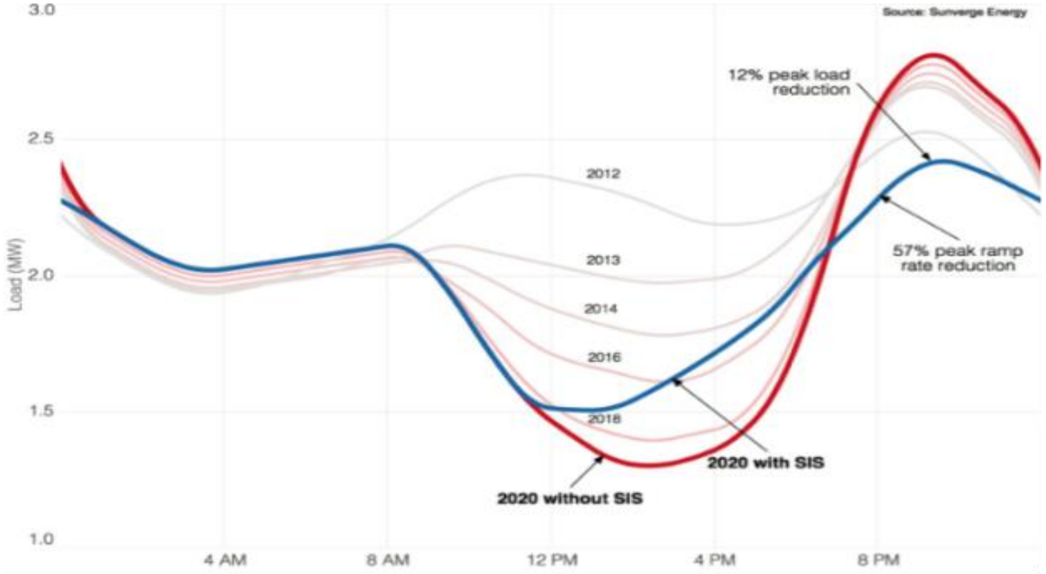
- **Giner ELX, Inc. / Plug Power, Inc.: "Demonstration of Integrated Hydrogen Production and Consumption for Improved Utility Operations"**
  – A hydrogen production, storage, and utilization system that supports stationary power, refueling of fuel cell vehicles, and grid optimization controls at a utility in Florida
- **Frontier Energy Inc.: "Demonstration and Framework for H2@Scale in Texas and Beyond"**
  – A renewable hydrogen generation system co-located with a computing center using fuel cell power to run operations and installing hydrogen refueling infrastructure for fuel cell vehicles in Texas
- **Exelon Generation Company, LLC: "Demonstration of electrolyzer operation at a nuclear plant to allow for dynamic participation in an organized electricity market and in-house hydrogen supply"**
  – An end-to-end integrated-scale carbon-free hydrogen production storage and utilization system at a nuclear power plant.

Integrated Hydrogen Production and Consumption for Improved Utility Operations

PI: Monjid Hamdan, VP of Engineering - Electrolyzers, Plug Power Inc.
Presenter: Adam Paxson, Program Manager – Electrolyzers, Plug Power Inc.

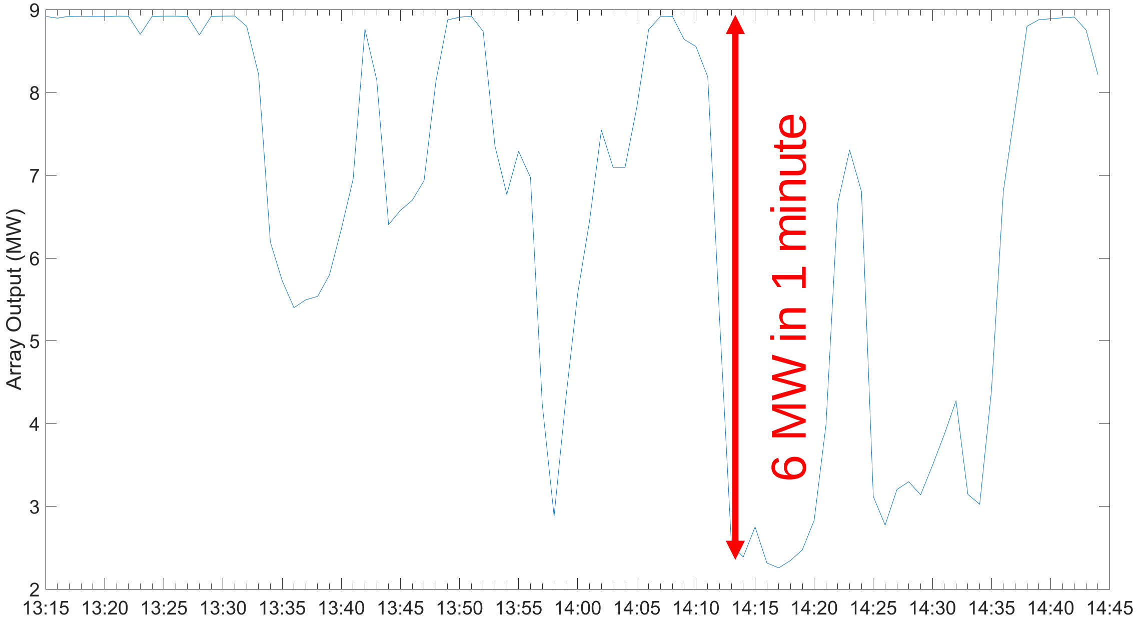
October 8, 2020

The California "Duck Chart"
Non-solar generation required over a 24-hour period (2012 to 2020)



- Steep ramping requirements & over-generation risk
- Accentuated by increasing solar PV
- Long-duration storage (8+ hours) required

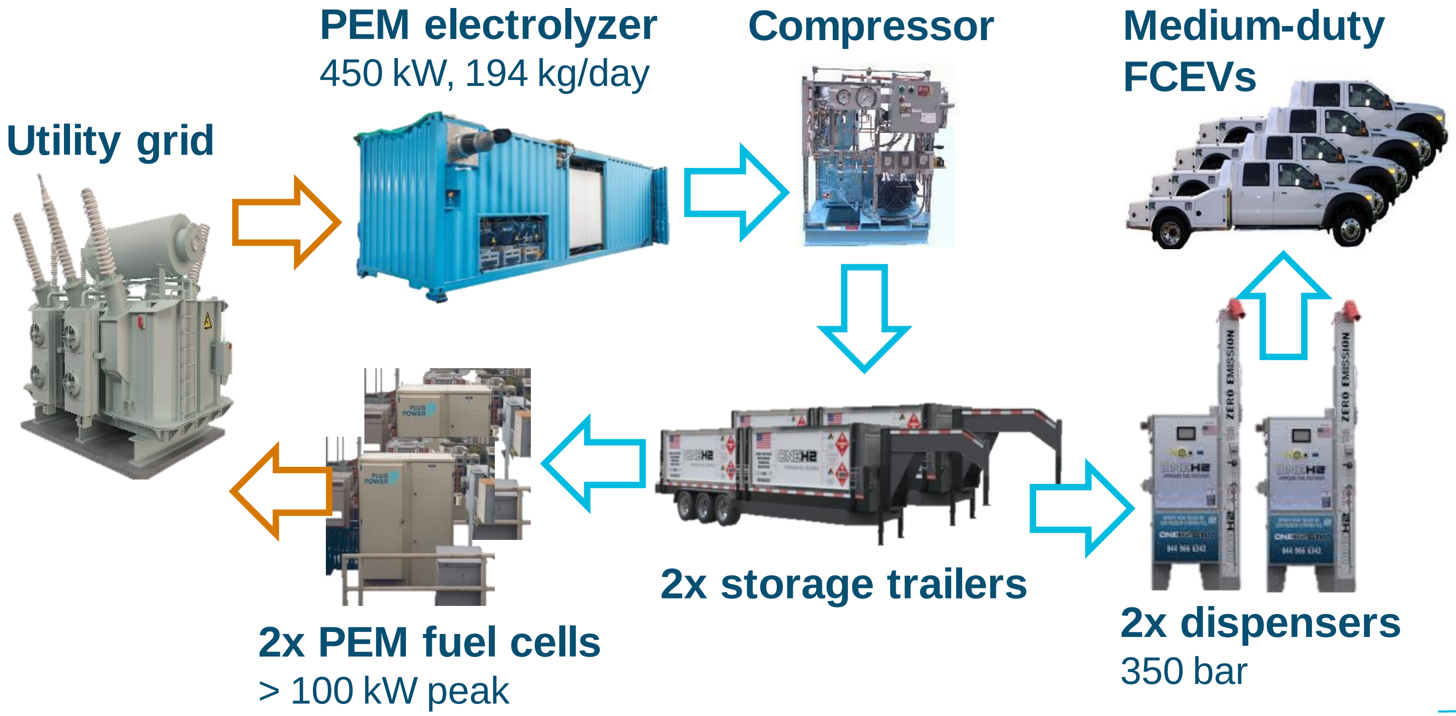
Orlando Utility Commission
Output Variation from an 8.9 MW_{AC} PV Array



- OUC solar PV to increase from 1% to 10% by 2022
  - Up to 20% by 2024+

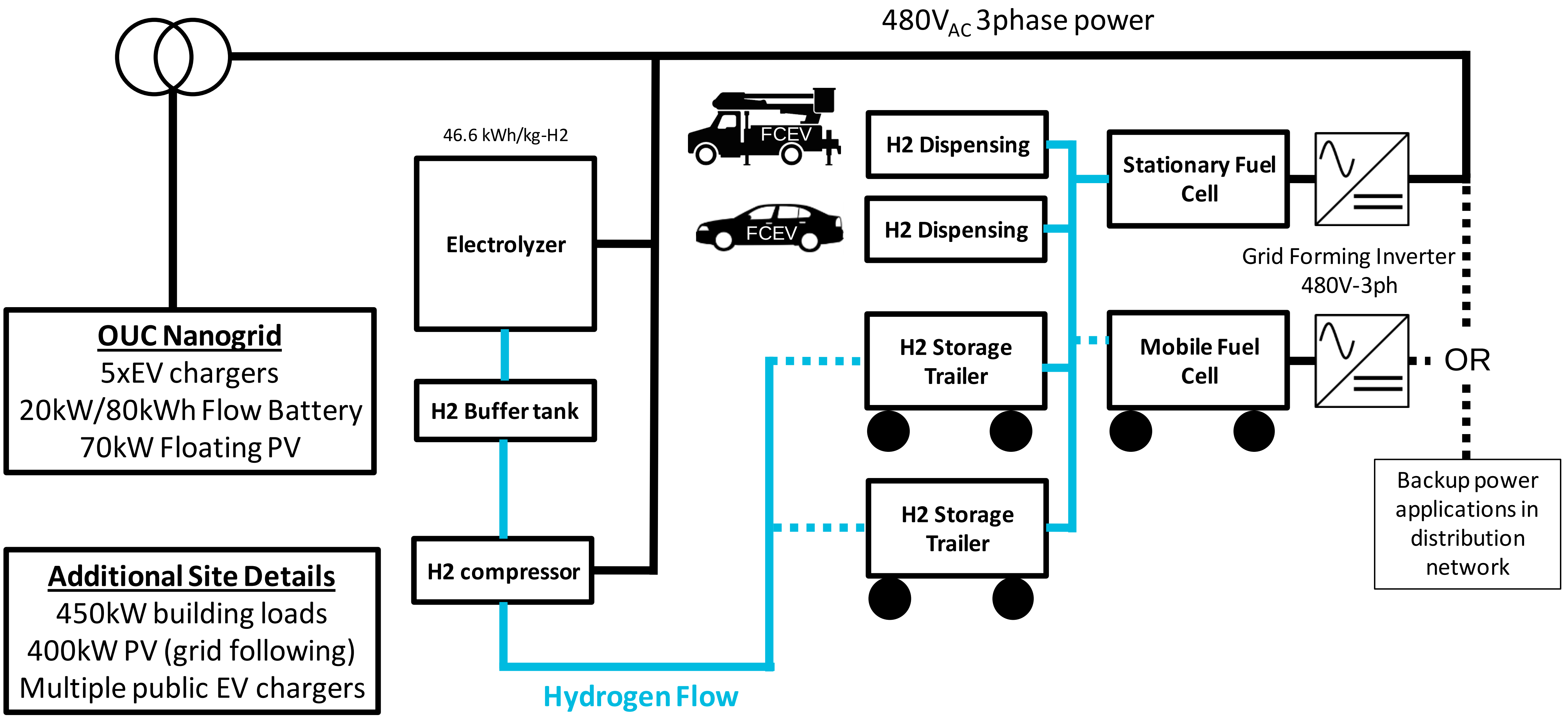
Solution: **PEM Electrolyzer with fast response time** to reduce overgeneration risks and smooth ramp rates

