H2@Scale: Energy System Wide Benefits of Increased Hydrogen Implementation

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Presented by Bryan Pivovar
National Renewable Energy Lab
bryan.pivovar@nrel.gov

Expanded content included in this presenation available at
https://www.hydrogen.energy.gov/pdfs/review18/h2000_pivovar_2018_o.pdf
https://www.hydrogen.energy.gov/pdfs/review18/tv045_ruth_2018_o.pdf
http://energy.gov/eere/fuelcells/downloads/h2-scale-potential-opportunity-webinar

Air Quality – Downtown Denver

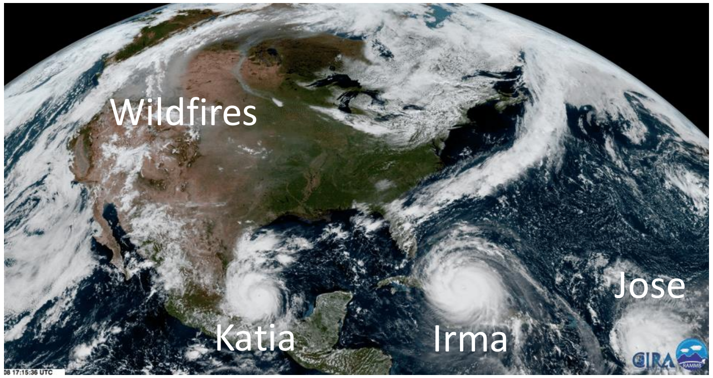
27 September 2016 | GENEVA - A new WHO air quality model confirms that 92% of the world's population lives in places where air quality levels exceed WHO limits.

WHO: Air pollution caused one in eight deaths / *March 25, 2014*

http://www.cnn.com/2014/03/25/health/who-air-pollution-deaths/

Select (Relevant) Megatrends

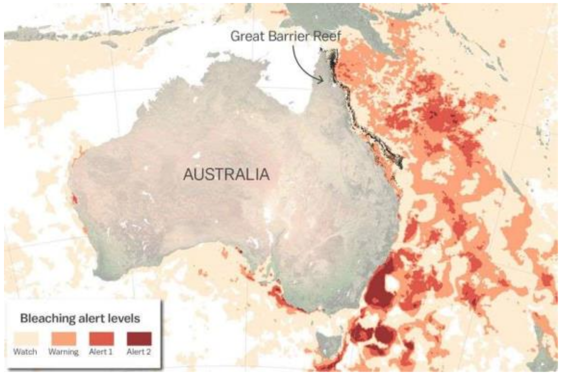
- Increased global focus on emissions, increased policy regulations (market impact)
- Low, cost intermittent renewable electrons
- Increased electrification
- Connectivity, Autonomy, Machine Learning



When the Planet Looks Like a Climate-Change Ad (9/12/17)
https://www.theatlantic.com/science/archive/2017/09/an-extraordinary-week-in-north-american-weather/539544/

Downtown Denver from NREL's Energy System Integration Facility

The Great Barrier Reef's catastrophic coral bleaching, in one map

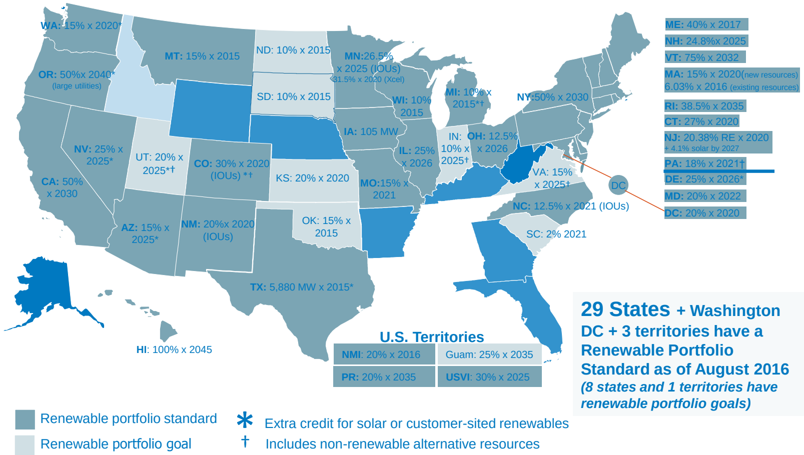


Changing Energy System – Policy

Renewable Portfolio Standards (RPS)

Senate Bill 100, signed by Gov. Edmund G. Brown, Jr. codifies 60% by 2030 & 100% by 2045 RPS (2018)

http://www.energy.ca.gov/renewables/



Zero Emission Vehicles (ZEV)

2016 ZEV Action Plan toward 1.5 million ZEVs by 2025.

https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf

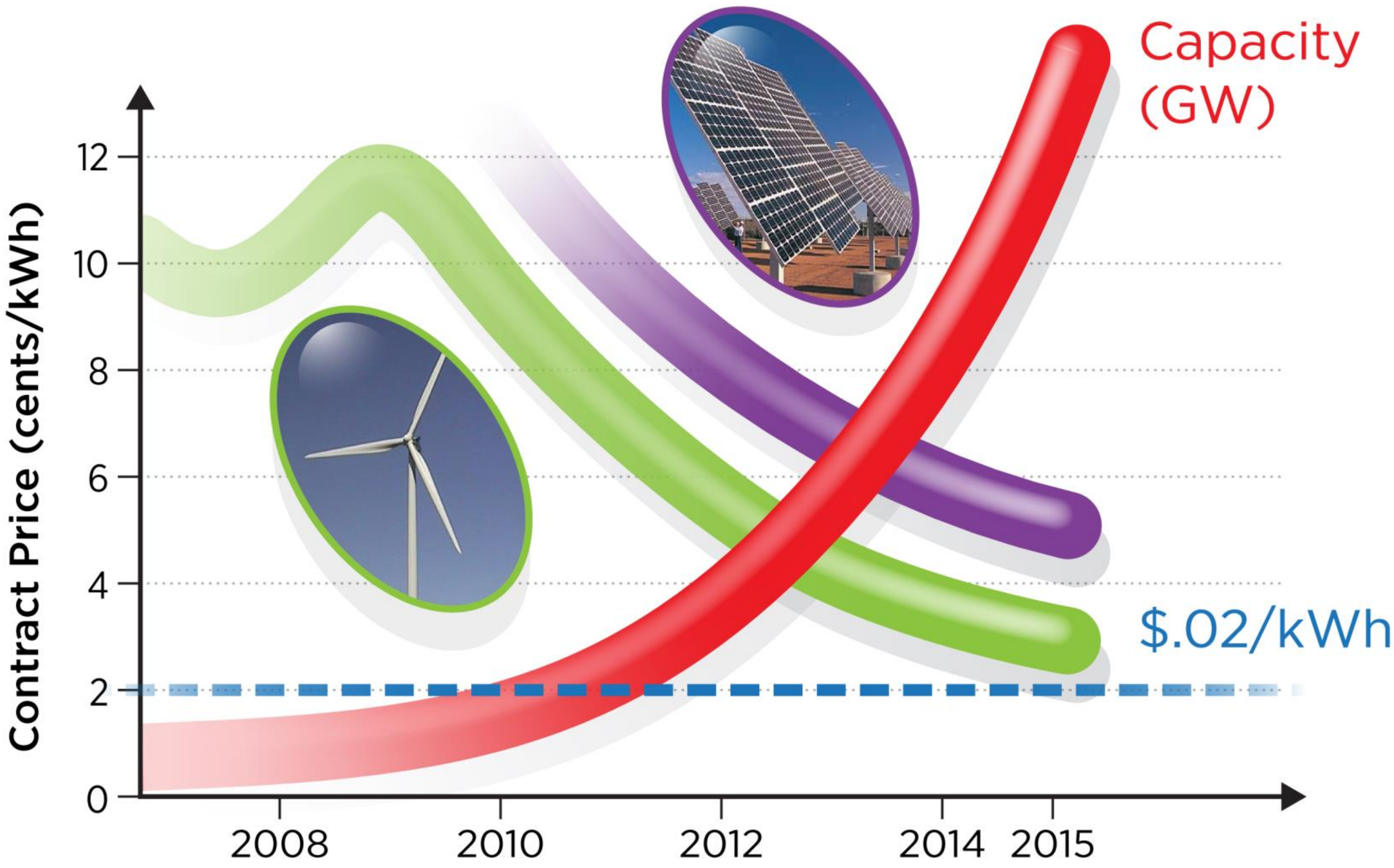
https://www.c2es.org/us-states-regions/policy-maps/zev-program

