Hydrogen and Fuel Cells Perspective and Opportunities

Sunita Satyapal – Director, Fuel Cell Technologies Office

American Nuclear Society Meeting – Nuclear Hybrid Systems Panel

Office of Energy Efficiency & Renewable Energy (EERE)

Sustainable TRANSPORTATION

Renewable ELECTRICITY GENERATION

Energy Saving HOMES, BUILDINGS, & MANUFACTURING
Overview

• H\textsubscript{2} and Fuel Cell Intro
• Technology Status
• Key Focus Areas and Opportunities
Why Hydrogen and Fuel Cells?

**Efficient**
- 20% - 30% for Internal combustion engine in a car
- 60% for Fuel cell in a car

**Uses domestic fuels**
- Natural gas
- Renewable sources (wind, solar, biomass, etc.)
- Nuclear
- Coal

**Convenient**
- Refuels in minutes

**Quiet**
- No noise in operation

**Clean**
- Zero tailpipe emissions

**Versatile and easily scalable**
- Transportation
- Stationary
Hydrogen as an Energy Carrier

Multiple sources can be used to produce $H_2$

Many applications rely on or could benefit from $H_2$

Clean, sustainable, versatile, and efficient energy carrier

About *three times* more energy by mass than gasoline. But worse in terms of volume.
The Beginning of the DOE Fuel Cell Program...

1970s

A group from labs, government and industry met at Los Alamos to set the foundation for DOE fuel cell programs.

Lab researchers taught scientists around the world how to fabricate fuel cell electrodes. Group from GM relocated to Los Alamos.
Forty years later, for the first time in history….

Commercial fuel cell electric cars are here!

Power, performance, petroleum-free, pollution-free

- Refuels in minutes
- More than 360 mi driving range
- Over 60 mpgge
Hydrogen refueling stations: strong State support

California
Over 30 open retail
Funding for 100

Northeast
Approx. 12 to 25 stations planned

Others with interest: Hawaii, Ohio, Texas, Colorado, South Carolina, and others
Life-cycle Emissions - Today’s Cars

Low, Medium & High Emissions/Mile for 2015 Technology

- **Fuel Cell Electric (FCE)**
- **Battery Electric (BEV)**
- **Extended-Range Electric (ERE)**
- **Hybrid Electric (HEV)**
- **Internal Combustion Engine (ICE)**

<table>
<thead>
<tr>
<th>Car Model</th>
<th>CO2e per Mile (Grams)</th>
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<tbody>
<tr>
<td>Honda Civic</td>
<td>360</td>
</tr>
<tr>
<td>Nissan Versa</td>
<td>343</td>
</tr>
<tr>
<td>Chevy Cruze Diesel</td>
<td>366</td>
</tr>
<tr>
<td>Honda Civic CNG</td>
<td>329</td>
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<tr>
<td>Toyota Prius</td>
<td>254</td>
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<tr>
<td>Chevy Volt</td>
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<tr>
<td>Nissan Leaf</td>
<td>230</td>
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<tr>
<td>Chevy Spark</td>
<td>216</td>
</tr>
<tr>
<td>Toyota Mirai (NG)</td>
<td>252</td>
</tr>
<tr>
<td>Toyota Mirai (33% Renewable)</td>
<td>187</td>
</tr>
</tbody>
</table>

Current gasoline ICEV: ~450

Source: Program Record 16004 (https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)

Joint VTO-FCTO Analysis Example
Life-Cycle Petroleum Use - Today's Cars

Low, Medium & High Petroleum Energy/Mile for 2015 Technology

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<tr>
<th>Car Model</th>
<th>Fuel Type</th>
<th>Btu of Petroleum Energy per Mile</th>
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<tr>
<td>Honda Civic</td>
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<tr>
<td>Honda Civic CNG</td>
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<td>98</td>
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<tr>
<td>Toyota Prius</td>
<td>BEV</td>
<td>2353</td>
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<tr>
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<td>ERE</td>
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Source: Program Record 16004 (https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)

Current gasoline ICEV: 4300
2016 Global Shipments – Trends

Total power (in MW) shipped by application

**Growth in Transportation**

<table>
<thead>
<tr>
<th>Year</th>
<th>PEMFC</th>
<th>DMFC</th>
<th>PAFC</th>
<th>SOFC</th>
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<th>AFC</th>
<th>Other</th>
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Total power (in MW) shipped by fuel cell chemistry

**Growth in PEMFC**

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- 500 MW fuel cell power shipped worldwide
- 62,000 fuel cell units shipped worldwide
- Approximately $1.6 Billion fuel cell revenue
Heavy Duty Vehicle Applications Emerging