Integrated system overview



OUC Gardenia Operations Facility

Site architecture (draft)



Timeline

Year 1

Prelim TEA

System Design

- Complete preliminary technoeconomic analysis
- Optimize design of individual system units (FC, electrolyzer, compression, storage, dispensing)
- Develop utility control architecture to dispatch Grid-integrated H2 Assets
- Demonstrate path to achieve < $2/kg-H2

Year 2

Unit assembly & installation

Utility integration

- Complete individual system unit assembly, delivery, and installation:
  - 450 kW electrolyzer
  - Two Fuel Cell systems (stationary and mobile)
  - 350 bar compressor, storage and dispensing units
- Integration of individual system units with OUC Utility

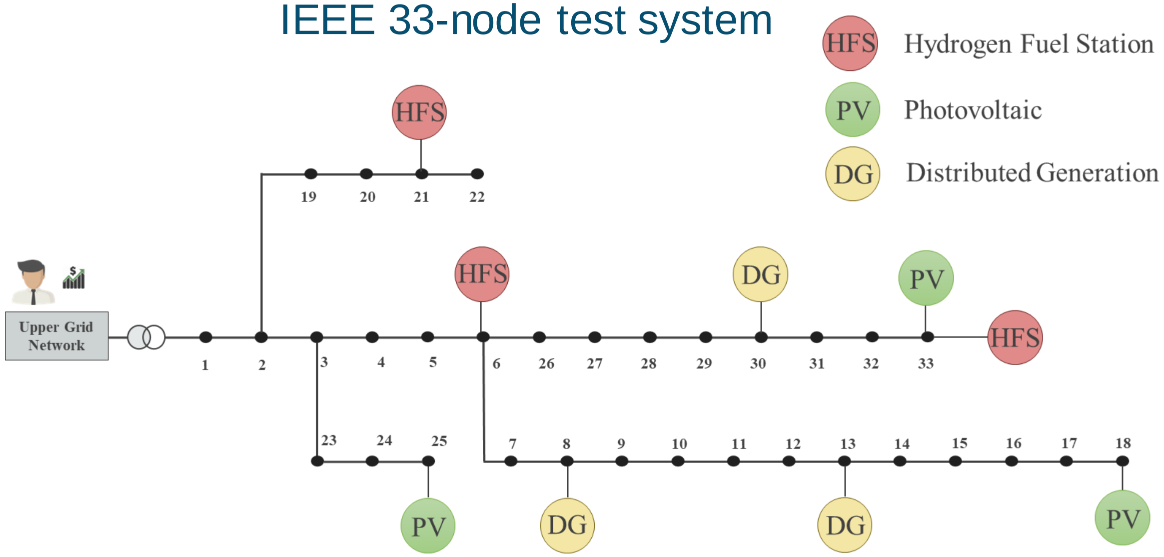
Year 3

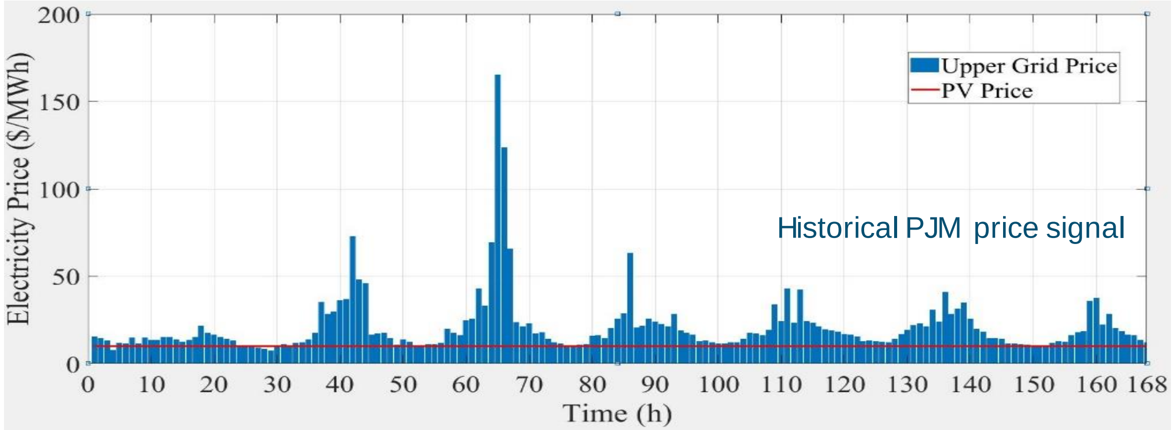
Integrated operation

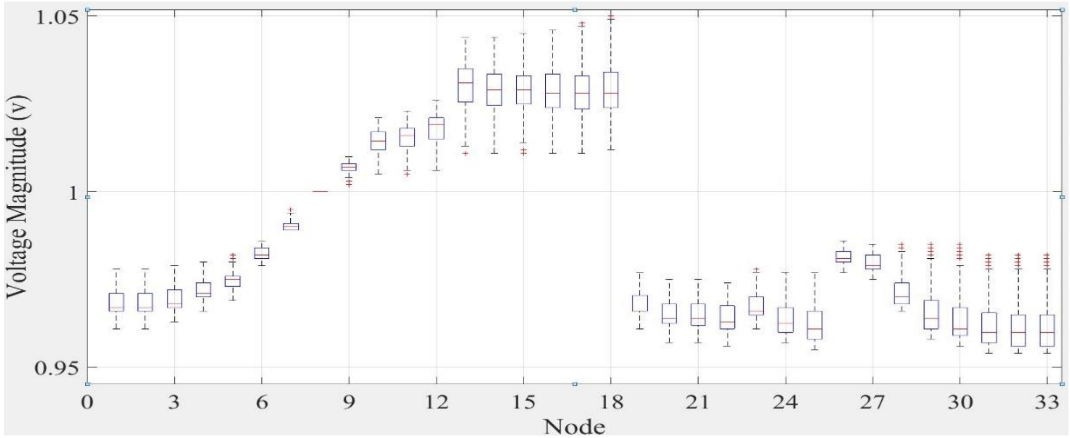
- Demonstrate integrated system dispatch with utility signals
- Complete economic and market feasibility studies
- Demonstrate multiple value streams for hydrogen