Renewable Gas Standard

SB-687 Renewable gas standard

http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB687

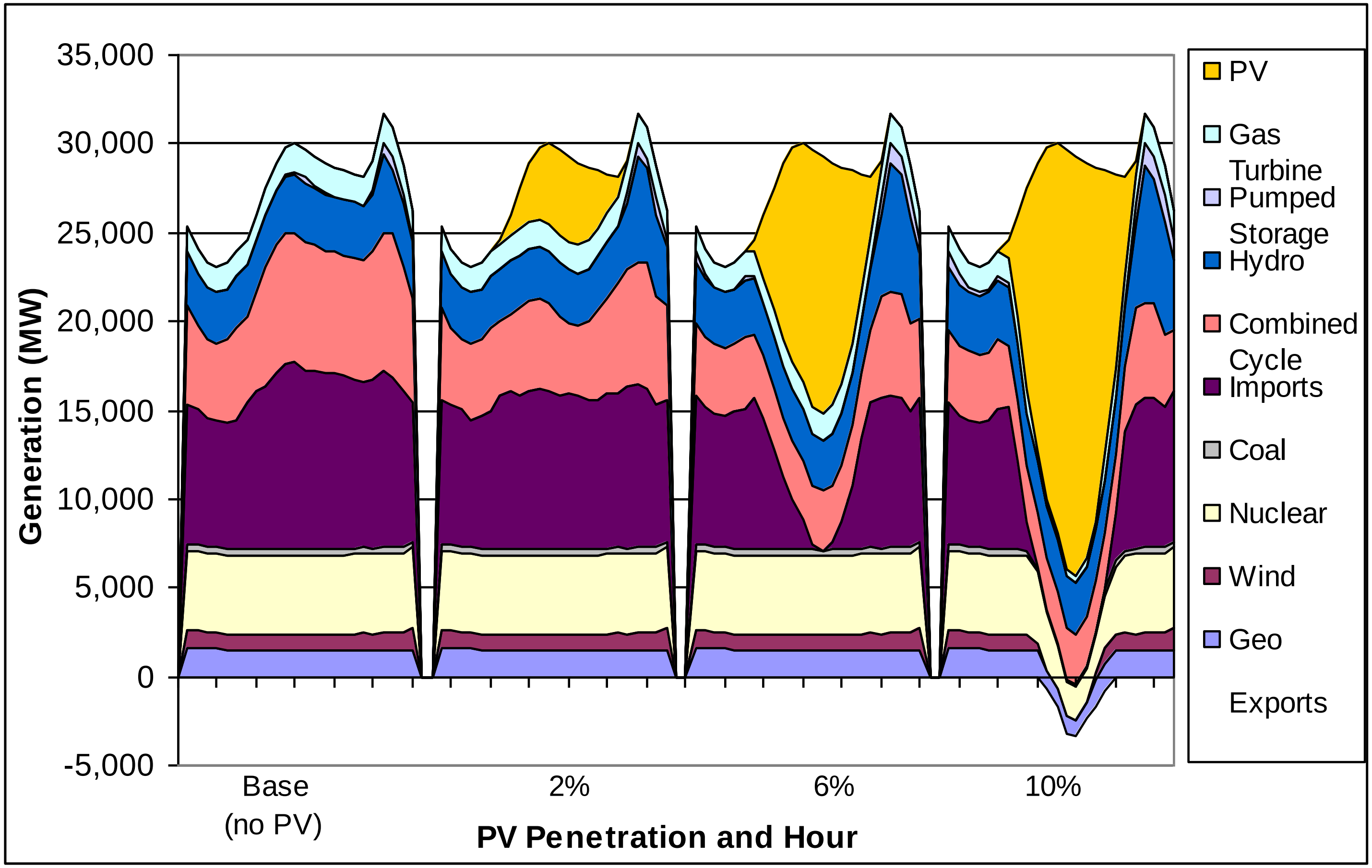
Renewable electricity price trends



Source: (Arun Majumdar) 1. DOE EERE Sunshot Q1'15 Report, 2. DOE EERE Wind Report, 2015

Renewable Challenges

Denholm et al. 2008



Energy System Challenge

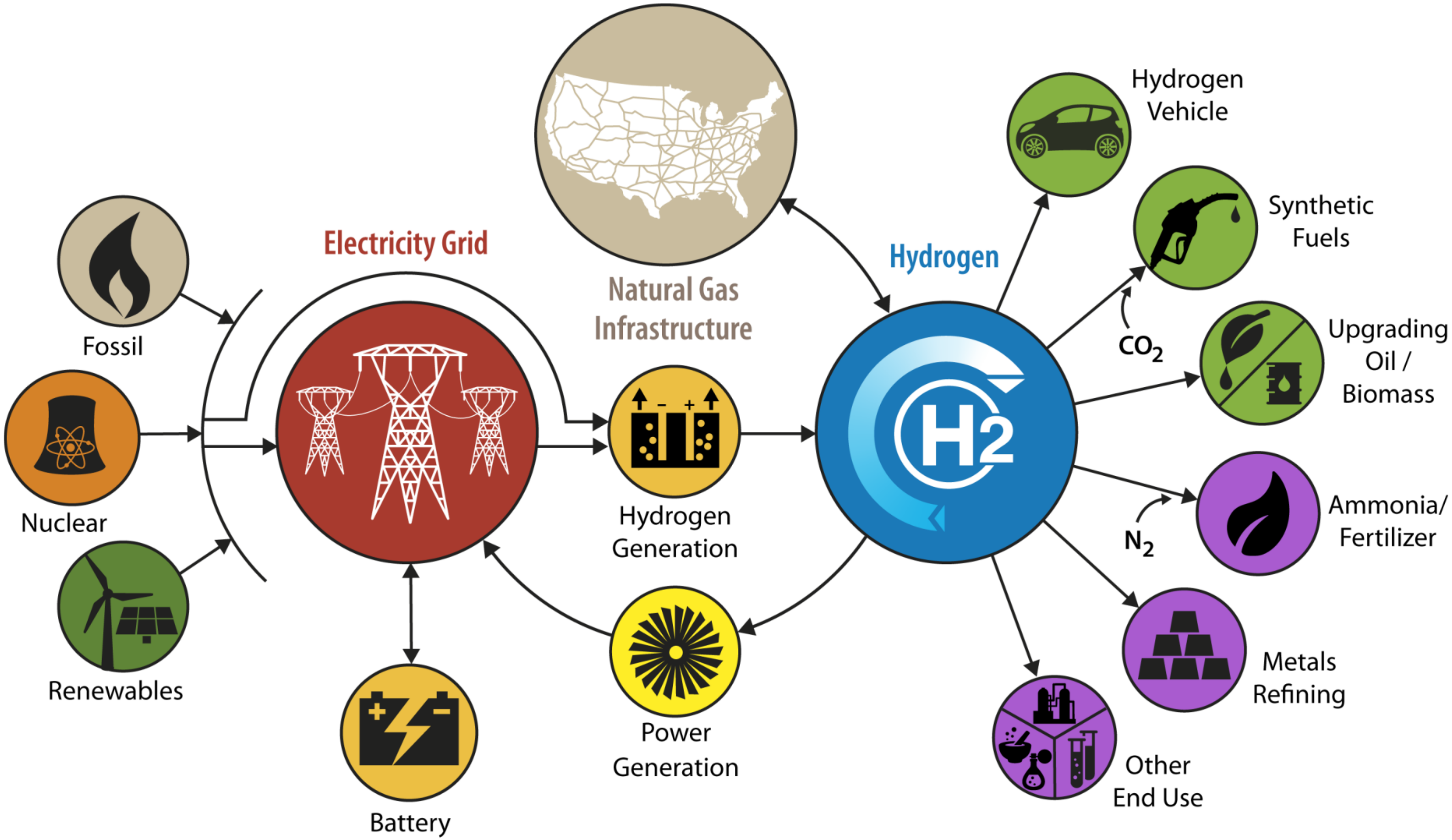
- **Multi-sector requirements**
  - Transportation
  - Industrial
  - Grid

How do we supply all these services in the best way?

