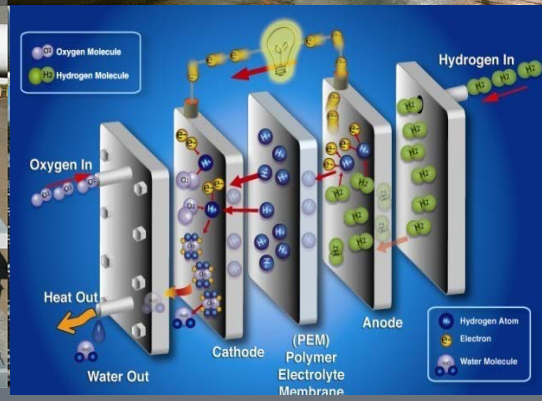
H2@Scale: Research Needs & Outreach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Enabling Resiliency of Domestic Energy Sectors and Industry

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U.S. Department of Energy

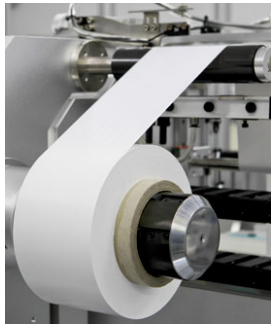
H2@Scale 2016 Workshop

Nuclear

Hybridization with electrolyzers to improve economics

Solar Power

Storage of heat in metal hydride beds

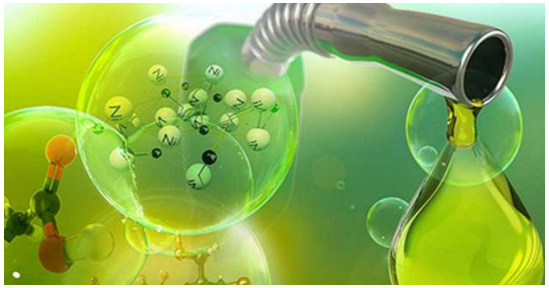


Manufacturing

Lower cost of H_2 production, and develop value-add applications

Fossil Energy

H_2 can be produced through coal gasification and chemical looping



Bioenergy

H_2 is necessary for biofuel production, and can also be produced from bio-oil and biogas

Geothermal Power

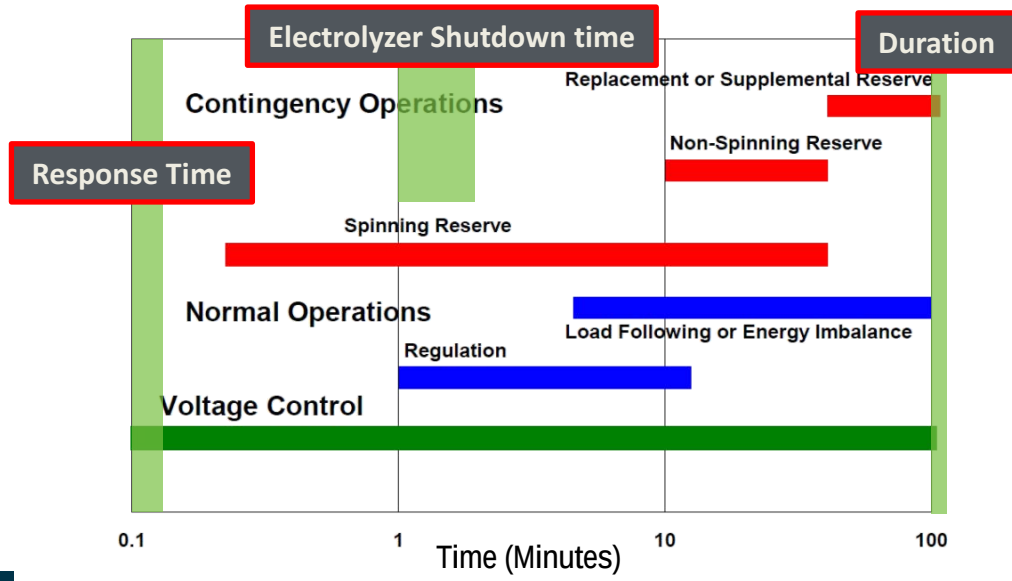
H_2 can be recovered from geothermal steam, and electrolyzers can be integrated with geothermal power

Workshop discussed cross-cutting potential of hydrogen.

Electrolyzer integration with Energy Transmission

Electrolyzer Value Proposition

- Verified sub-second response times
- Decouple power and energy
- Can be deployed more quickly and at lower cost than transmission lines.