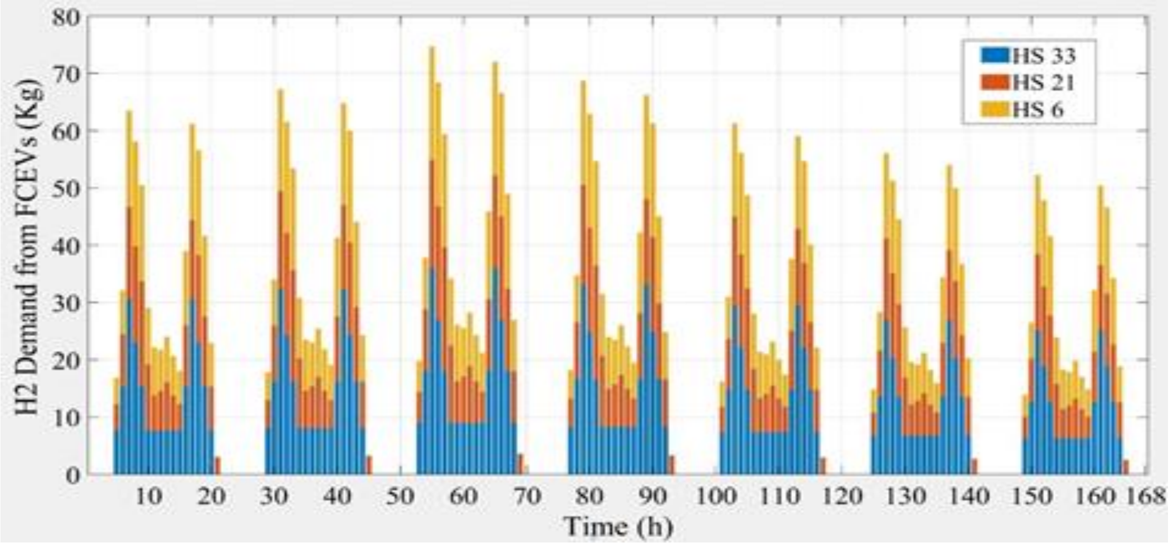
Technoeconomic Analysis

IEEE 33-node test system





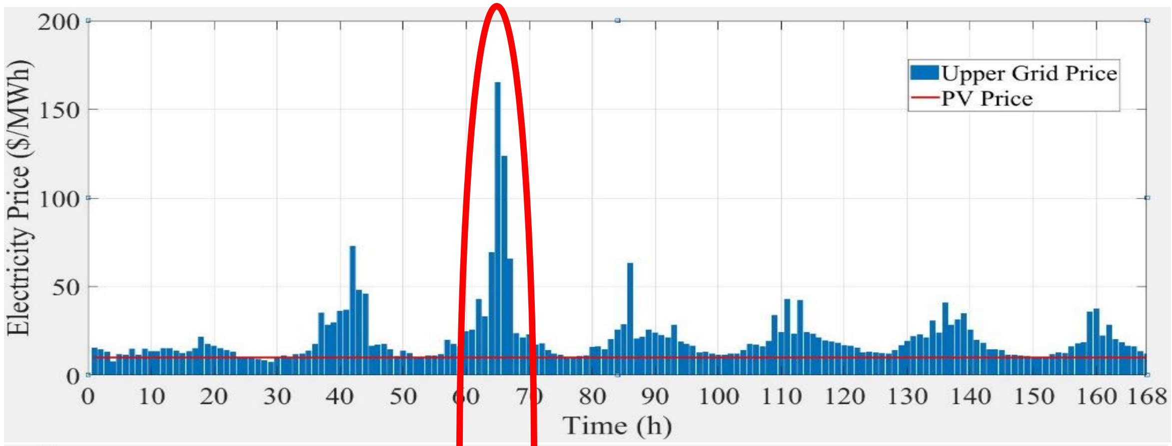


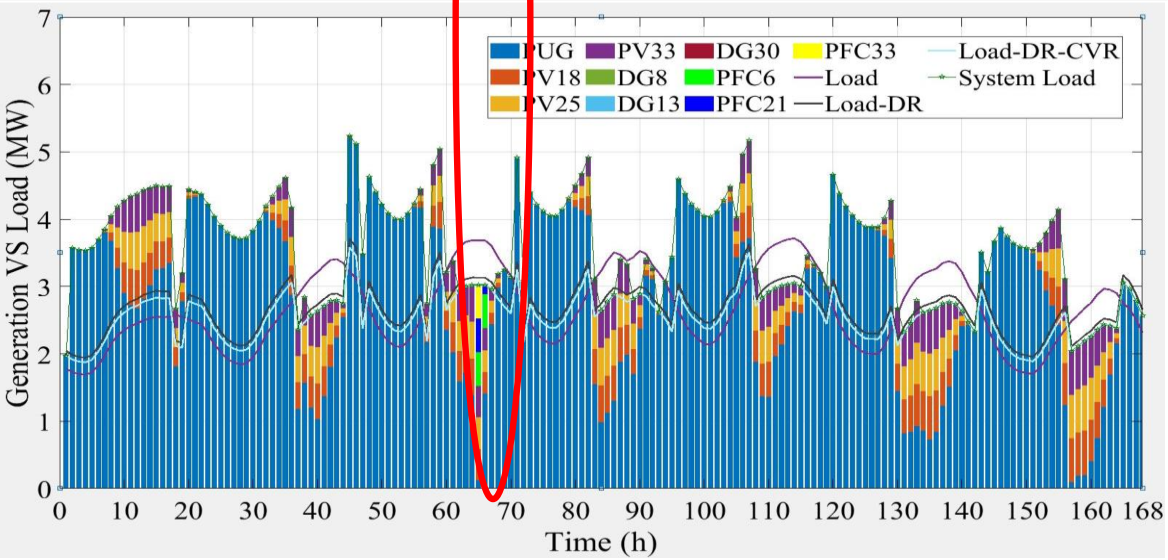


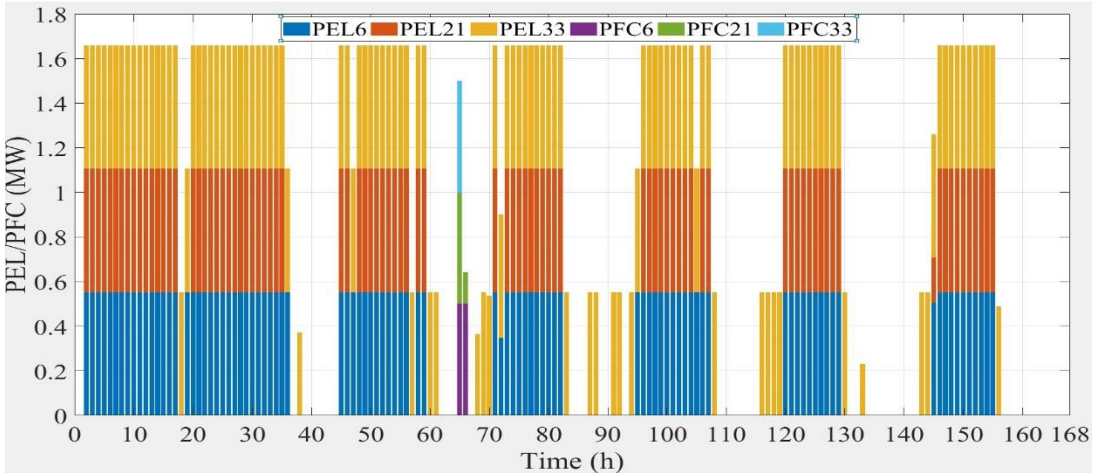
Figures credit: H. Haggi, UCF-FSEC

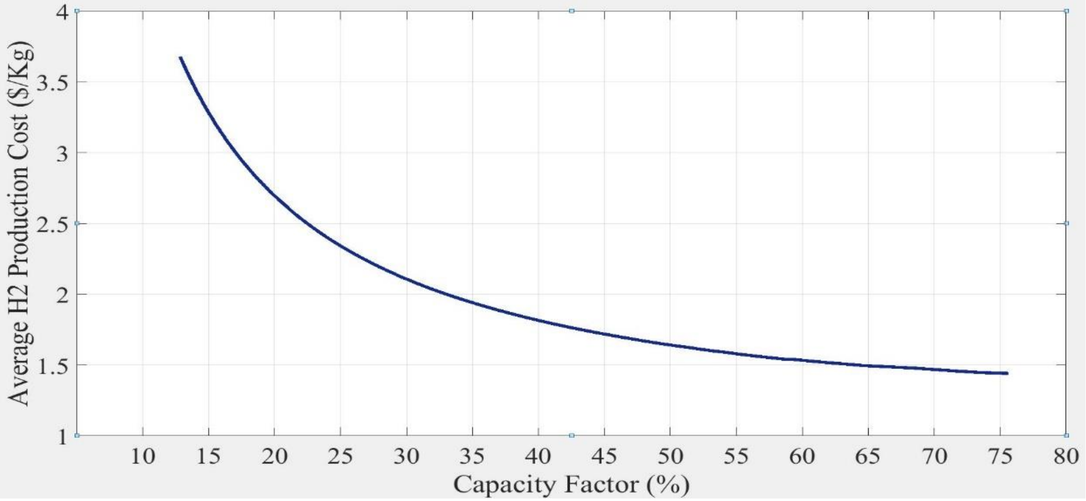
Technoeconomic Analysis

Fuel cell dispatched
during price spike



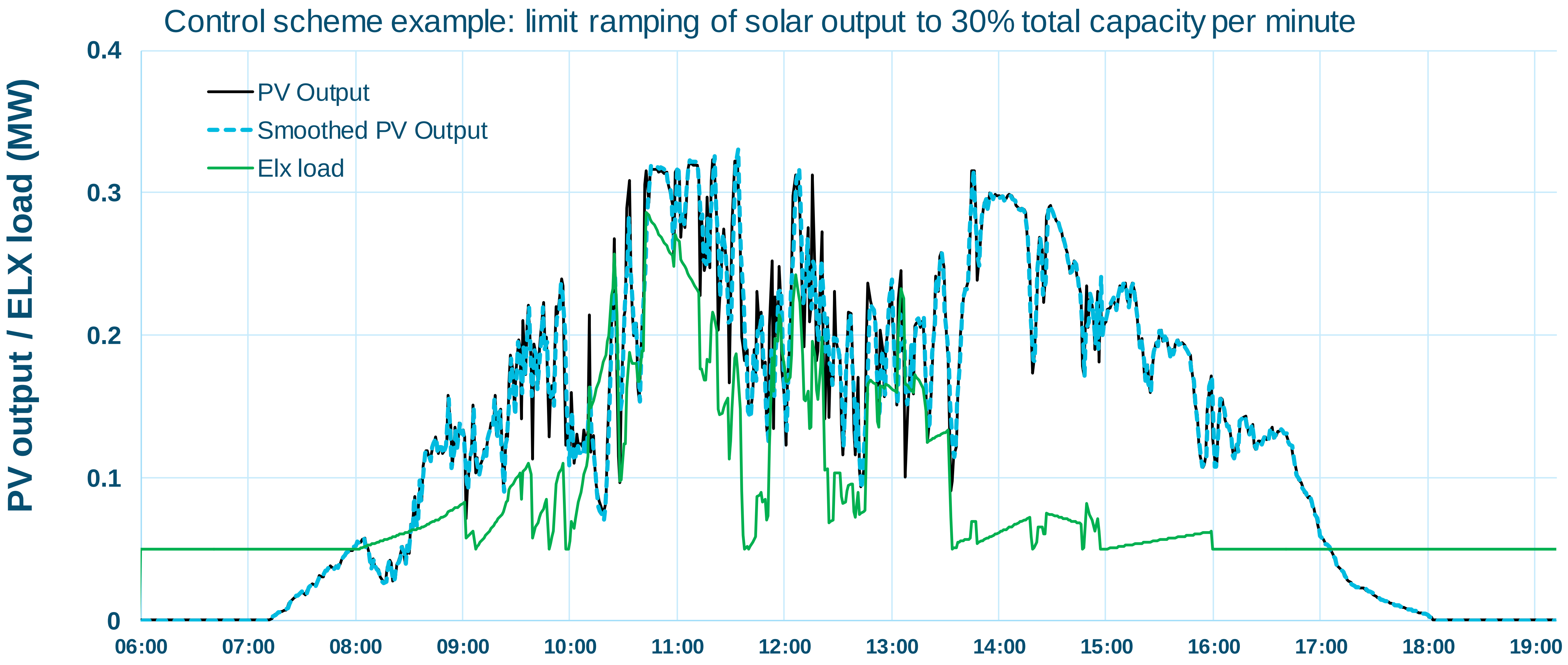






Figures credit: H. Haggi, UCF-FSEC

Controlling electrolyzer load for PV smoothing



Figures credit: P. Brooker, OUC

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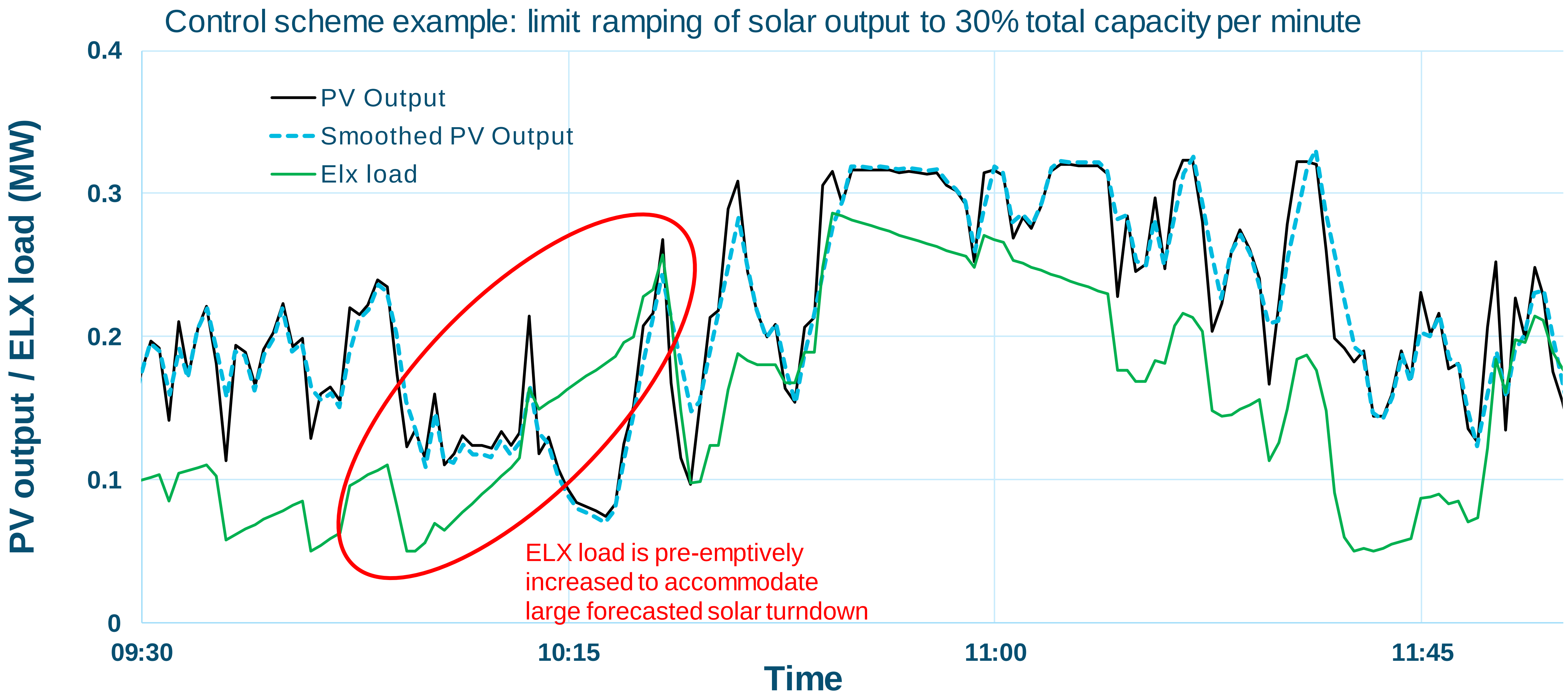


Figures credit: P. Brooker, OUC

Collaborators

Plug Power, Inc. - Monjid Hamdan - Adam Paxson	Industry Prime	Electrolyzer and fuel cell
Orlando Utilities Commission (OUC) - Justin Kramer - Paul Brooker - Chanda Durnford	Utility Subcontractor	Utility Company/Solar Integration/FCEV Fleet
OneH2 - Michael Dawson	Industry Subcontractor	Storage and dispensing
University of Central Florida-Florida/Solar Energy Center (UCF-FSEC) - James Fenton	Academia Subcontractor	Techno-Economic Analysis of integrated system
National Renewable Energy Lab (NREL) - Paige Jadun - Mark Ruth - Bryan Pivovar	National Lab Subcontractor	PV-electrolyzer penetration via ReEDS

Corporate Headquarters
968 Albany Shaker Road, Latham, NY 12110

Electrolyzers
134 Rumford Ave., Newton, MA 02466

West Coast
15913 E. Euclid Avenue, Spokane, WA 99216

plugpower.com

FRONTIER energy

Demonstration and Framework for H2@Scale in Texas and Beyond

Nico Bouwkamp – PI

Michael Lewis – Co-PI – University of Texas at Austin

H2IQ Hour

October 8, 2020

FRONTIER energy

- Energy Engineering
- Electric Transportation
- Energy Efficiency Programs
- Advanced Power Generation
- Foodservice Energy & Water
- Cloud-based Software