- **Dwight D. Eisenhower**

"If you can't solve a problem, enlarge it"

Conceptual H_2@Scale Energy System*



Hydrogen at Scale (H_2@Scale): Key to a Clean, Economic, and Sustainable Energy System, Bryan Pivovar, Neha Rustagi, Sunita Satyapal, Electrochem. Soc. Interface Spring 2018 27(1): 47-52; doi:10.1149/2.F04181if

*Illustrative example, not comprehensive

H2@Scale Vision

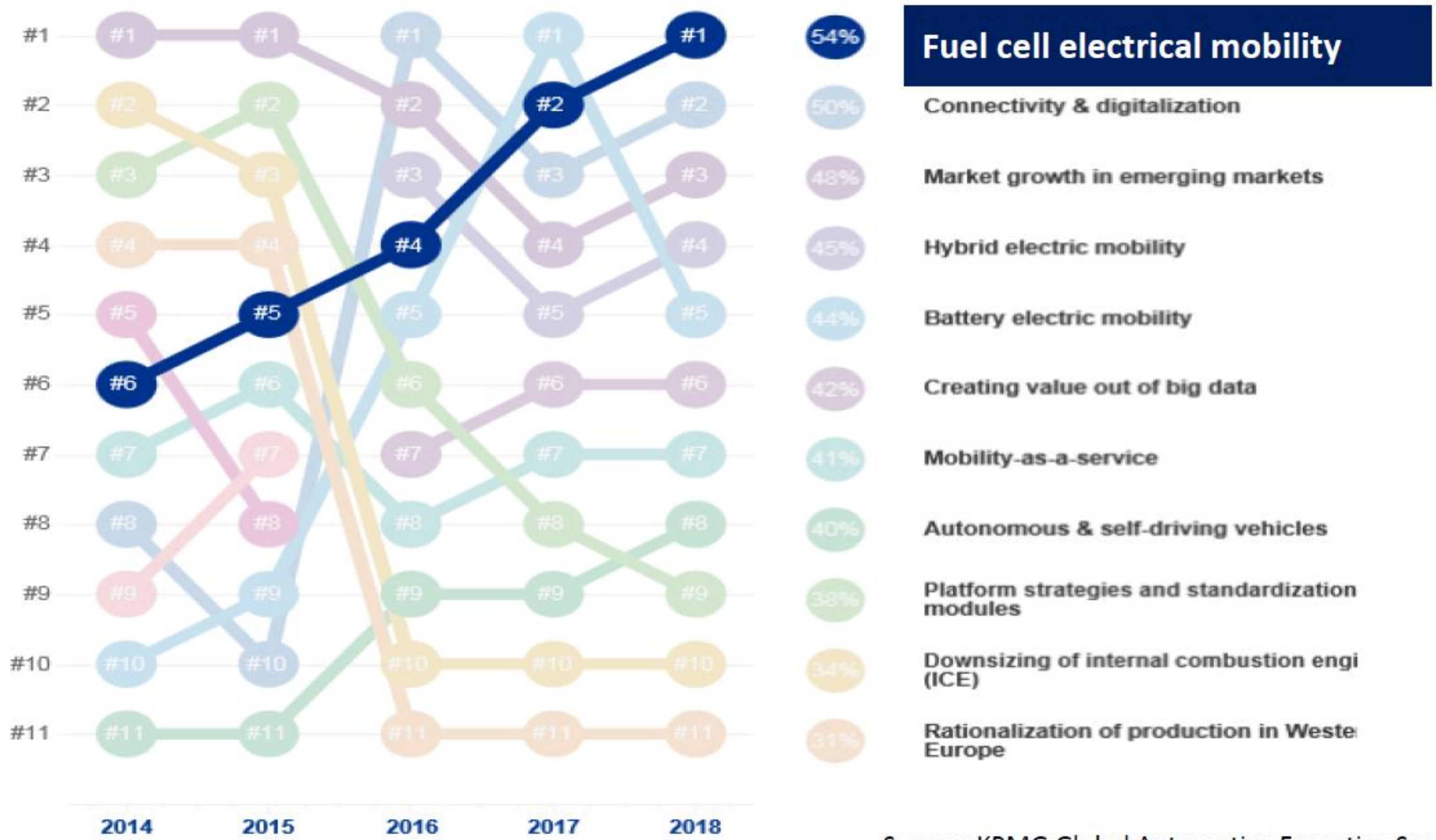
- **Attributes**
  - Cross-sectoral and temporal energy impact
  - Clean, efficient end use

- **Benefits**
  - Economic factors (jobs, GDP)
  - Enhanced Security (energy, manufacturing)
  - Environmental Benefits (air, water)

Getting all these benefits in a single energy system significantly enhances value proposition.

Changing times for H2

First time fuel cell electric mobility ranks #1 trend among automotive executives



Source: KPMG Global Automotive Executive Survey 2018

H_2 is different and changing fast

- **H_2 Council***
  - Launched in January 2017 its members include leading companies with over $10 billion in investments along the hydrogen value chain, including transportation, industry, and energy exploration, production, and distribution.

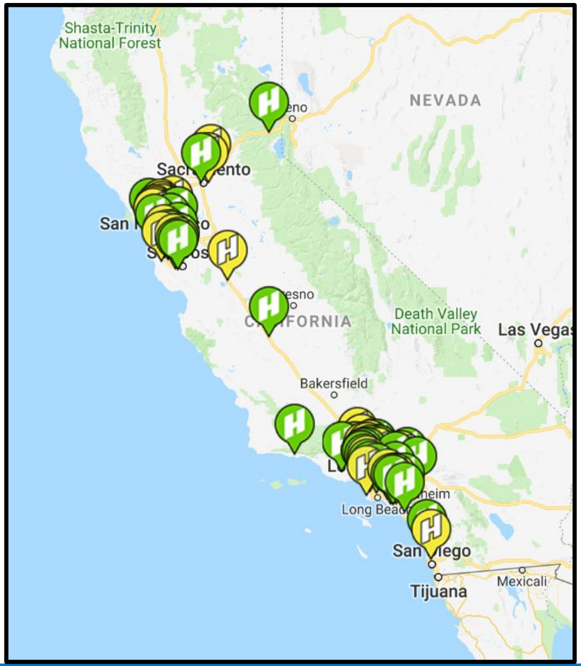
> ***Potential Impacts from Hydrogen Council Roadmap Study. By 2050:***
> - *$2.5 trillion in global revenues*
> - *30 million jobs*
> - *400 million cars, 15-20 million trucks*
> - *18% of total global energy demand*

13 members (Jan 2017).

32 steering members and 20 supporting members (Nov 2018).