Meet the performance needs of ancillary services

Examples of Foundational Research Needs *(aligned with HydroGEN)*

- Discovery and development of membranes and catalysts that minimize the use of precious metals
- Determination of impact of intermittent operation on electrolyzers with low PGM loading
- Development of manufacturing technologies (e.g. roll-to-roll processing) and balance of plant components (e.g. electronics)

Workshop Findings

- Expected use profiles and scales of electrolyzers for grid stability should be defined
- Regulatory framework necessary to value electrolyzers in grid services
  - ✓ Stakeholder education is important
  - ✓ Value proposition over conventional solutions must be more specifically defined

Integration with Nuclear Generation

Value Proposition

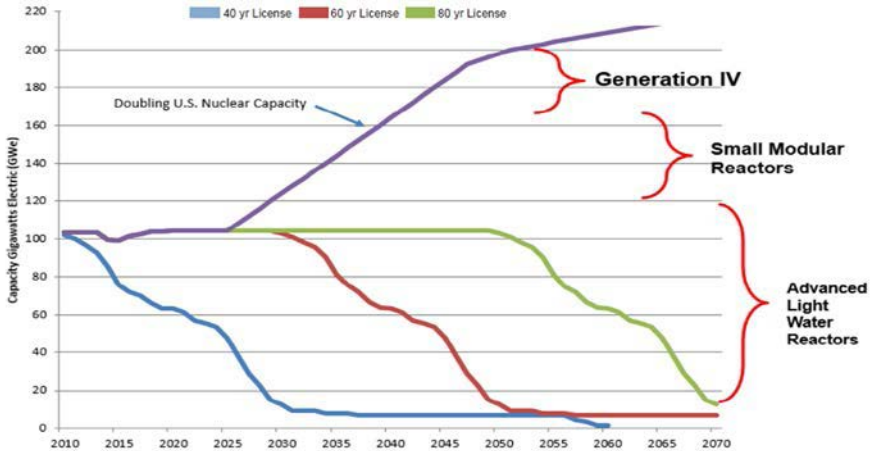
Hybridization of H_2 production with next generation nuclear generation can monetize process heat

Generation IV Nuclear Reactors (2030-2050)

- Very high temperature*
- Sodium-cooled
- Gas-cooled fast*
- Supercritical Water*
- Lead-cooled fast
- Molten salt*

* Outlet temperature: 500-1,000°C, compatible with high-temperature H_2 production

Possible U.S. Nuclear Capacity



Source: U.S. DOE Office of NE Vision and Strategy for the Development and Deployment of Advanced Reactors

Examples of Foundational Research Needs

(aligned with HydroGEN)

High-temperature Electrolysis

- Elucidation of degradation mechanisms
- Development of materials for durable high current density operation
- Determination and improvement of load following capability