FrontierEnergy.com

Project Timeline And Partners

Timeline

- Project Start Date: July 2020
- Project End Date: June 2023

Period of performance: 36 months

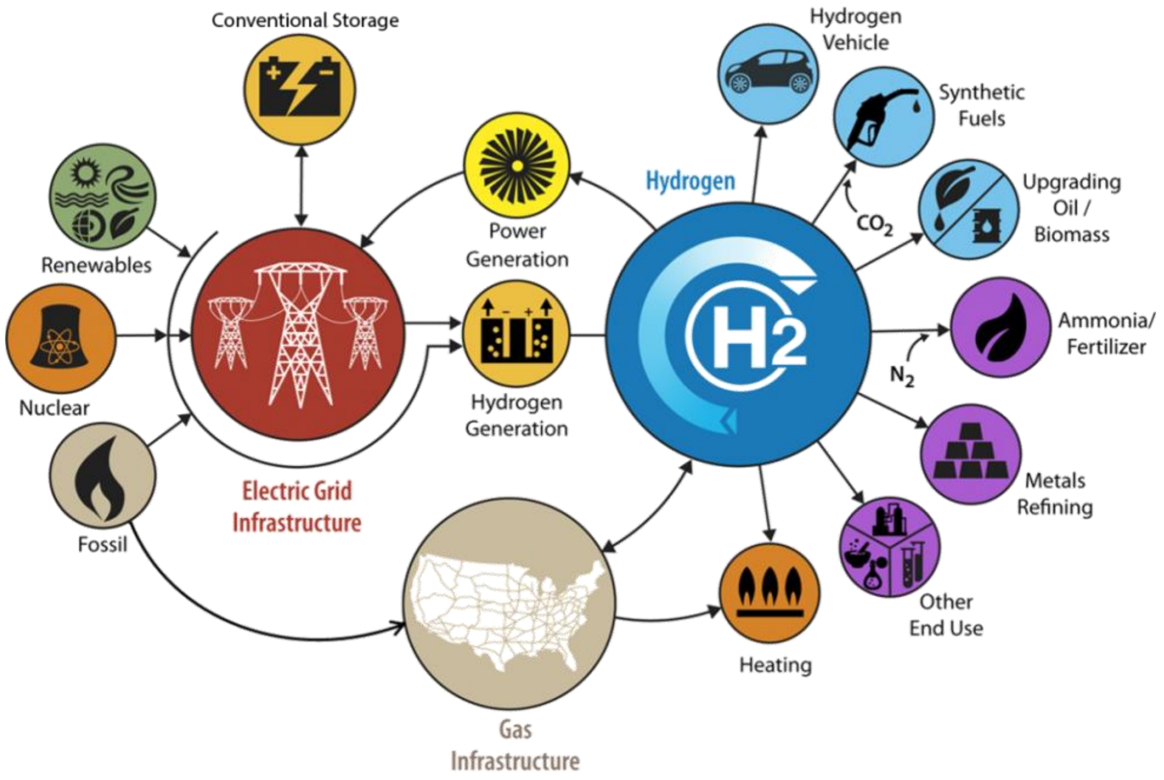
Currently finalizing subcontracts and beginning design activities

Partners

- Gas Technology Institute
- Mitsubishi Heavy Industries
- OneH2
- ONE Gas
- Shell
- SoCalGas
- Toyota
- University of Texas at Austin, Center for Electromechanics
- University of Texas at Austin, Energy Institute
- Waste Management

H2@Scale Vision

- H_2 enables zero emissions in transportation, stationary, remote, and portable power
- H_2 used as a grid "responsive load" for grid stability and GWh energy storage, and increase power generators utilization
- H_2 critical feedstock for entire chemicals industry
- Domestically sourced H_2 for multiple sectors or export

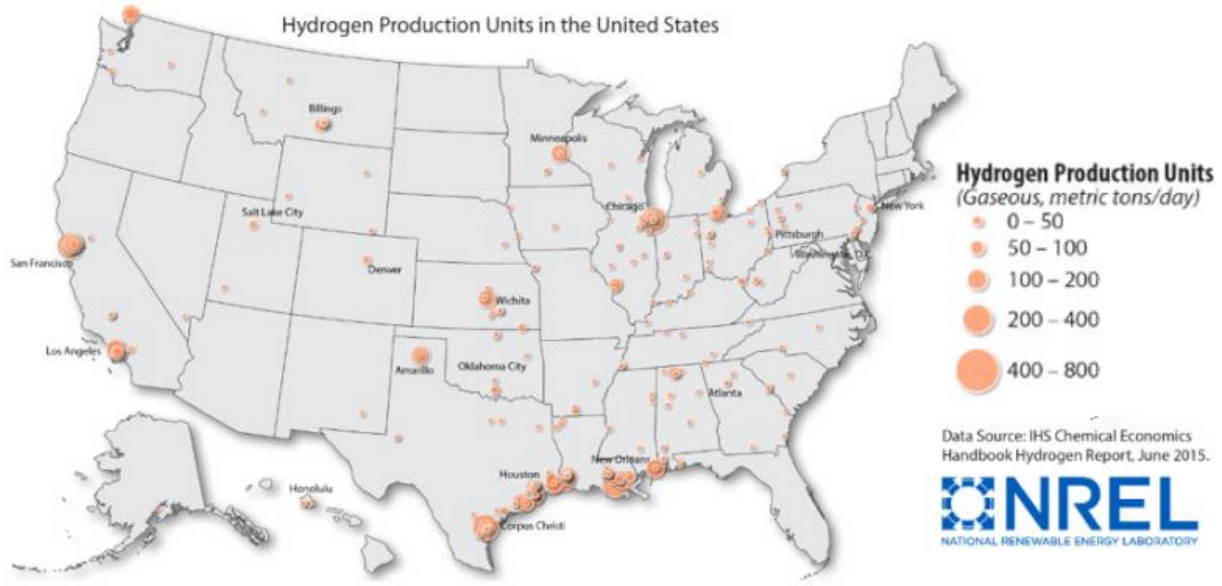


https://www.energy.gov/eere/fuelcells/h2scale

Relevance for Texas

Texas ideal to lead H_2 production for a sustainable energy system

- Excellent resources of natural gas, solar and wind for RH_2
- Largest H_2 producer in the nation
- Major industry leaders on Hydrogen Council have significant presence in Texas
  - Toyota, Shell, and Air Liquide



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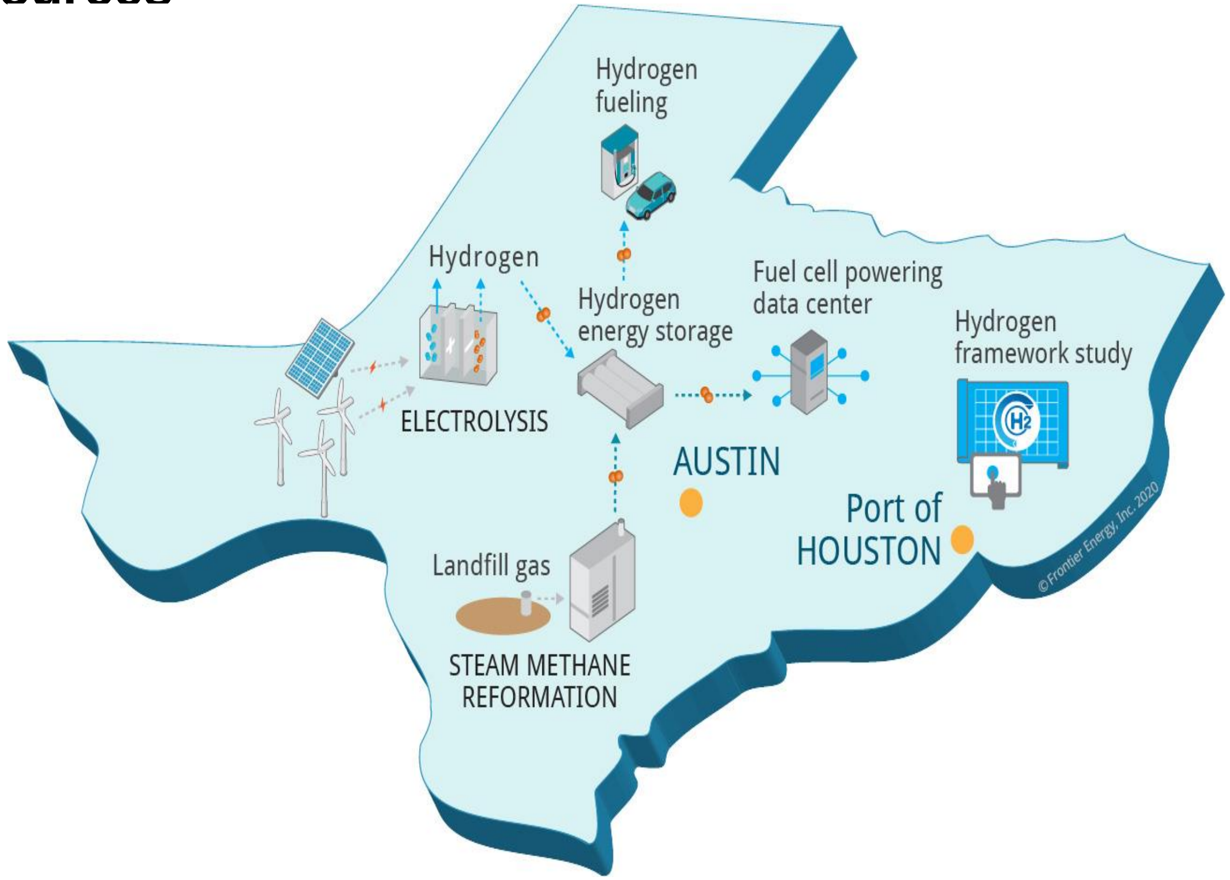
Approach

Two unique RD&D tracks to understand the potential of integrating hydrogen with multiple co-located platforms and existing resources

- Demonstrate multiple RH_2 generation options, co-located with vehicle fueling and a large base load consumer to enable cost-effective H_2 energy solutions
- Develop framework for actionable H2@Scale pilot plans in Texas, Port of Houston and Gulf Coast region, including energy storage



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Project Activity Timeline

	Key milestones & deliverables
Year 1	• Demonstration site planning and construction • Technoeconomic H2@Scale models in Texas
Year 2	• Commence demonstration activities • Complete framework for H2@Scale in Texas
Year 3	• Complete demonstration and assess ability to provide cost-effective hydrogen

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Demonstration activities at UT *(track 1)*

Renewable H_2 generation

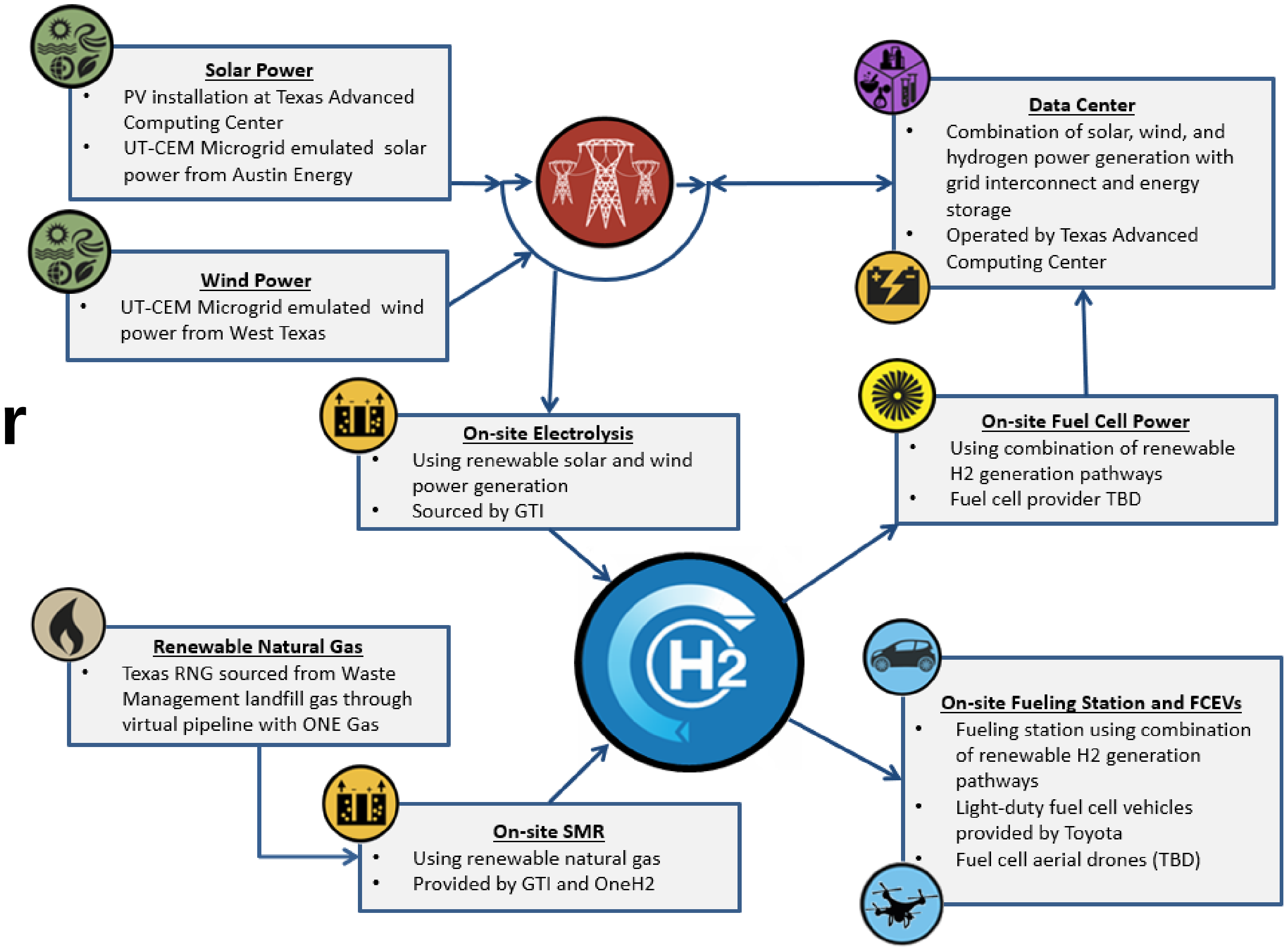
- SMR using RNG
- Electrolysis using wind and solar power