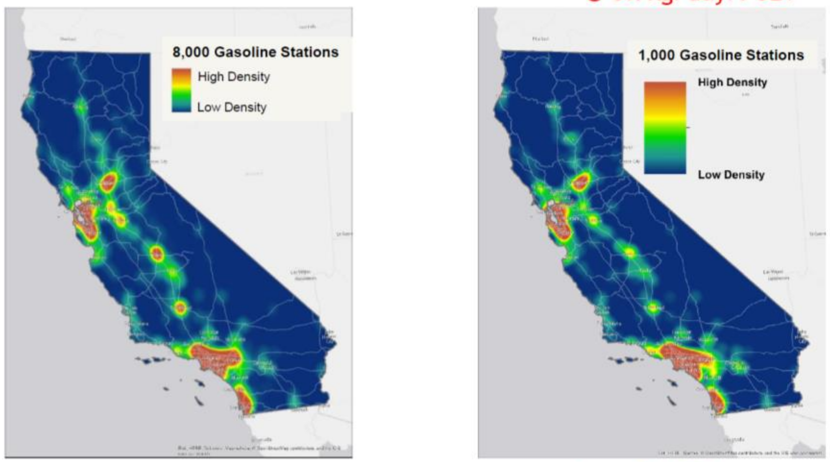
*Steering members shown, additional supporting members
www.hydrogencouncil.com

Real-world H2@Scale Examples



>5,000 Fuel Cell Vehicles and 35 commercial H_2 fueling stations open in CA.

8,000 gasoline stations vs. 1,000 H2 stations
for 1,000,000 FCEVs
@ 0.7kg/day/FCEV



by 2030

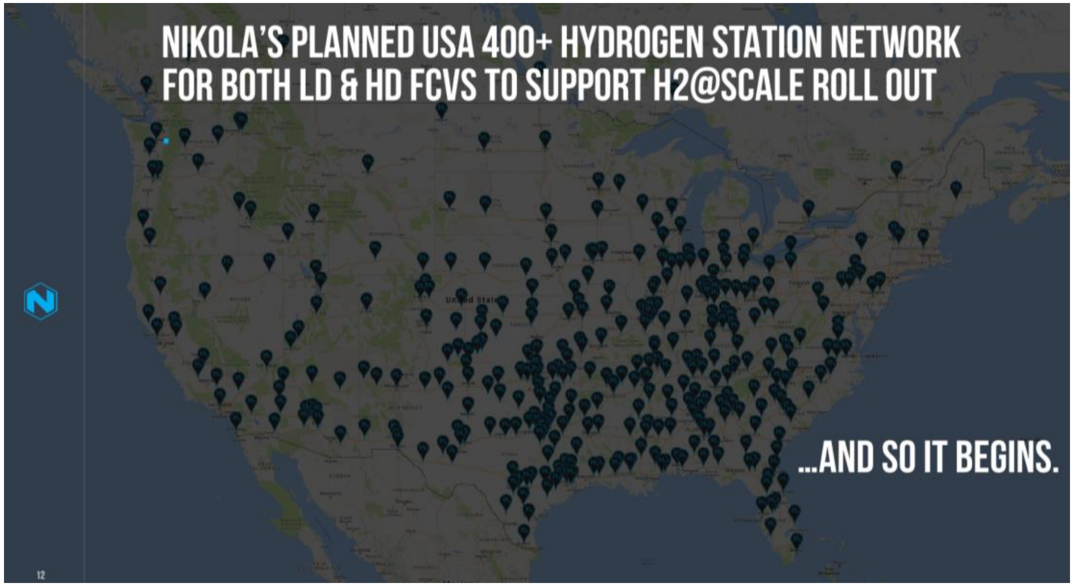
https://www.energy.gov/sites/prod/files/2018/08/f54/fcto-h2-scale-kickoff-2018-14-bouwcamp.pdf

Real-world H2@Scale Examples

8.08 AM CEST / 28-Jun-2018 / NEL ASA (OSE:NEL)

Nel ASA: Awarded multi-billion NOK electrolyzer and fueling station contract by Nikola

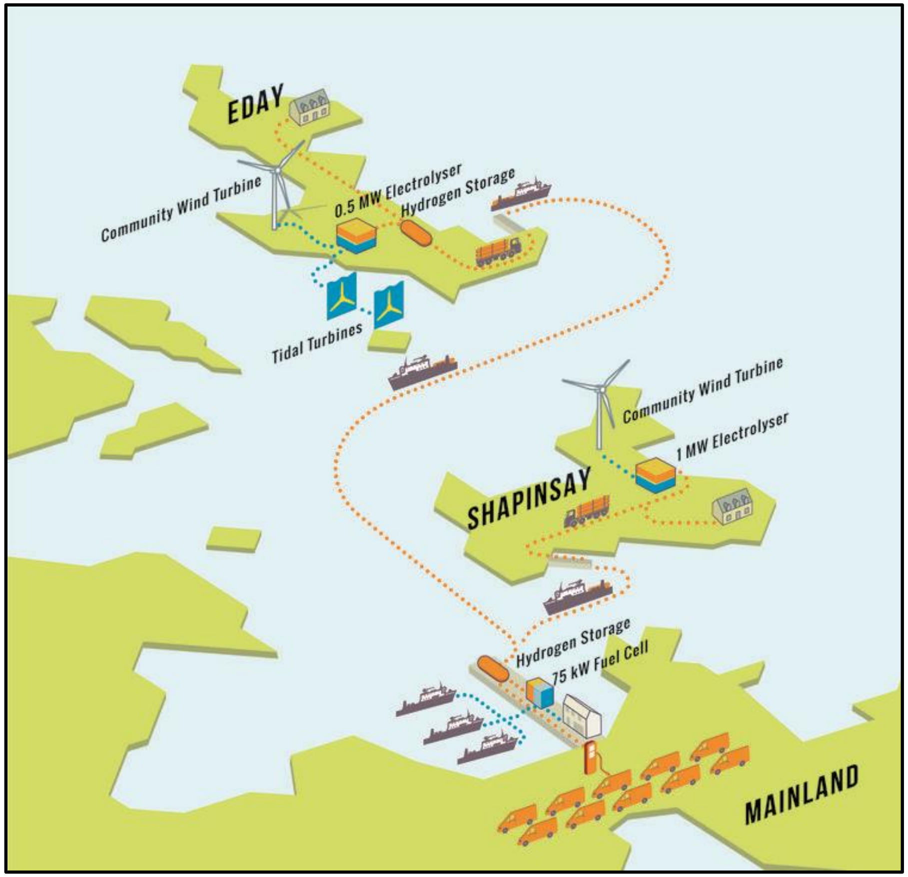
1,000 kg/day hydrogen stations to be deployed in 14-28 locations for fuel cell trucks (2018; Nikola, Nel)



https://www.energy.gov/sites/prod/files/2018/08/f54/fcto-h2-scale-kickoff-2018-17-schneider.pdf

Real-world H2@Scale Examples

750,000 tonne/year ammonia plant using by-product hydrogen opens in Freeport, TX
(2018; Yara, BSF)



Integration of 1.5-MW of electrolysis with wind and tidal power in Orkney, Scotland
(2018; BIG HIT project)

H2@Scale CRADA Call Selections

First round of Selections Include 24 Applications from:

H_2 Station Risk Analysis
- Air Liquide
- California Energy Commission
- Connecticut Center for Advanced Technology
- PDC Machines
- Quong & Associates, Inc.

