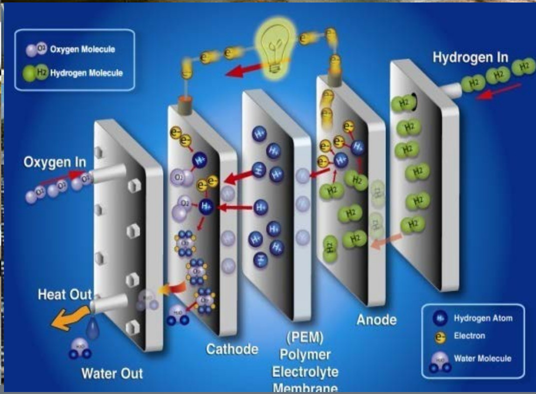
# H2@Scale: Research Needs & Outreach

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








## Enabling Resiliency of Domestic Energy Sectors and Industry

Washington, D.C.

05/04/2017

**Neha Rustagi**

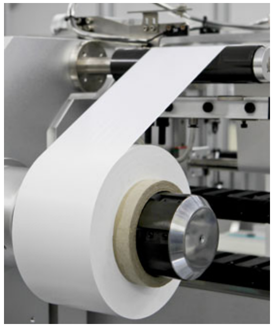
Fuel Cell Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

***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**

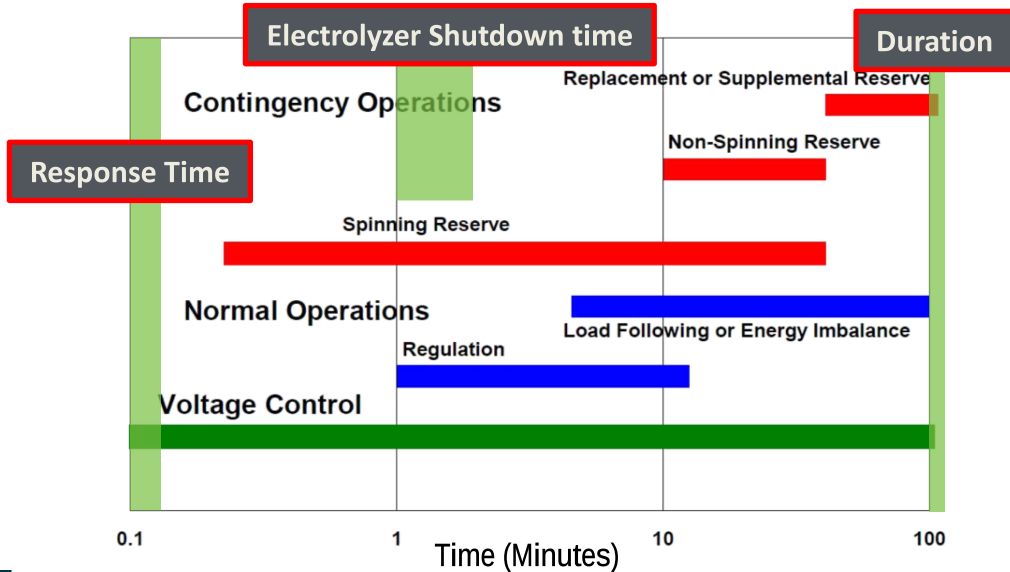
***Geothermal Power***

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

***Workshop discussed cross-cutting potential of hydrogen.***

## Electrolyzer 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

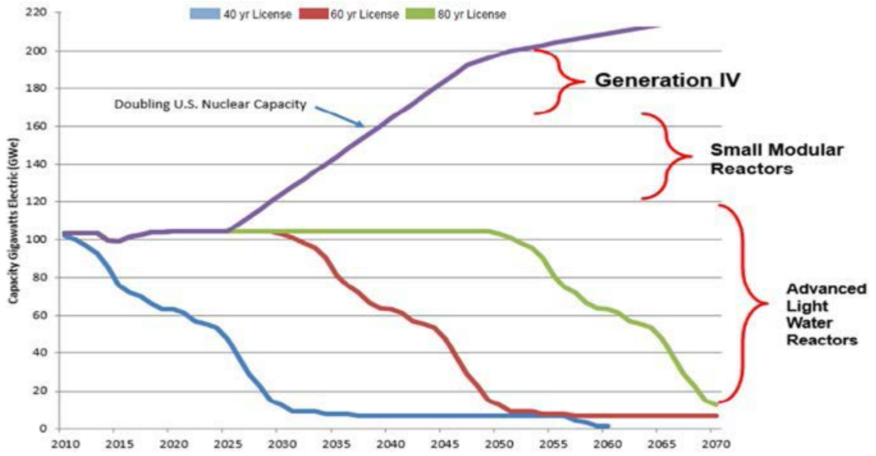
*Hybridization of $H_2$ production with next generation nuclear generation can monetize process heat*