Thermochemical

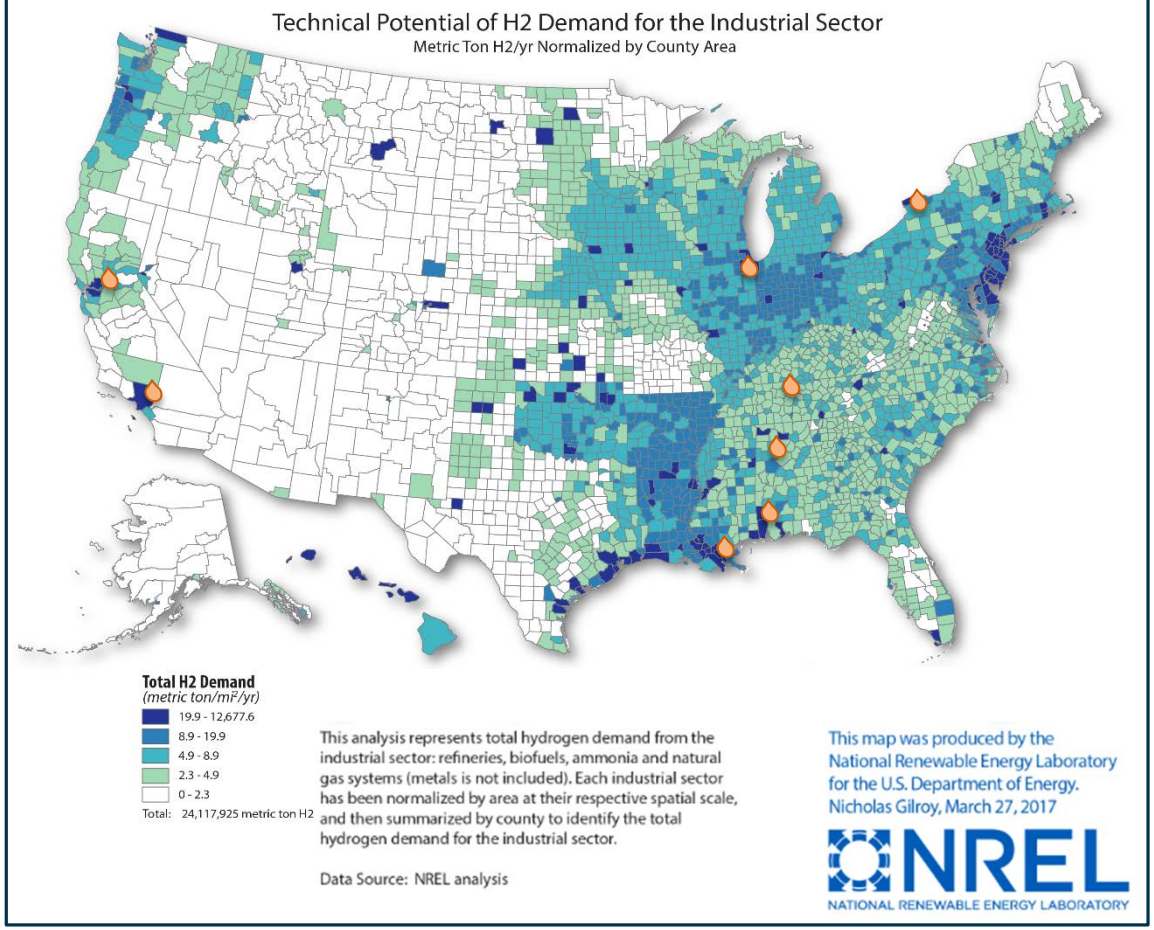
- Discovery of redox materials capable of efficient H_2 production
- Development of high-temperature materials for thermochemical reactors