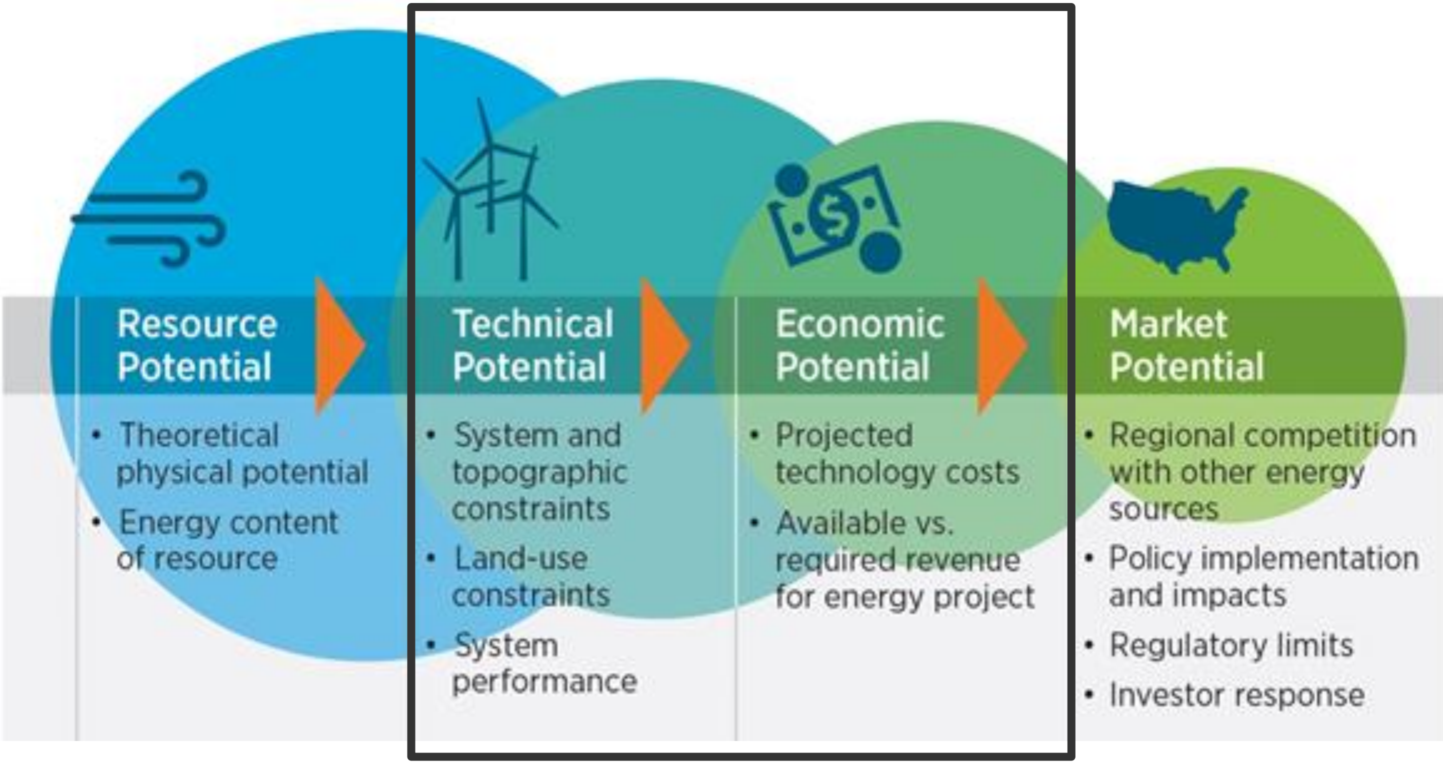
Hydrogen Integration
- Electric Power Research Institute
- Exelon
- Southern Company / Terrestrial Energy
- Nikola Motor
- Pacific Gas & Electric
- TerraPower

Hydrogen Production R&D
- Honda
- C4-MCP, Inc.
- GinerELX
- GTA, Inc.

Component R&D
- California Go-Biz Office
- Frontier Energy
- HyET
- Honda
- NanoSonic
- RIX
- Tatsuno

Selections and subsequent working group assignments are subject to negotiation.

Approach: Analyze the Technical and Economic Potential of the H2@Scale Concept



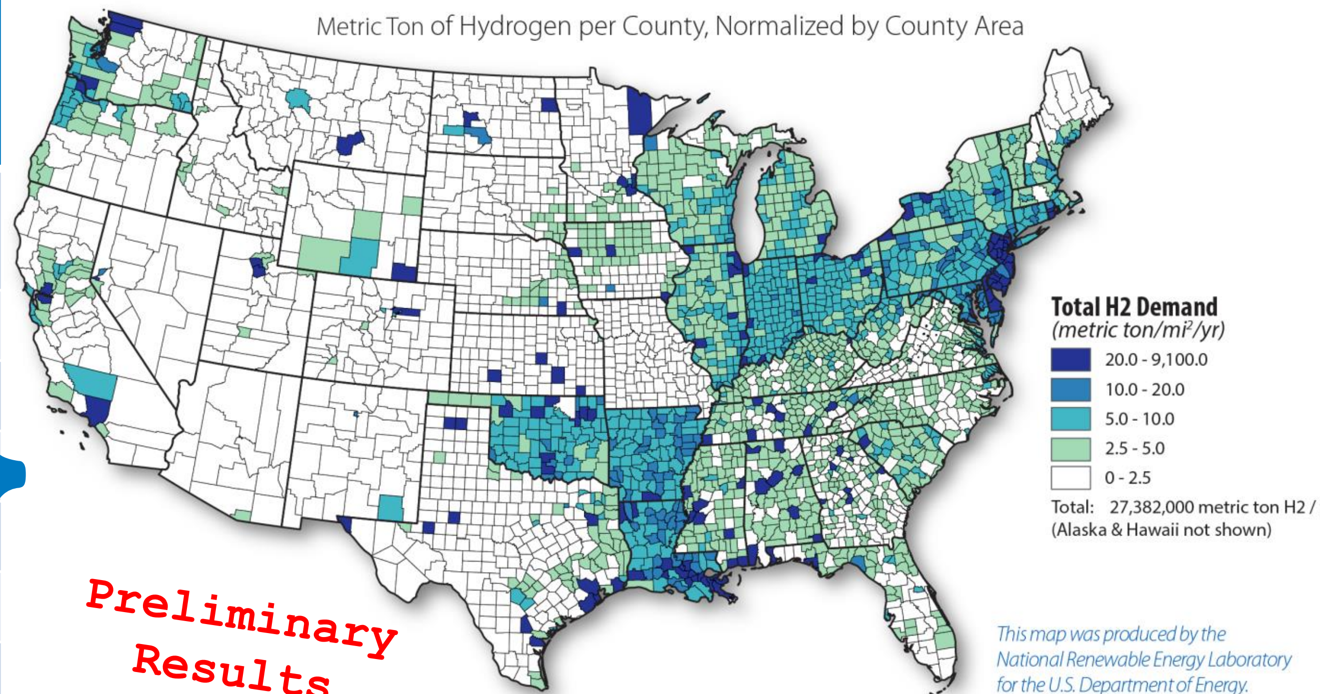
Technical potential – market and resource potential that is constrained by existing end-uses, real-world geography, and system performance. *Not constrained by economics.*

Economic potential – subset of the technical potential where hydrogen is less expensive than other options that can supply the end use.

Figure Source: Brown, A., P. Beiter, D. Heimiller, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro. 2015. *Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-64503

Accomplishment: Estimated Technical Potential Hydrogen Demand

Demand	Technical potential (MMT* / year)
Refineries & CPI[§]	8
Metals	6
Ammonia	5
Methanol	1
Biofuels	1
Natural Gas	7
Light Duty Vehicles	28
Other Transport	3
Electricity Storage	28
Total	**87**



This analysis represents the total hydrogen demand estimated to be achievable in the U.S. in the following sectors: refineries, biofuels, ammonia, metals, methanol, natural gas systems, and seasonal energy storage. Each industrial sector was summarized by county to identify the total hydrogen demand for the industrial sector and then normalized by area.