Large scale, industry H_2 user

- Fuel cell powering Texas Advanced Computing Center

Vehicle refueling

- Light-duty vehicles
- Unmanned aerial vehicles



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Demonstration activities at UT *(current details)*

~100% renewable H_2 generation

- 75 kg/day SMR: GTI, OneH2, ONE Gas, Waste Management
- 20 kg/day PEM electrolyzer in H70 SimpleFuel: MHIA, SoCalGas, TACC
  - Emulated wind and solar power through UT CEM microgrid

Large scale, industry H_2 user

- 100kW fuel cell powering TACC

Vehicle refueling

- Published SAE J2601-4 fueling of 7-10 Toyota Mirai's
- Drones under discussion

Port of Houston H_2 Framework

- Identify policy and regulatory barriers
- Define use and implementation plans leveraging existing industry resources
- Develop actionable plan for H2@Scale and FCEV rollout in region

- Since project announcement:
  - Receiving a great deal in interest from industry
  - Partnering with other synergistic activities currently underway in Texas

FRONTIER energy

Program summary

Period of performance: 36 months

	Key milestones & deliverables
Year 1	•Demonstration site planning and construction •Technoeconomic H2@Scale models in Texas
Year 2	•Commence demonstration activities •Complete framework for H2@Scale in Texas
Year 3	•Complete demonstration and assess ability to provide cost-effective hydrogen

Questions?

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FRONTIER energy

Value propositions of hydrogen generation for flexible operation of nuclear plants

H2IQ Hour

October 8th 2020

Exelon®

Exelon overview

Exelon nuclear plants are located in competitive electricity markets and face economic pressure due to market prices

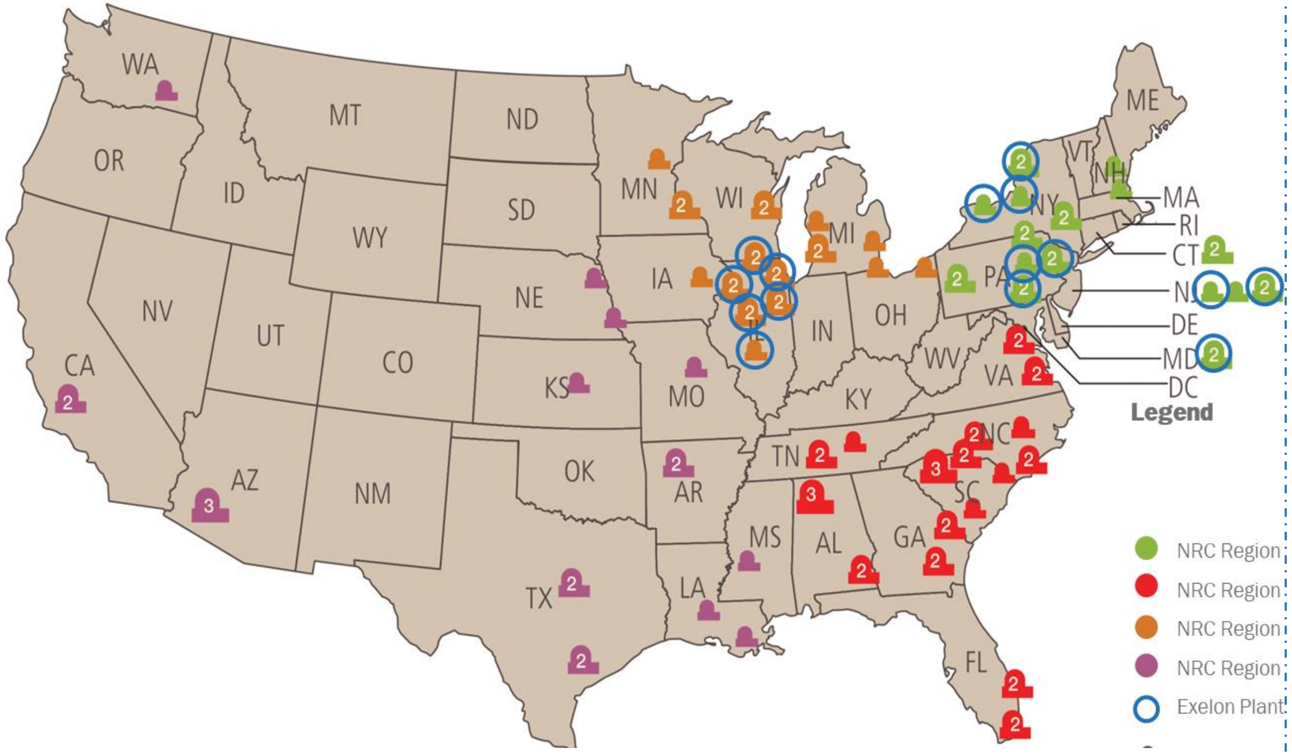
Macro trends in Power Markets

- **Natural gas prices** (which fuels marginal generators in many regions) are persistently low

- **Load growth is down** due to both the economy and increased energy efficiency programs

- **Renewables penetration** has suppressed wholesale energy prices in some regions

Exelon nuclear plants operate in competitive markets



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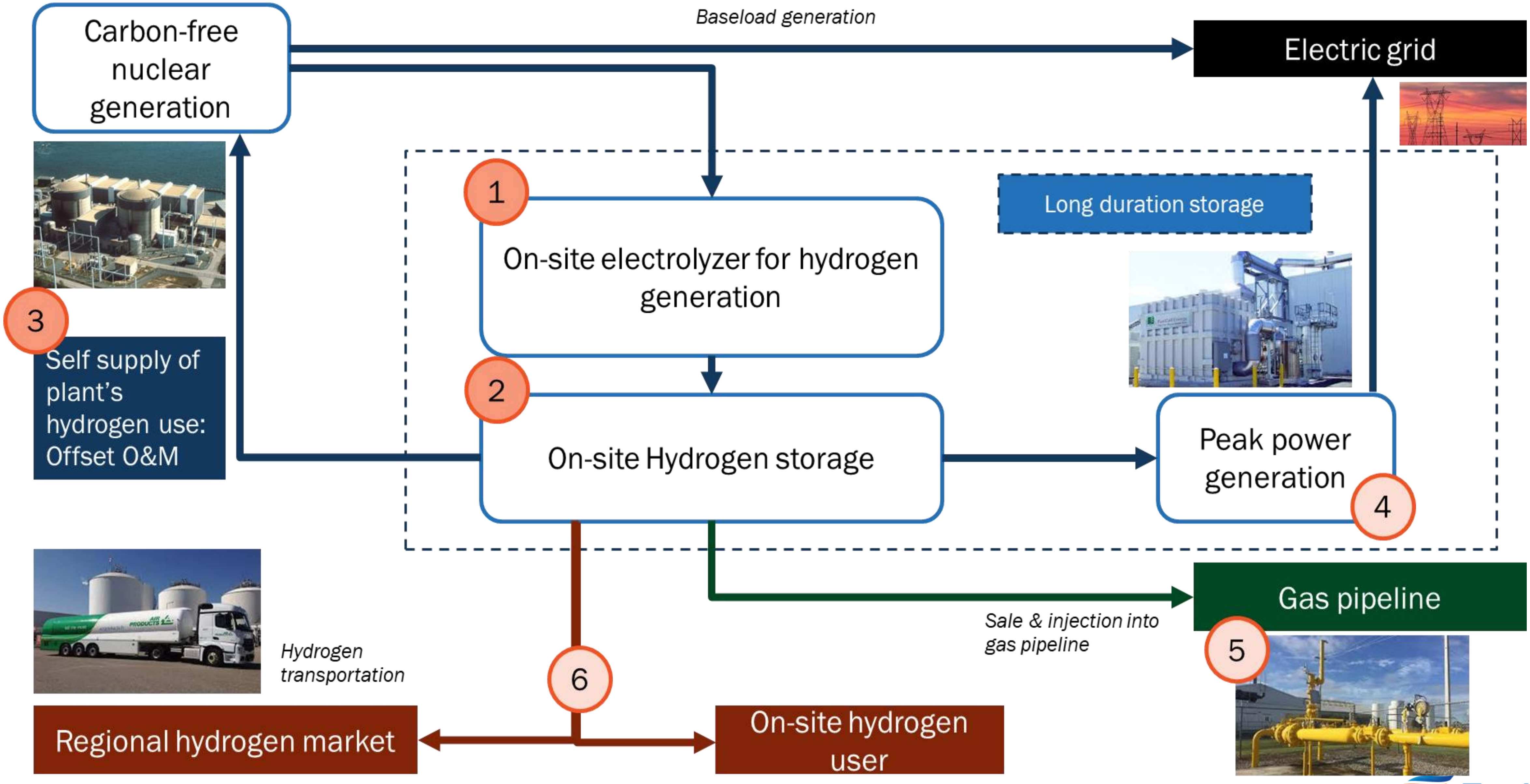
Exelon.

Exelon has been assessing hydrogen production as an option to repurpose nuclear plants to produce alternative products and enhance long term value



Exelon won a DOE grant to demonstrate 1MW scale hydrogen production at a nuclear plant

Objective

- Install a 1MW Polymer Electrolyte Membrane (PEM) electrolyzer and supporting infrastructure at an Exelon nuclear power plant
- Provide economic supply of in-house hydrogen consumption at the plant
- Simulate a scale-up operation of a larger electrolyzer participation in power markets

Timeline and budget

- Conditional award: 10/01/2019
- Removal of condition: 04/01/2020
- Project End Date: 04/01/2023
- Total Project Budget: $7.2MM
  - Industry cost share $3.6MM
  - Total Federal Share: $3.6MM

Questions, challenges

- **Site Selection**
  - What are the criteria for site selection?
- **Regulatory**
  - What are the relevant regulations that affect nuclear hydrogen production?
- **Market-related**
  - What is the effective electricity price that the electrolyzer pays?

Partners/Sponsors

- DOE-FCTO funding
- Exelon Corporation
- Nel Hydrogen
- Idaho National Laboratory
- National Renewable Energy Laboratory
- Argonne National Laboratory

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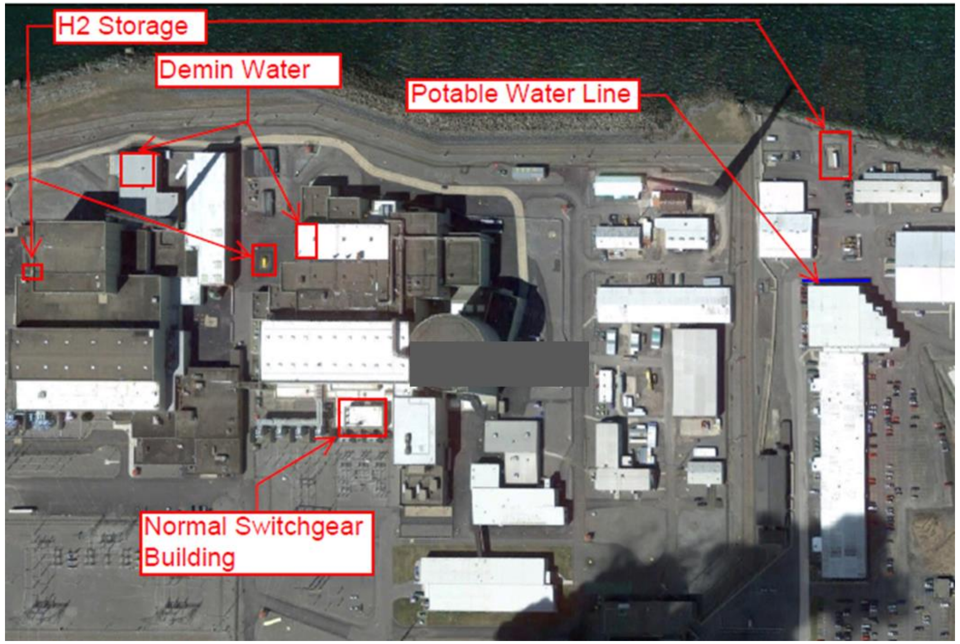
Exelon has completed a site selection matrix to identify highest ranking sites