Fuel cell delivery and parcel trucks starting deliveries in CA and NY

Industry demonstrates first heavy duty fuel cell truck in CA

Fuel cell buses in CA surpass 17M passengers

ZH2: U.S. Army and GM collaboration First of its kind
Stationary Power Applications Emerging – Examples

- Fuel cells provided backup power during Hurricane Sandy in the U.S. Northeast
- Fuel cell power for maritime ports demonstrated in Honolulu, Hawaii
- Fuel cells used to power new World Trade Center in NYC
- Over 235 MW of fuel cell stationary power installed across more than 40 US states
Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states

Over 8,000 backup power units deployed or on order

Over 235MW in stationary fuel cell power installed

What can we learn from history?
Henry Ford’s Quadricycle in 1896 to Model T in 1908
DOE Cost Status and Targets

**Fuel Cell R&D**

- **System**
  - $180/kW
  - $50/kW
  - $45/kW
  - $40/kW

- **Production, Delivery & Dispensing**
  - $16/gge
  - $7.5*/gge
  - <$4/gge

- **Onboard Storage (700-bar compressed system)**
  - $24/kWh
  - $17/kWh
  - $10/kWh

**Hydrogen R&D**

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*Based on Electrolysis  **Based on NG SMR  †Preliminary, updates underway
Onboard storage cost status from DOE Program Record 15013

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Note: Graphs not drawn to scale and are for illustration purposes only.
H₂ Production from Diverse Domestic Resources

Broad portfolio of near- to longer-term H₂ production technologies addressed through early-stage R&D

Continued Innovation is Needed across the Spectrum of Options

FOSSIL RESOURCES
- Low-cost, large scale H₂ production with CCUS options
- New options offer scalability and byproduct benefits (e.g. CHHP)

WASTE/BIOMass
- Options included biogas reforming & fermentation of waste streams
- Byproduct benefits include clean water, electricity & chemicals

WATER SPLITTING
- Grid electrolysis is proven process being improved with innovation
- Emerging nuclear/solar options offer long-term sustainable H₂

Coal Processing
Natural Gas Reforming
Biomass Processing
Waste to Energy
Grid H₂O Splitting
Solar-Based
Nuclear-Based
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H₂ Production R&D

Pathway using domestic natural gas can be competitive today

Portfolio Covers*:

- Fossil Resources
- Waste and Biomass
- Water-splitting

*examples

Cost by Component

High-T Electrolysis Example

Projected Production Cost* by Pathway

- Production Pathway:
  - PEM Electrolysis: 3c-8c/kWh electricity
  - High-T Electrolysis: 3c-8c/kWh electricity
  - Biomass Gasification: $40-$120/ dry short ton

- 2020 target: Production < $2 /kg

- Fossil Resources (broad range of projected spot prices)

- *Ranges with sensitivities to feedstock price variations

Consortium leveraging National Lab capabilities

U.S. DEPARTMENT OF ENERGY OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY FUEL CELL TECHNOLOGIES OFFICE
H₂ at Scale Energy System

*Illustrative example, not comprehensive
Source: NREL
H₂ at Scale Energy System

Power Generation

Hydrogen/ Natural Gas Infrastructure

Value Added Applications

Hydrogen Vehicle

Synthetic Fuels

Upgrading Oil / Biomass

Transportation

Industrial

INDUSTRIAL

Hydrogen Storage/Distribution

N₂

CO₂

NH₃

Other End Use

Metals Refining
### How much H₂ is needed?

#### How much hydrogen for 1 car?

<table>
<thead>
<tr>
<th>12,000 miles per year</th>
<th>200 kg or 0.2 tonnes per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 miles per kilogram</td>
<td></td>
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</table>

#### How much hydrogen for many cars?

<table>
<thead>
<tr>
<th>1 M cars</th>
<th>0.2 M tonnes H₂ per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 M kg H₂ per year</td>
<td>100,000 cars</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>100 M cars</th>
<th>20M tons H₂ per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 B kg H₂ per year</td>
<td>10M cars</td>
</tr>
</tbody>
</table>
Hydrogen Production Sites in the U.S.

U.S. annual hydrogen production
10 million metric tons

Largest Users in the U.S.