Data Source: NREL analysis

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Technical Potential Demand: 87 MMT/yr

Current U.S. market: ≈ 13 MMT/yr

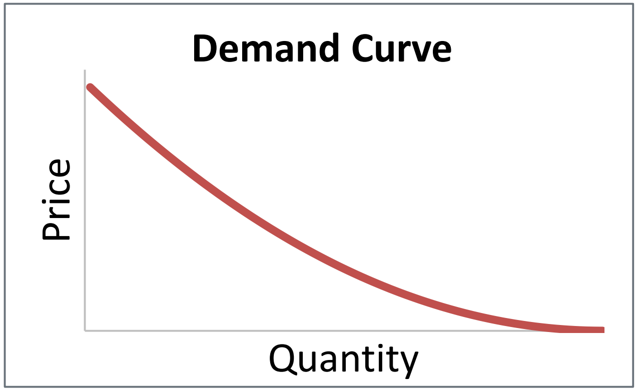
Including captive generation for ammonia and refining

* MMT: Million metric tonnes

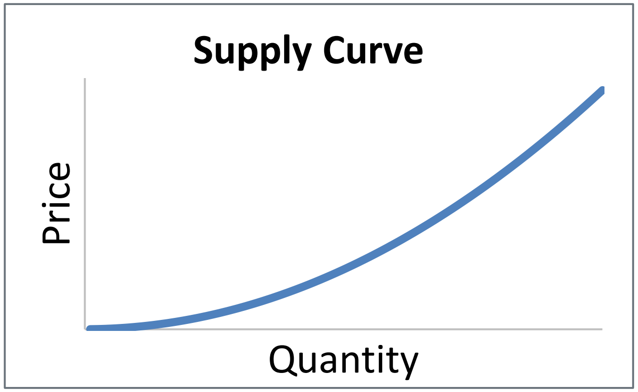
§ CPI: Chemical Processing Industry not including metals, ammonia, methanol, or biofuels

Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

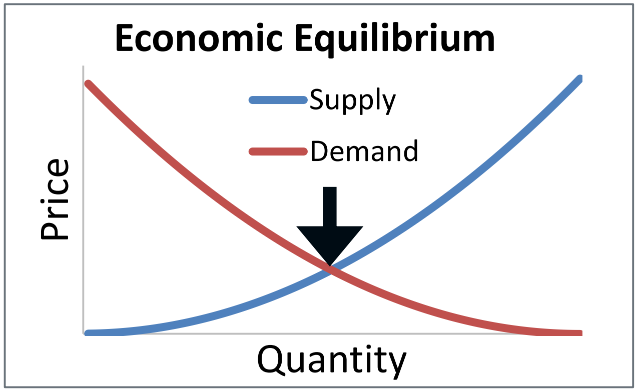
Approach: Estimate Economic Potential as Hydrogen Prices and Quantities at Market Equilibria



Demand Curve: how much are consumers willing and able to pay for a good?



Supply Curve: how much are producers willing and able to produce at various prices?



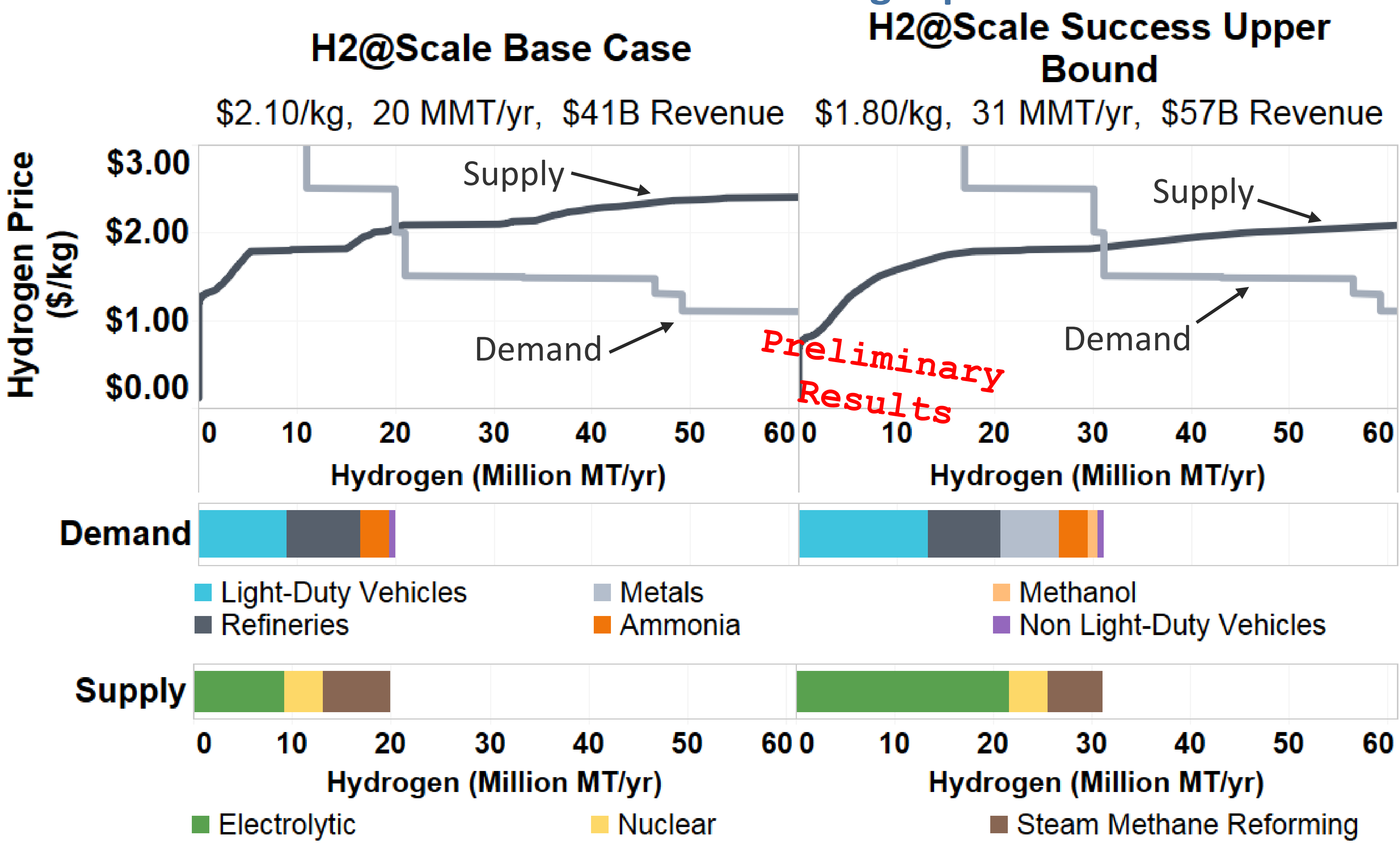
Economic Equilibrium: Quantity where the demand price is equal to the supply price.

- No excess supply or demand.
- Market will push price and quantity to equilibrium.

Schwartz, Robert A. *Micro Markets A Market Structure Approach to Microeconomic Analysis*. Wiley Finance. Chichester: Wiley, 2010.