Wide-scale Hydrogen Infrastructure

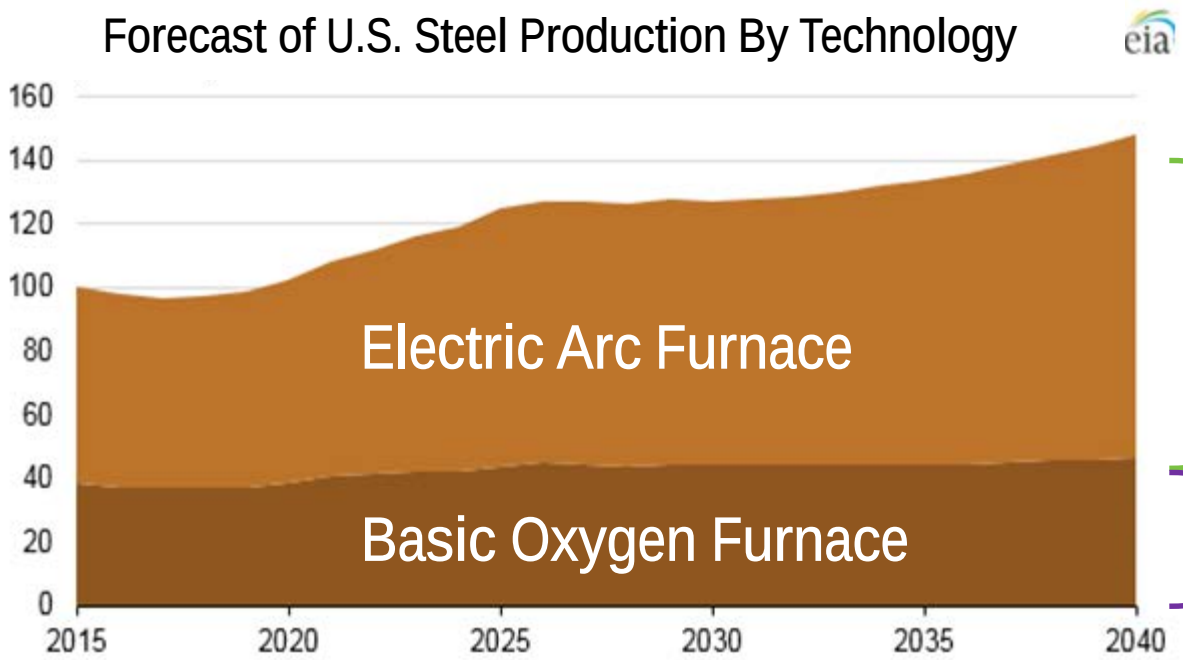
Examples of Research Needs

- Delivery and Storage
  - ✓ High-throughput compression for pipelines
  - ✓ Purification technologies to enable co-leveraging of infrastructure
  - ✓ Liquid carriers
- Liquefaction
  - ✓ Advanced expanders and compressors for mixed refrigerants
  - ✓ Non-mechanical approaches (e.g. magneto-caloric materials, thermo-acoustics)
  - ✓ Small-scale technologies
- Cross-Cutting
  - ✓ Capture of H_2 from existing process streams (e.g. chlor-alkali plants)
  - ✓ Development of skilled workforce

Current Status



Value-Add Applications for H2: Ironmaking



Feedstock: Recycled scrap metal, and sponge iron (produced via direct reduction of iron [DRI])

Feedstock: Pig iron

Benefits of Electric Arc Furnaces

- Lower cost feedstock (recycled scrap)
- Cyclability
- Scalability
- Purity of resulting iron

Ongoing Research

Engineering of DRI reactors to manage kinetics in H_2 (e.g. flash ironmaking technology)

Current Applications for H2: Oil and Chemicals

Drivers for Demand

Oil Refining

- Quality of crudes
- Air quality (removal of sulfur and aromatics)
- Demand for gasoline

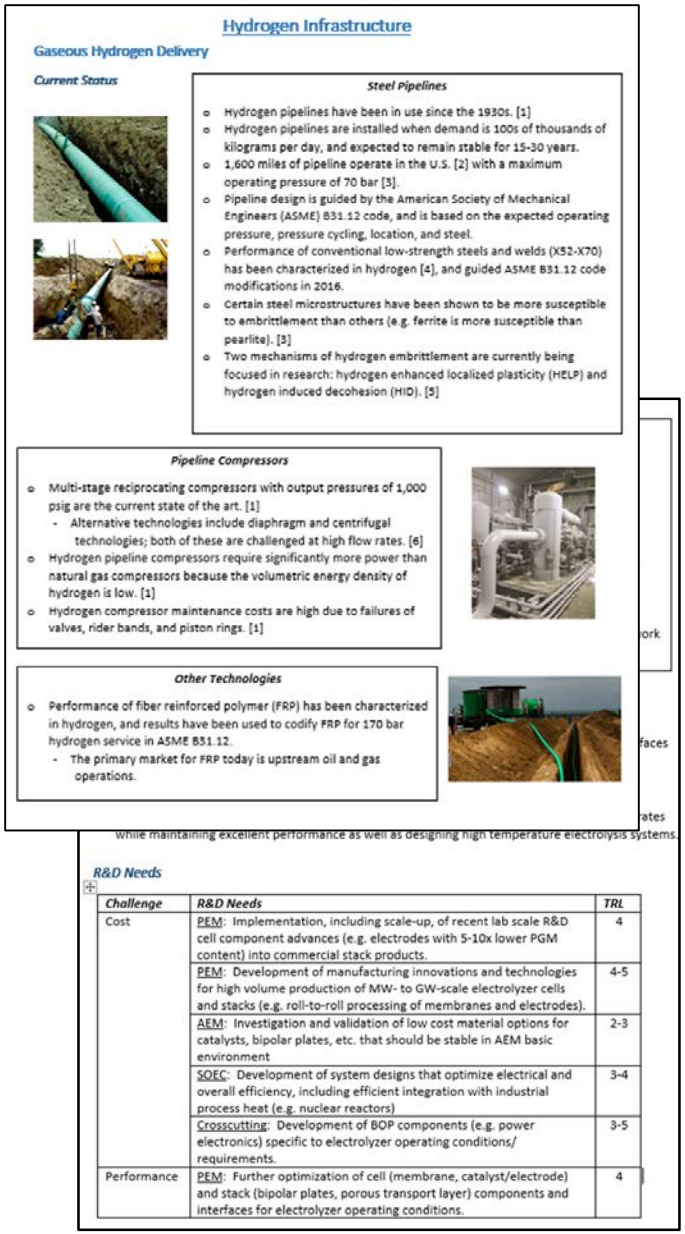
Ammonia

- Demand for food crops
- Demand for biofuels
- Emerging applications, such as NOx control
- Demand for liquid carriers