Petroleum Processing 68%  
Fertilizer Production 21%

Example of H₂ and Electrolyzer Benefits

H₂ can supply GW-scale energy storage

Source: Hydrogen Council

Preliminary analysis - to be updated
Example of H₂ and Electrolyzer Benefits

H₂ can be cost effective for long duration storage

Preliminary analysis - to be updated
Examples of H₂ and Electrolyzer Benefits

First ever validation of real time grid simulation with electrolysers

First independent validation of frequency regulation with electrolysers and sub-second response times (INL, NREL)

Preliminary analysis- to be updated
Market Potential for Hydrogen Demand

60 Million Metric Tons of Hydrogen/Year

Total Hydrogen Demand for the Industrial Sector
Metric Ton H2/yr. Normalized by County Area
Preliminary

Multiple Industries:
- Refinery
- Metals
- Ammonia
- Natural Gas
- Biofuels
- LDVs
- Other transportation

Total Demand (metric ton H2 per sq mi/yr)
- 19.9 – 12,677
- 8.9 – 19.9
- 4.9 – 8.9
- 2.3 – 4.9
- 0 – 2.3

Total: 24,117,925 metric ton H2/yr.

NREL
National Renewable Energy Laboratory
Labs assess resource availability. Most regions have sufficient resources.

Red: Only regions where projected industrial & transportation demand exceeds supply.
Market Conditions Pushing Nuclear Power Transition

Over 20 GW in existing nuclear plants retired or at risk of retiring

Nuclear Plants at Risk or Recently Retired in GW¹

Gen IV Reactors (2030 – 2050) Compatible with High Temp. Electrolysis:

- High-temperature*
- Gas- cooled fast
- Supercritical Water
- Molten salt

¹ U.S. DOE Quadrennial Energy Review, 01/2017

* Outlet temperature: 500-1,000°C
Market Conditions Pushing Nuclear Power Transition

7,000 MW Nuclear Plants Announced Retirement since 2016*

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Map Source: Bloomberg New Energy Finance
Note: For more information of U.S. electric generators, see U.S. Plant Stack: Info on Every Generator Unveiled (web | Terminal)

*DOE Staff Report to the Secretary on Electricity Markets and Reliability
High-Temp. Steam (HTSE) Electrolysis and Nuclear Gen IV Reactors produce process heat compatible with high-temp. steam electrolysis (HTSE)

Benefits

- High electrical efficiency
- Scalable
- Leverages heat sources from nuclear
- Improves economics of nuclear reactors
- Can operate over wide range of loads

Needs

- Electrolyzer cell/stack durability improvements
- Load following capability dependent on time-frame (minutes vs hours)
- System-level demonstration
H2@Scale CRADA Call

- To leverage lab capabilities and expertise to address challenges—materials R&D, analysis, safety R&D, etc.
- Round 1 closed Sept. 15 — stay tuned for winners and future rounds

CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project (‘Work for Others’)
H2@Scale CRADA Call Addressing R&D Needs relevant to Nuclear – Example

**Technoeconomic Modeling and Analysis**

Energy Security Benefit - Petroleum Reduction Attributed to FCEV Market Penetration

- Petroleum Reduction (Bbl/day)

<table>
<thead>
<tr>
<th>Year</th>
<th>2017</th>
<th>2025</th>
<th>2035</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bbl/day</td>
<td></td>
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</table>

**Hydrogen Materials Compatibility R&D**

- Friction & wear
- Pressure cycle aging
- Fundamental property changes

**Grid simulation and Testing**

**Safety R&D**

**Labs**
- Argonne National Laboratory
- Oak Ridge National Laboratory
- NREL
- SRNL
- Pacific Northwest National Laboratory
- INL
- NREL

**HyRAM**

HYDROGEN RISK ASSESSMENT MODELS

**Labs**
- Sandia National Laboratories
- Pacific Northwest National Laboratory
Information sharing and education are critical as we move forward.
H₂Tools: One-stop for H₂ safety knowledge

- Includes resources on safety best practices, first responder training, and H₂ codes & standards

- Site visit tracking shows a global reach: 50% of visits are international!
- Over 31,000 site visits in the first year alone
- Training resource translated into Japanese
## Ways to Spread the Word

### Celebrate Hydrogen & Fuel Cell Day

**October 8 or 10/8**

(Held on its very own atomic-weight day)

Learn more:
[energy.gov/eere/fuelcells](https://energy.gov/eere/fuelcells)

### Give an “Increase your H2IQ” presentation in your community!

Download for free at:
[energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource](https://energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource)
Summary

• Enable early R&D innovation
  • Hydrogen fuel
  • Fuel cells
  • H2@Scale

• Leverage activities to maximize impact
  • Enable infrastructure and cross-sector impacts
  • Partnerships- other agencies, industry, states, etc.
  • Collaboration on safety R&D and information sharing
Thank You

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Fuel Cell Technologies Office
Sunita.Satyapal@ee.doe.gov

energy.gov/eere/fuelcells