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

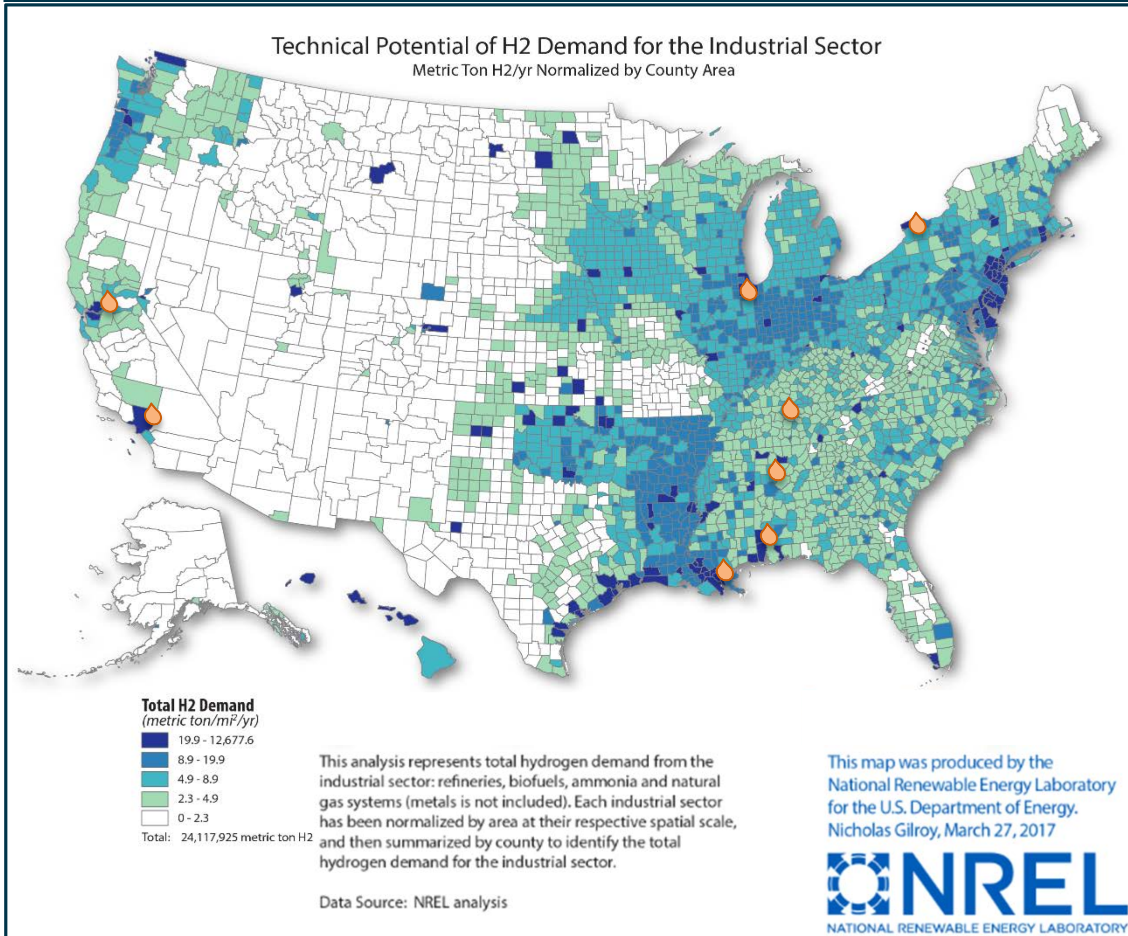
# Wide-scale Hydrogen Infrastructure



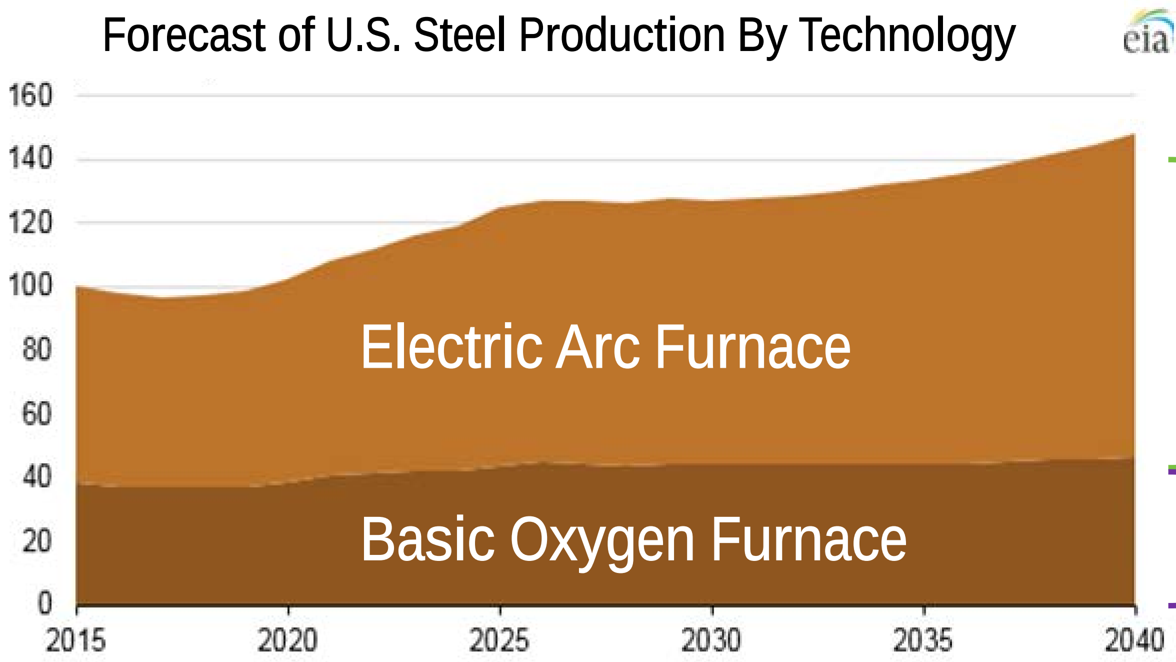
## Examples of Research Needs

- **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



Forecast of U.S. Steel Production By Technology




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**