H_2 Production Pilot Site Selection Matrix				Site#1			Site#2			Site#3			Site#4		
	Overall Score					326.9			332.7			234.2			253.5
Criterion	Description	Must vs Want	Weight	Must Req Met	Score	Subtotal	Must Req Met	Score	Subtotal	Must Req Met	Score	Subtotal	Must Req Met	Score	Subtotal
V	Electrical	Must Have	7	Yes		60.8	Yes		68.5	Yes		60.9	Yes		45.7
V01	House Load Margin		5		10	50		10	50		9	45		10	50
V02	Availability of Spare MV Switchgear	Y	10	Y	7	70	Y	10	100	Y	10	100	Y	4	40
V03	Spare Switchgear Proximity to PEM-ES		3		10	30		8.2	24.6		1.8	5.4		0	0
V04	Short Circuit Rating		7		10	70		10	70		10	70		10	70
V05	House Load Tariff		1		5.9	5.9		10	10		5.9	5.9		9.8	9.8
C	Constructability	Must Have	10	Yes		58.4	Yes		69.8	Yes		39.9	Yes		39.2
C01	Concrete Slab Space	Y	10	Y	5	50	Y	7	70	Y	8	80	Y	5	50
C02	Tie In to Plant H2 Location		1		8	8		5	5		10	10		8	8
C03	Siting Constructability		4		7	28		7	28		4	16		5	20
C04	Trenching / Penetrations		4		6	24		4	16		2	8		3	12
C05	Routing of MV Power		2		10	20		8.2	16.4		1.8	3.6		0	0
C06	Routing of Potable Water		5		8	40		6	30		2	10		3	15
C07	Routing of Drains		2		8	16		8	16		2	4		4	8
C08	Security Hardware		2		6	12		10	20		2	4		6	12
C09	Mod for H2 Storage Type		8		3	24		8	64		2	16		3	24
W	Water Management		7			56.0			53.7			15.6			25.7
W01	Overall Convenience of Quality Supply		3		8	24		7	21		2	6		2	6
W02	Preferred Water Source		5		8	40		8	40		2	10		4	20
W03	Testability of Water Source		1		8	8		8	8		4	4		7	7
H	Hydrogen Use	Must Have	10	Yes		83.4	Yes		77.9	Yes		79.0	Yes		83.2
H01	Site H2 Use < Expected H2 Production		3		10	30		10	30		10	30		8	24
H02	Site H2 Cost ($)		8		5.2	41.6		10	80		4.9	39.2		5.5	44
H03	PEM-ES Operating (% Time)		4		9.2	36.8		3.7	14.8		7.1	28.4		10	40
H04	H2 Value to the site	Y	10	Y	10	100	Y	7	70	Y	10	100	Y	10	100
R	Regulatory Issues		5			41.3			41.3			31.3			41.3
R01	Distance to Safety-Related Structures		1		10	10		10	10		10	10		10	10
R02	Distance to Security		1		8	8		10	10		10	10		10	10
R03	Emergency Plan Impact		1		10	10		10	10		10	10		10	10
R04	Environmental Impact		4		7	28		7	28		3	12		7	28
R05	Government Stakeholder		1		10	10		8	8		8	8		8	8
F	Human Factors		3			27.0			21.5			7.5			18.5
F01	Operational / Chemistry Convenience		3		8	24		7	21		1	3		5	15
F02	Supply Convenience		1		10	10		2	2		10	10		2	2
F03	Security Monitoring Convenience		2		10	20		10	20		1	2		10	20

Project timeline and next steps

	Key Milestones & Deliverables
Year 1 (BP1)	• Site selection, 30% engineering design • Simulation using prototype electrolyzer
Year 2 (BP2)	• 100% engineering design, decision to install • Complete manufacture, test of electrolyzer.
Year 3 (BP2)	• Start of steady state operation of electrolyzer • Simulation of scale-up electrolyzer operation • Demonstration of dynamic operation on site



Removal of condition for BP1, 4/1/2020

Go/No Go decision point 4/1/2021

End of Project 4/1/2023

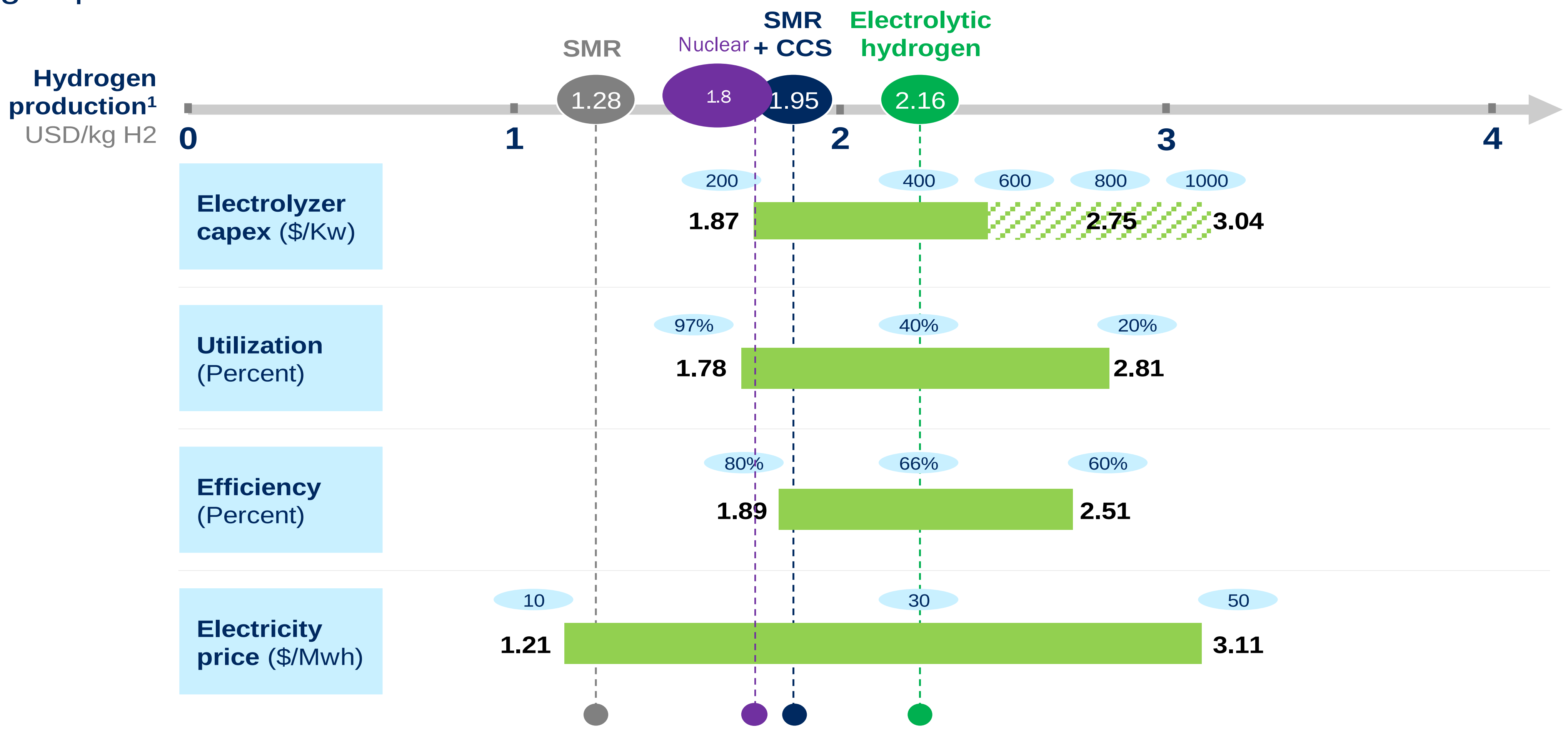
Budget Period 1:
Complete 30% Design
Demonstrate dynamics operation

Budget Period 2:
Finish 100% design, install, operate at steady state
Demonstrate dynamic operation, simulate scaleup

Exelon

Hydrogen Production Cost Is Sensitive To Electricity Price, Electrolyzer CAPEX And Capacity Factor (2030 view)

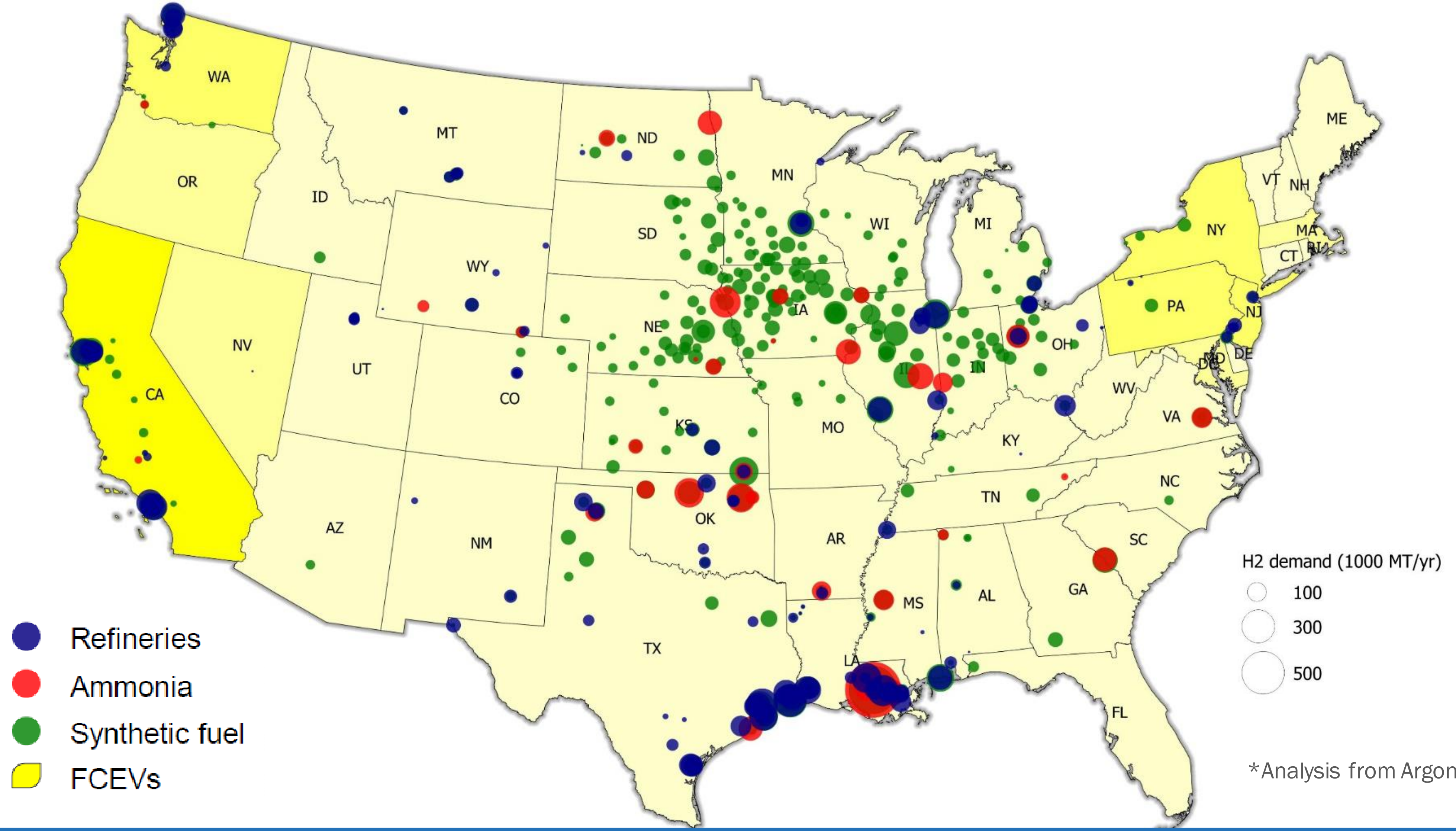
Hydrogen production cost scenarios in 2030



1 Natural Gas price of 4.59 USD/mmbtu in 2030
2 Capture Cost - 66 USD/ton CO2, Storage Cost - 20 USD/ton CO2, Transportation Cost – 6 USD/ton CO2
3 For electrolytic hydrogen: 20,000 Nm3/h electrolyzer assumed (~43,000 kg/day); electrolyzer capex includes the electrolyzer stack + Balance of Plant (e.g., valves, compressors, DI water system, pipes, rectifiers, heat exchangers, etc),installation costs are included in the model, capex related to transmission lines, buildings, civil works, water purification system, high purity dryer system, thermal control unit, and electric substation are not included