Technical and Market Needs

- Low-cost distributed H_2 production
- Co-electrolysis for methanol synthesis
- Identification of opportunities to use O_2 from electrolysis
- Valuation of renewable H_2 in regulatory frameworks
- Creation of "Sustainability Index" for investors

Next Steps



Hydrogen Infrastructure

Gaseous Hydrogen Delivery

Current Status

Steel Pipelines

- Hydrogen pipelines have been in use since the 1930s. [1]
- Hydrogen pipelines are installed when demand is 100s of thousands of kilograms per day, and expected to remain stable for 15-30 years.
- 1,600 miles of pipeline operate in the U.S. [2] with a maximum operating pressure of 70 bar [3].
- Pipeline design is guided by the American Society of Mechanical Engineers (ASME) B31.12 code, and is based on the expected operating pressure, pressure cycling, location, and steel.
- Performance of conventional low-strength steels and welds (X52-X70) has been characterized in hydrogen [4], and guided ASME B31.12 code modifications in 2016.
- Certain steel microstructures have been shown to be more susceptible to embrittlement than others (e.g. ferrite is more susceptible than pearlite). [3]
- Two mechanisms of hydrogen embrittlement are currently being focused in research: hydrogen enhanced localized plasticity (HELP) and hydrogen induced decohesion (HID). [5]

Pipeline Compressors

- Multi-stage reciprocating compressors with output pressures of 1,000 psig are the current state of the art. [1]
  - Alternative technologies include diaphragm and centrifugal technologies; both of these are challenged at high flow rates. [6]
- Hydrogen pipeline compressors require significantly more power than natural gas compressors because the volumetric energy density of hydrogen is low. [1]
- Hydrogen compressor maintenance costs are high due to failures of valves, rider bands, and piston rings. [1]

Other Technologies

- Performance of fiber reinforced polymer (FRP) has been characterized in hydrogen, and results have been used to codify FRP for 170 bar hydrogen service in ASME B31.12.
  - The primary market for FRP today is upstream oil and gas operations.

while maintaining excellent performance as well as designing high temperature electrolysis systems.

R&D Needs

Challenge	*R&D Needs*	*TRL*
Cost	PEM: Implementation, including scale-up, of recent lab scale R&D cell component advances (e.g. electrodes with 5-10x lower PGM content) into commercial stack products.	4
	PEM: Development of manufacturing innovations and technologies for high volume production of MW- to GW-scale electrolyzer cells and stacks (e.g. roll-to-roll processing of membranes and electrodes).	4-5
	AEM: Investigation and validation of low cost material options for catalysts, bipolar plates, etc. that should be stable in AEM basic environment	2-3
	SOEC: Development of system designs that optimize electrical and overall efficiency, including efficient integration with industrial process heat (e.g. nuclear reactors)	3-4
	Crosscutting: Development of BOP components (e.g. power electronics) specific to electrolyzer operating conditions/ requirements.	3-5
Performance	PEM: Further optimization of cell (membrane, catalyst/electrode) and stack (bipolar plates, porous transport layer) components and interfaces for electrolyzer operating conditions.	4

- **FY16-FY17**
  - H2@Scale Workshop to obtain feedback that guided roadmap development
  - Preliminary analysis to determine technical potential of hydrogen supply and demand
- **FY17-FY18**
  - H2@Scale Roadmap identifying and prioritizing RD&D needs
  - Analysis to assess potential supply and demand of H2@Scale under future market scenarios
- **May 23-24, 2017**
  - H2@Scale workshop in Houston, TX to assess regional challenges, and obtain feedback on draft sections of roadmap
- **June 10, 2017**
  - Review session at FCTO's Annual Merit Review to obtain feedback on technoeconomic analysis, and roadmap

Conclusion

Value Proposition for H2@Scale

- Grid stability with increasing penetration of non-dispatchable power
- Enhancing economics of next generation baseload (high-temperature nuclear reactors)
- Enabling distributed chemicals production
- Reduction in emissions from steelmaking and oil refining

Next Steps

- Foundational research to lower the costs of water splitting, H_2 infrastructure, and value-add applications for H_2
- Identification of markets and regions that will be early adopters

Thank You

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Hydrogen Production and Delivery

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