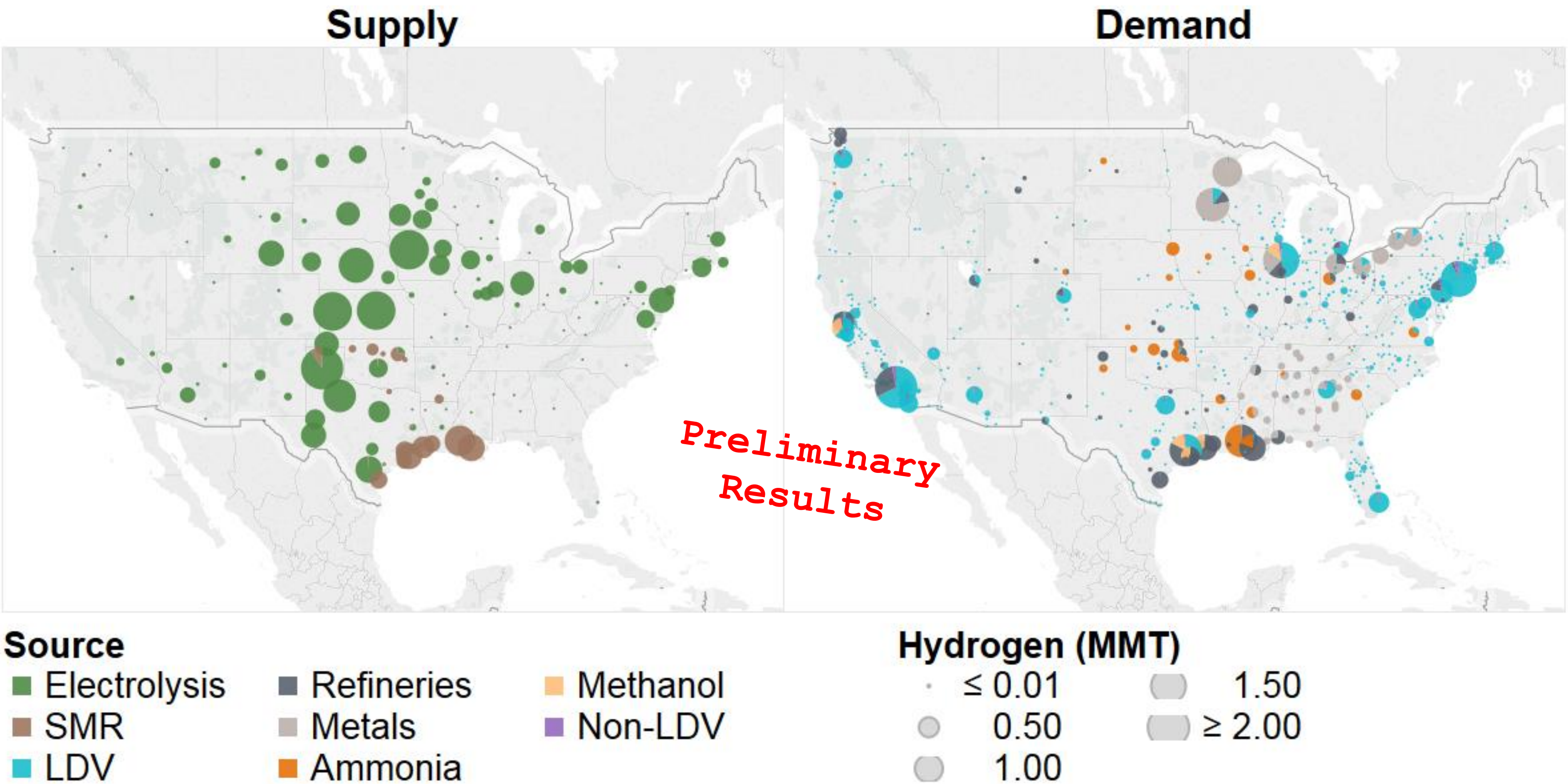
Accomplishment: Developed Four Economic Potential Scenarios

Estimated hydrogen market size: 20-31 MMT/yr with AEO Low Oil & Gas Resource Scenario natural gas prices.



Accomplishment: Initiated Analysis of Spatial and Temporal Issues

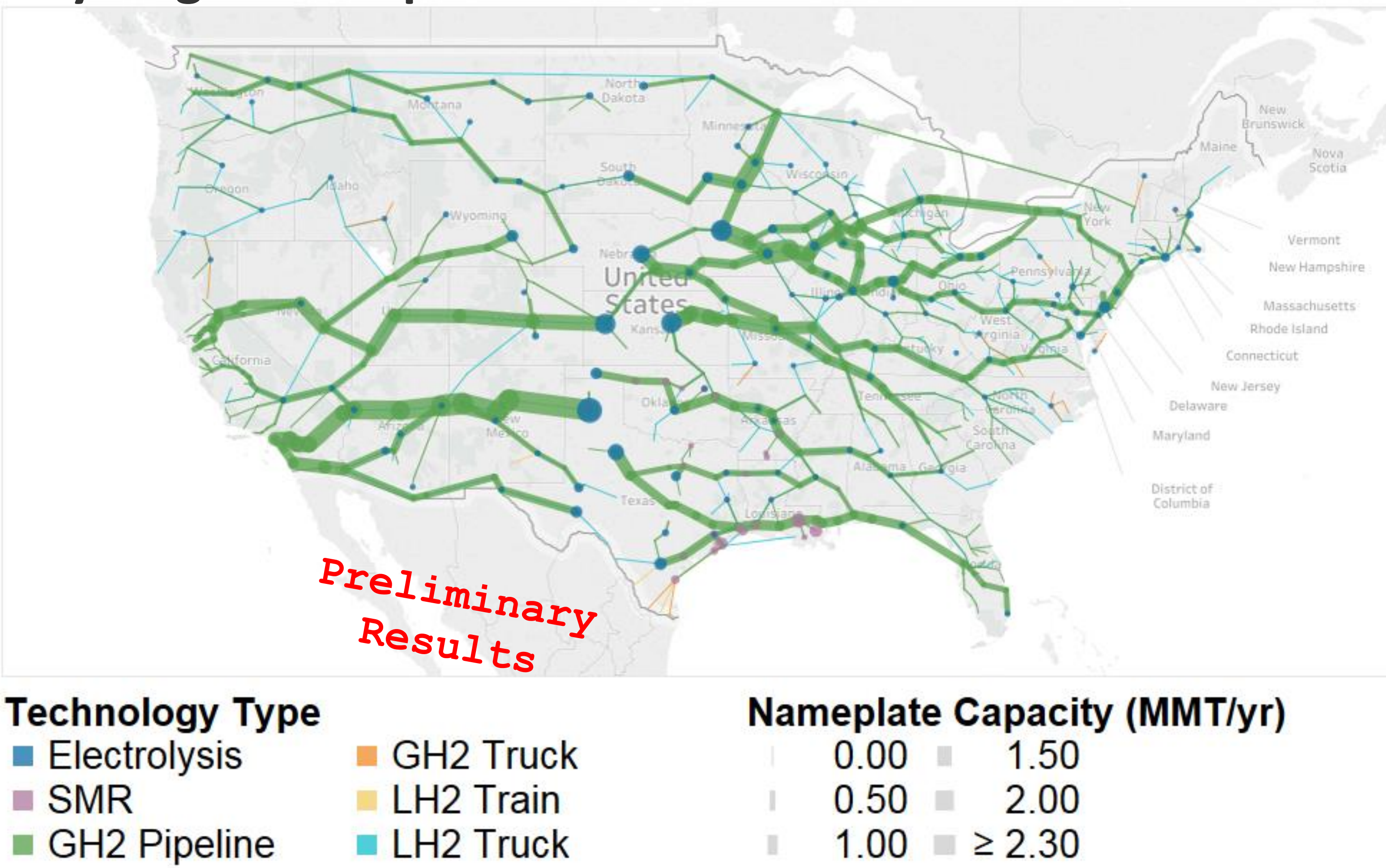
In the H2@Scale Success Upper Bound scenario, most of the hydrogen is produced from wind power in the middle of the country and demand is dispersed, but mainly on the coasts.