SOURCE: McKinsey modelling, EIA

Today, ~13M metric tons of hydrogen are produced in the U.S. annually- Equivalent to ~74GW if produced from electricity



*Analysis from Argonne National Lab

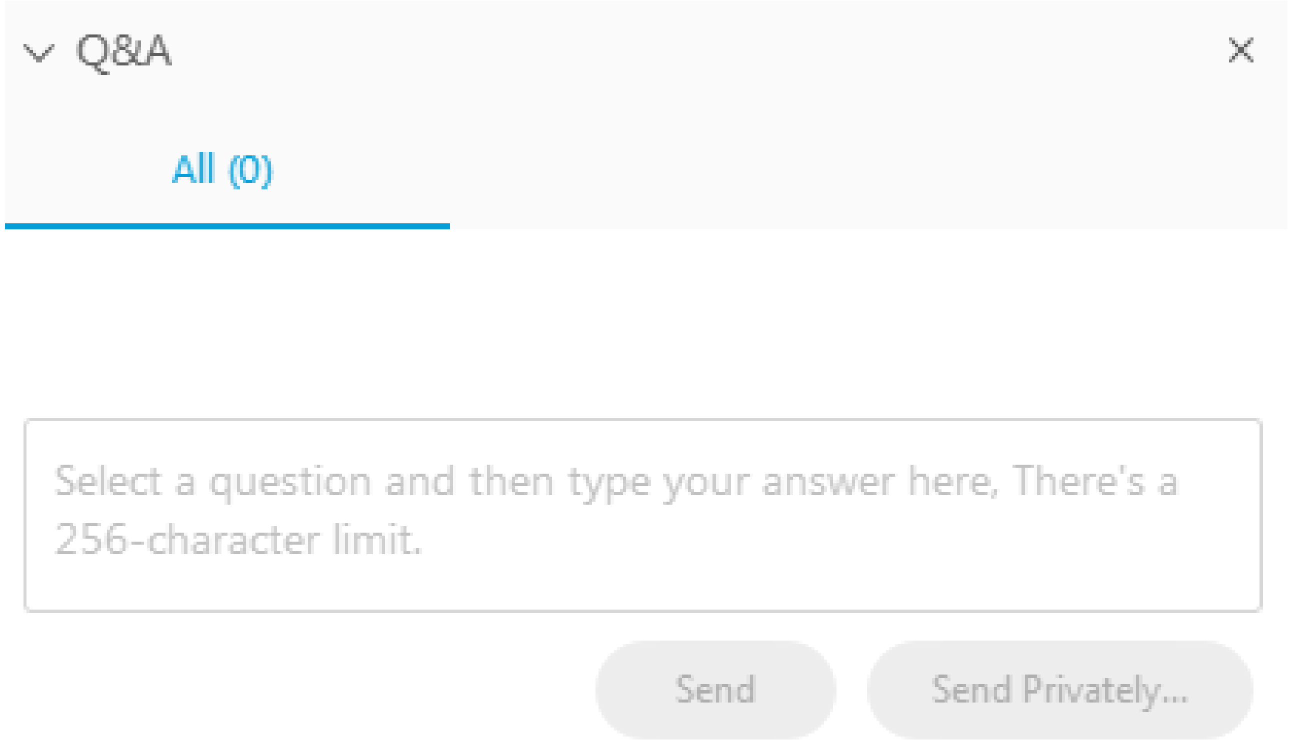
By 2030, potential hydrogen demand could grow to 25.6MMT (~140GW equivalent)

Conclusion and next steps

1. **Project is in Phase 1 execution**
    a) Exelon led team is executing Phase 1 of the project to reach Go/No Go decision in April 2021
2. **Team coordination setup**
    a) Exelon assembled a multidisciplinary team for the project including expertise from centralized engineering design organization, licensing, environmental, supply/procurement, legal, policy and others.
    b) Exelon finalizing procurement contract with Nel
3. **Technical achievements**
    a) Exelon has selected a site and executing site-specific design for 1MW PEM electrolyzer
    b) Pending authorization for communication regarding the site
    c) Exelon completed a robust economic analysis for hydrogen generation to off-set site hydrogen use
    d) Research scope is in progress on laboratory testing of a prototype PEM unit and electric grid modeling, hydrogen market research around the site
4. **Continue to assess the business feasibility of scaleup**
    a) Exploring potential customers and attributes that may be available
    b) Participate in further DOE funded research and demonstration projects

The #H2IQ Hour Q&A

Please type your questions into the **Q&A Box**



INCREASE YOUR H2IQ

The #H2IQ Hour

Thank you for your participation!

Learn more:

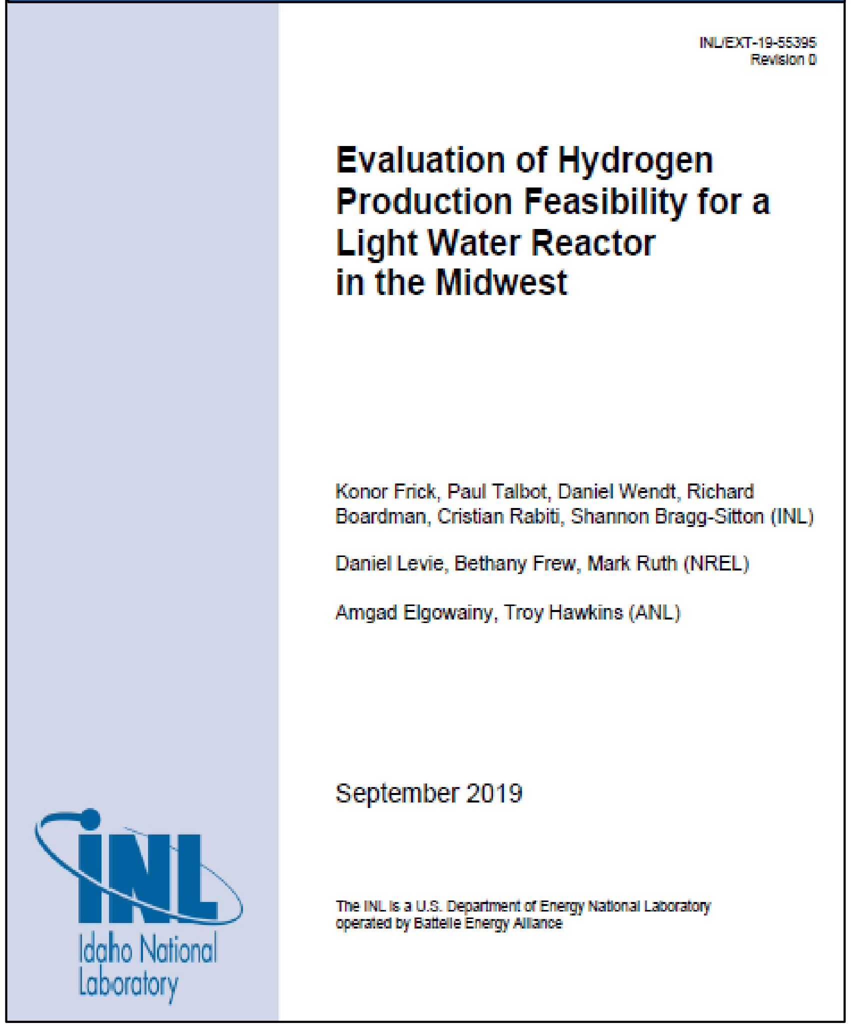
energy.gov/fuelcells
hydrogen.energy.gov

Backup Slides

Backup slides

Exelon participated in DOE funded studies to explore the economics of nuclear hydrogen production

2019 INL Study


INL/EXT-19-55395
Revision 0

Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest

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Daniel Levie, Bethany Frew, Mark Ruth (NREL)

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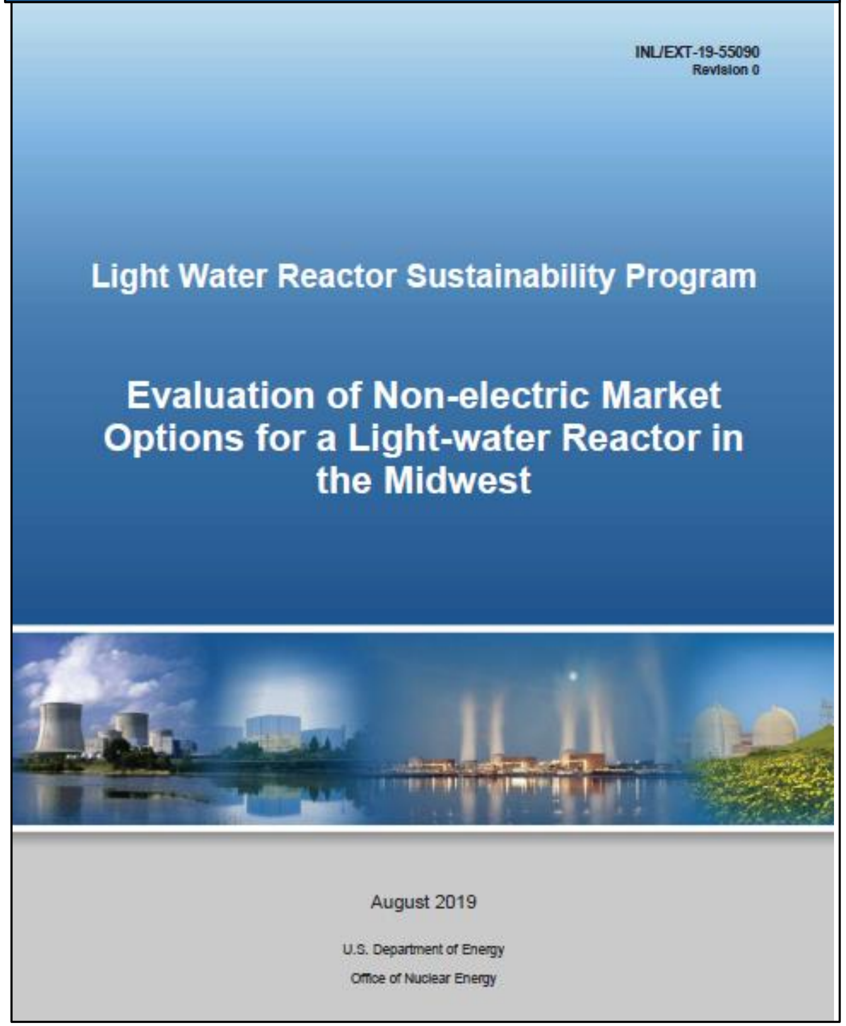
September 2019

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance

2019 LWRS report


INL/EXT-19-55090
Revision 0

Light Water Reactor Sustainability Program

Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest

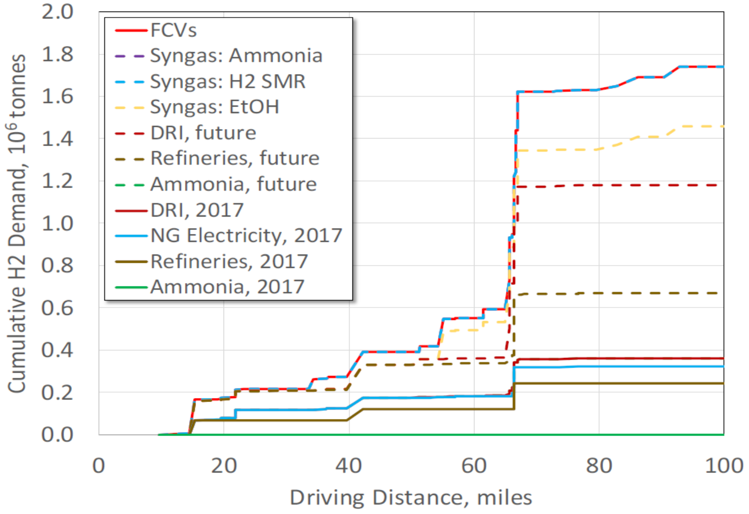
August 2019

U.S. Department of Energy

Office of Nuclear Energy

Preliminary result: Hydrogen demand

Hydrogen Demand near a nuclear site



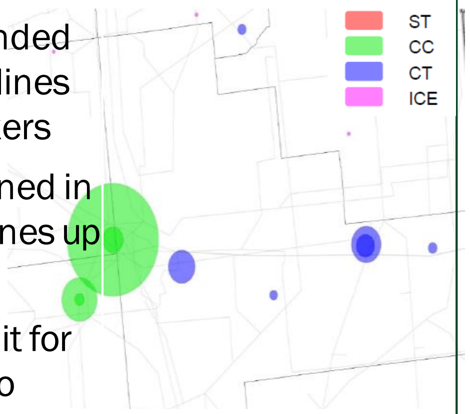
*Analysis from Argonne national lab

~1 MW electrolyzer

- 300 kg/day H2 for 8 hydrogen buses at a university campus
- Consistent with 1 MW electrolyzer @ 75% capacity factor
- ~100 miles tube trailer delivery