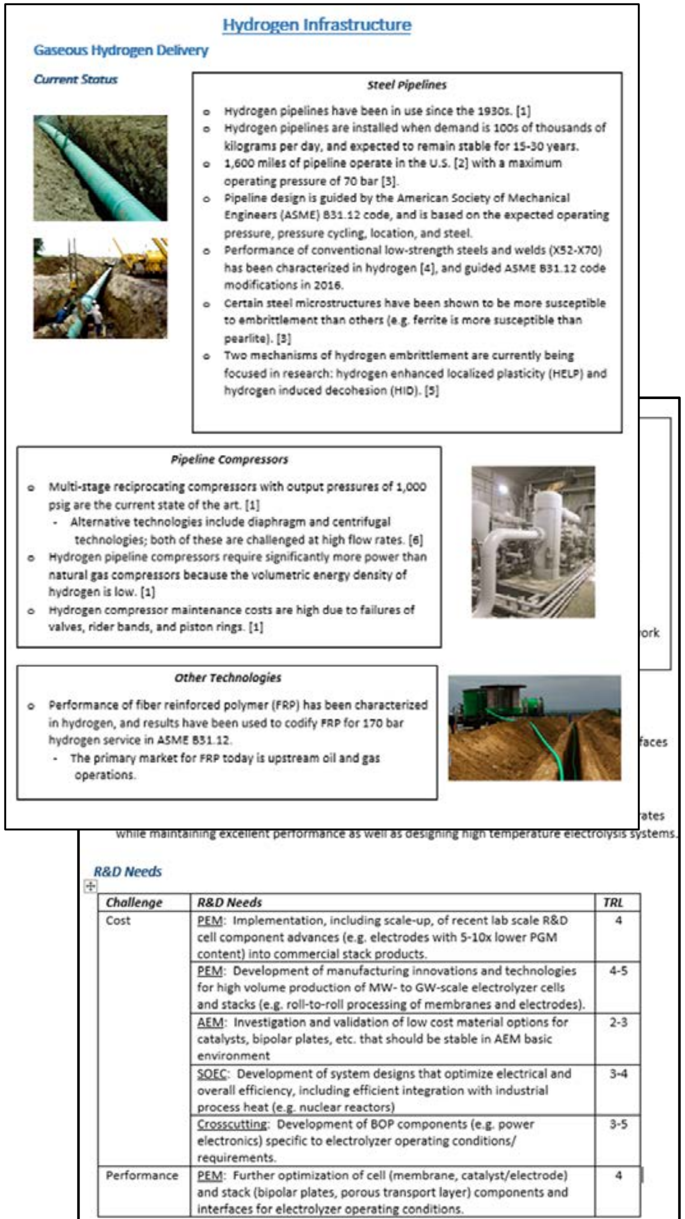
- Demand for food crops
- Demand for biofuels
- Emerging applications, such as NOx control
- Demand for liquid carriers

## 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

**Neha Rustagi**

**Hydrogen Production and Delivery**

**Fuel Cell Technologies Office**

**neha.Rustagi@ee.doe.gov**

**hydrogenandfuelcells.energy.gov**