Electrolysis includes low-temperature and high-temperature electrolysis

Accomplishment: Initiated Analysis of Spatial and Temporal Issues

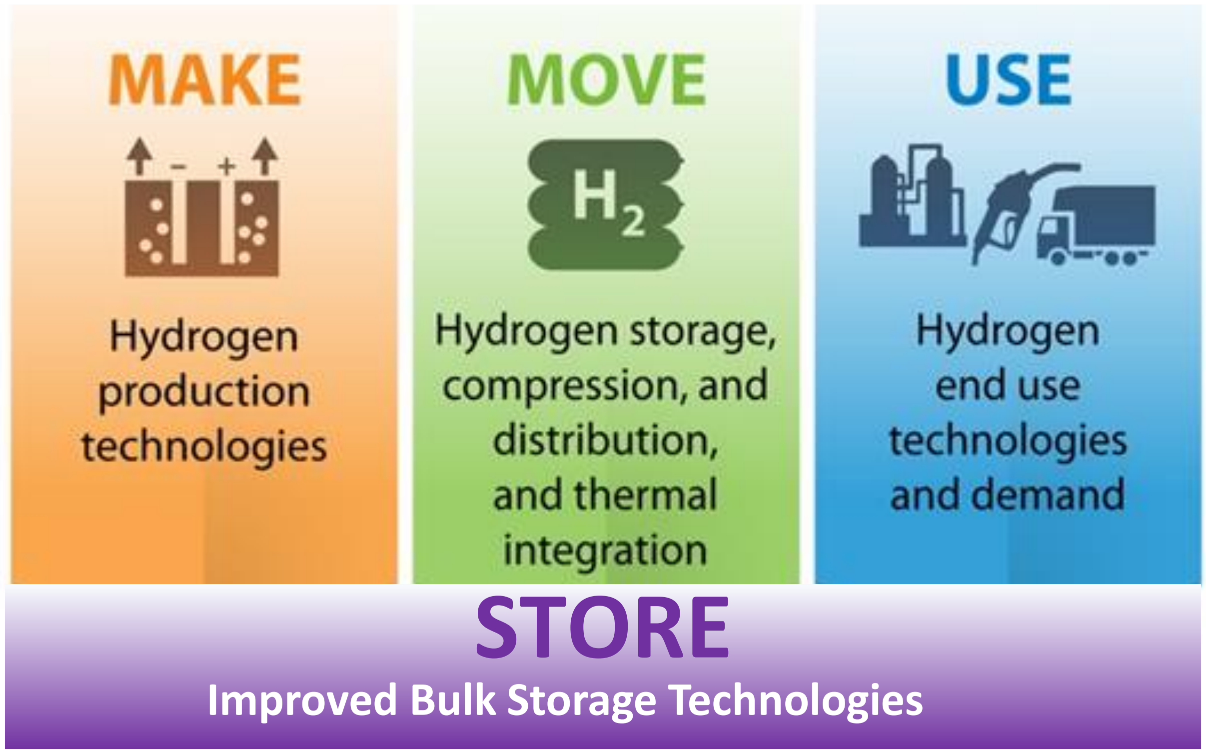
In the H2@Scale Success Upper Bound scenario, initial analyses indicate pipeline transport is the most economic method to get hydrogen from production to demand for most corridors.



Electrolysis includes low-temperature and high-temperature electrolysis

Improving the economics of H2@Scale

Early-stage research is required to evolve and de-risk the technologies



Preliminary

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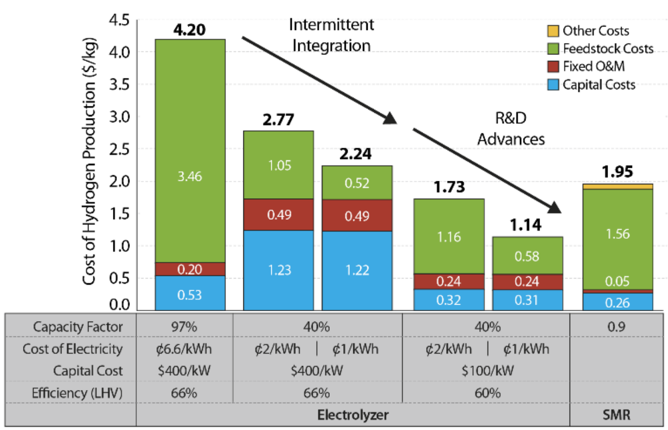
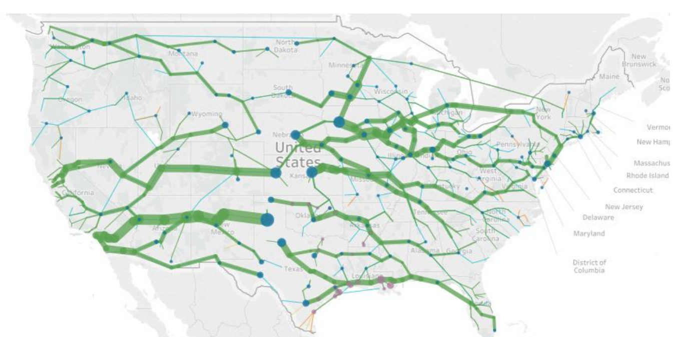


Decreasing cost of H_2 production



Optimizing H_2 storage and distribution

Leveraging of national laboratories' early-stage R&D capabilities needed to develop affordable technologies for production, delivery, and end use applications.

https://www.hydrogen.energy.gov/pdfs/review18/tv045_ruth_2018_o.pdf

H_2 at Scale Big Idea Teams/Acknowledgement

H2@Scale has moved beyond this National Lab team to include DOE offices, and industrial/other stakeholders.

Steering Committee:

Bryan Pivovar (lead, NREL), Amgad Elgowainy (ANL), Richard Boardman (INL), Adam Weber (LBNL), Rod Borup (LANL), Mark Ruth (NREL), Jamie Holladay (PNNL), Chris Moen (SNL), Don Anton (SRNL)

Low T Generation:
Rod Borup (lead, LANL); Jamie Holladay (PNNL); Christopher San Marchi (SNL); Hector Colon Mercado (SRNL); Kevin Harrison (NREL); Ted Krause (ANL); Adam Weber (LBNL); David Wood (ORNL)

High T Generation:
Jamie Holladay (lead, PNNL); Jim O'Brien (INL); Tony McDaniel (SNL); Ting He (INL); Mike Penev (NREL); Bill Summers (SRNL); Maximilian Gorensek (SRNL); Jeffery Stevenson (PNNL); Mo Khaleel (ORNL)

Storage and Distribution:
Don Anton (lead, SRNL); Chris San Marchi (SNL); Kriston Brooks (PNNL); Troy Semelsberger (LANL); Salvador Aceves (LLNL); Thomas Gennett (NREL); Jeff Long (LBNL); Mark Allendorf (SNL); Mark Bowden PNNL; Tom Autrey PNNL

Utilization:
Richard Boardman (lead, INL); Don Anton (SRNL); Amgad Elgowainy (ANL); Bob Hwang (SNL); Mark Bearden (PNNL); Mark Ruth (NREL); Colin McMillan (NREL); Ting He (INL); Michael Glazoff (INL); Art Pontau (SNL); Kriston Brooks (PNNL); Jamie Holladay (PNNL); Christopher San Marchi (SNL); Mary Biddy (NREL) ; Geo Richards (NETL)

Future Electric Grid:
Charles Hanley (lead, SNL); Art Anderson (NREL); Bryan Hannegan (NREL); Chris San Marchi (SNL); Ross Guttromson (SNL); Michael Kintner-Meyer (PNNL); Jamie Holladay (PNNL); Rob Hovsapian (INL)

Foundational Science:
Adam Weber (lead, LBNL); Voja Stamekovic (ANL); Nenad Markovic (ANL); Frances Houle (LBNL); Morris Bullock (PNNL); Aaron Appel (PNNL); Wendy Shaw (PNNL); Tom Jaramillo (SLAC); Jens Norskov (SLAC); Mark Hartney (SLAC), Vitalij Pecharsky (Ames); Alex Harris (BNL)

Analysis:
Mark Ruth (lead, NREL); Amgad Elgowainy (co-lead, ANL); Josh Eichman (NREL); Joe Cordaro (SRNL); Salvador Aceves (LLNL); Max Wei (LBNL); Karen Studarus (PNNL); Todd West (SNL); Steve Wach (SRNL); Richard Boardman (INL); David Tamburello (SRNL); Suzanne Singer (LLNL)

Thank You