~10 MW electrolyzer

- Hydrogen can be blended into natural gas pipelines and sold to NG offtakers
- Hydrogen can be burned in NG combustion turbines up to 5% by volume
- Need significant credit for the green-hydrogen to make it economical



Large-scale (~100MW electrolyzer)

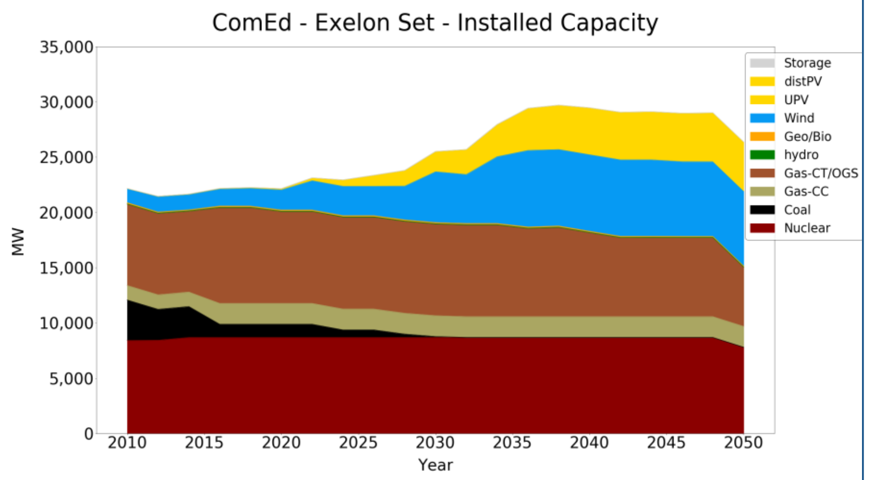
- ~50 MT/day additional hydrogen demand expected at a Refinery
- Consistent with ~100 MW electrolyzer @ 100% capacity factor

Electric power scenario modeling

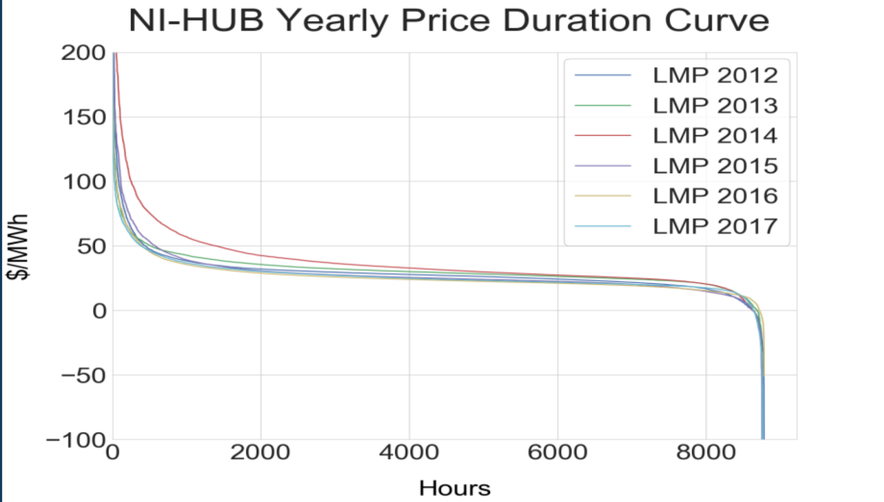
Future scenario assumptions

- **Low NG + Low RE** – AEO 2018 High Oil & Gas Resource and Technology & 2018 ATB Renewable Low-Case Projections (no increase in NG prices from 2018-2050)
- **80 Year Nuclear Lifetime** – All nuclear plants have an 80-year lifetime
- **Low Demand Growth** – AEO 2018 Low Economic Growth Rate (approximately 19% increase in U.S electricity demand from 2018 to 2050)
- **Vehicle Electrification** - Adoption of plug-in electric vehicles and plug-in hybrid electric vehicles reaches 40% of sales by 2050; 45% of charging utility-controlled, 55% opportunistic

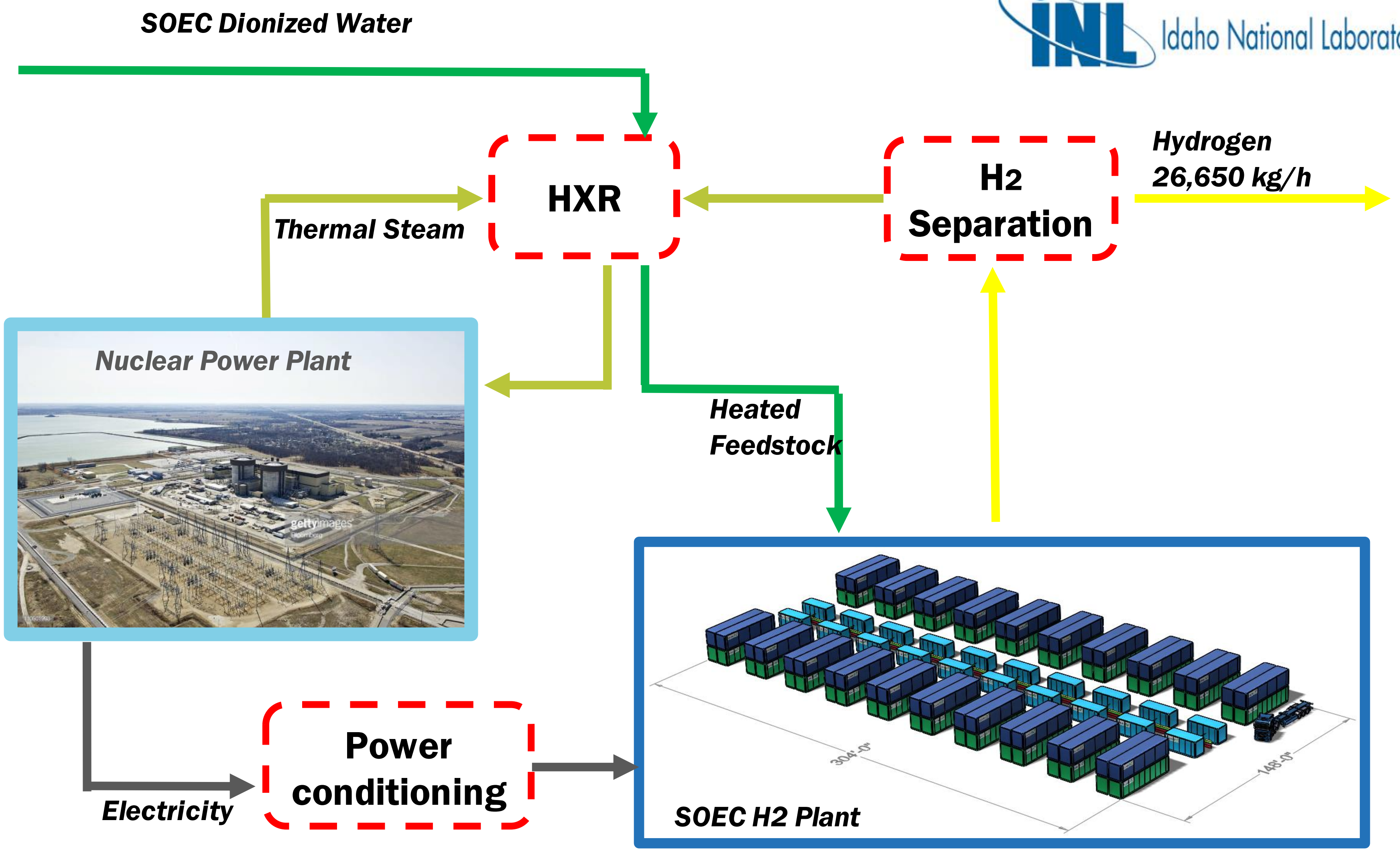
Capacity buildout projections



Price duration curves



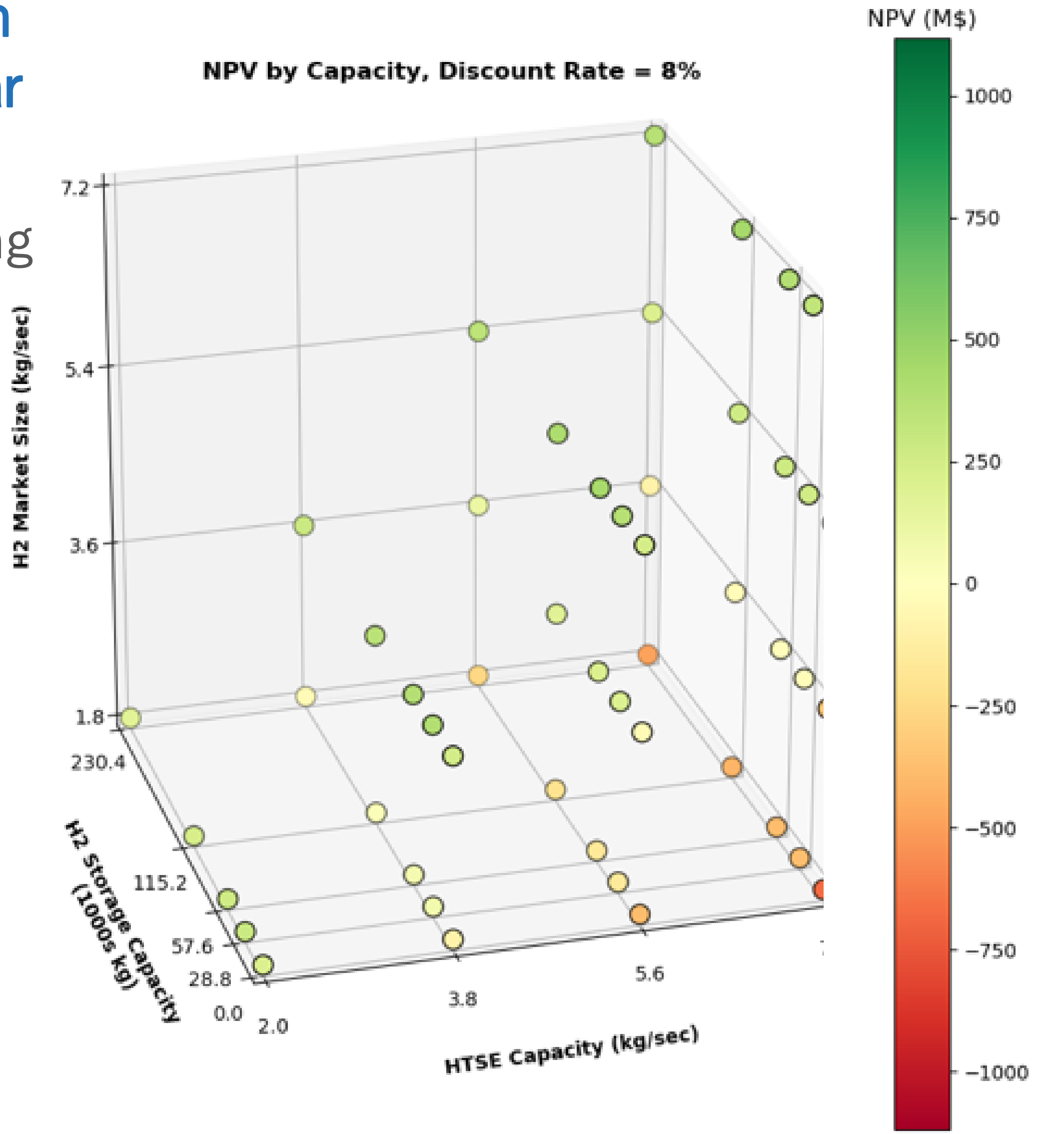
Preliminary result: Nuclear-integrated Electrolyzer Plant System Architecture



Dynamic HTSE operation results- Preliminary

Differential NPV over seventeen years of a co-generating nuclear station in PJM

- Medium hydrogen market selling prices ($/kg-$H_2$)
- Discount Rate = 8%
- Corporate Tax Rate = 21%,
- Inflation = 2.2%
- No carbon tax credits
- No participation in ancillary services market
- Assumes building a pipeline for delivery
- No ability to thermally cycle the HTSE plant due to current thermal constraints



Exelon.