Hydrogen: Fuel of the Future?

Wednesday 18 March 2020
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1. Welcome from Eric Ingersoll

2. Hydrogen Technical Expertise
   1. Dr. Sunita Satyapal
   2. Alice Caponiti
   3. Dr. Sellathurai (Sam) Suppiah
   4. Toshiyuki Shirai
   5. Peter Fraser

3. Question & Answer
Eric Ingersoll

Eric Ingersoll is co-founder of Energy Options Network and Managing Partner of LucidCatalyst. He is an entrepreneur and consultant with deep experience in clean energy commercialization and industrial transformation strategy. His professional experience spans energy startups, energy policy, and large energy companies. He has extensive project experience in renewables, energy storage, oil & gas, and nuclear, with a special emphasis on advanced nuclear technologies. He applies rigorous economic and strategic analysis of new delivery models and cost reduction strategies for zero carbon generators and develops innovative ways to improve product and system performance while lowering barriers to market and increasing the potential rate of deployment.
Leveraging the CEM Opportunity: Expanding Partnerships to Bring Cost Effective Hydrogen for Clean Synthetic Fuels to the World

Eric Ingersoll and Kirsty Gogan
Energy Options Network / Energy for Humanity
Opportunities for Hydrogen

Today’s webinar illustrates new opportunities and partnerships within, beyond CEM:

First ever co-branded webinar on hydrogen and nuclear.
Even in projections of massive growth of renewables, most primary energy is still fossil in 2050.
Some industries will be very difficult to decarbonize

- Biofuels cannot scale to the levels necessary to decarbonize industries like air travel or marine shipping

- Low-carbon options for heavy industry like steel and cement are scarce and expensive.
There is an emerging consensus about Hydrogen as a Decarbonization Fuel

“Hydrogen is a credible option to help decarbonise the UK energy system, but its role depends on early Government commitment and improved support to develop the UK’s industrial capability, says a new report by the Committee on Climate Change (CCC).”
Evidence suggests that nuclear is a promising candidate for low-cost H$_2$ production.

Decades of research suggests that nuclear could offer the most cost-effective means of zero-CO$_2$ hydrogen production.

This is largely due to its relatively high capacity factor.

Four reasons why we need dedicated hydrogen production

1. The global liquid fuels market is 4x larger (in GJ) than the global electricity market. \( \text{H}_2 \) is the primary basis for zero-CO\(_2\) liquid fuels.

2. Using electricity from curtailed renewables results in a prohibitively low capacity factors (i.e., intermittent use of intermittent generation = extremely low capacity factors/ economics).

3. Electricity prices go up when you start using the power (demand curve shifts to the right)

4. Society is paying even if price is low. Below market recoverable prices is not a scalable strategy
Flexible Nuclear Campaign – The Team

CONTACT INFO:

info@nice-future.org
Dr. Sunita Satyapal


Sunita Satyapal is the Director of the U.S. Department of Energy’s Hydrogen and Fuel Cells program and is responsible for overseeing staff and approximately $150 million per year in hydrogen and fuel cell research, development and demonstration activities. She has been at DOE since 2003 and has experience in industry and academia, including at United Technologies, Columbia University and Cornell University.
Hydrogen and Fuel Cell Perspectives

Dr. Sunita Satyapal, Director, U.S. Dept. of Energy Hydrogen and Fuel Cells Program


March 18, 2020
Hydrogen – One Part of a Comprehensive Energy Strategy

H₂ can be produced from diverse domestic sources

Many applications rely on or could benefit from H₂

Clean, sustainable, versatile, and efficient energy carrier
Fuel Cell Basics

Fuel cells can operate on hydrogen or other fuels and do not involve combustion so have high electrical efficiencies.
Example of Well-to-Wheels Analysis: Petroleum Use and Emissions

Program Record #13005: [http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf](http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf); updates underway will include heavy duty vehicles - focus for hydrogen fuel cells
H₂@Scale: Enabling affordable, reliable, clean, and secure energy across sectors
H₂@Scale: Enabling affordable, reliable, clean, and secure energy across sectors
Guiding Legislation and Budget

- Authorizes U.S. DOE to lead a comprehensive program to enable commercialization of hydrogen and fuel cells with industry.
- Includes broad applications: Transportation, utility, industrial, portable, stationary, etc.

**Program To Date**
- $100M to $250M per year
- 100 to 200+ projects per year
- >100 organizations & extensive collaborations
- Includes H2, fuel cells and cross cutting RD&D:
  - H2 production, delivery, storage, utilization (including fuel cells)
  - Analysis, systems development/integration, safety, codes and standards, education & outreach
- Reduced fuel cell cost 60%, quadrupled durability, reduced electrolyzer cost 80% and other advances
Snapshot of Hydrogen and Fuel Cells Applications in the U.S.

Examples of Applications

- **>500MW** Stationary Power
- **>33,000** Forklifts
- **>30** Fuel Cell Buses
- **>45** H₂ Retail Stations
- **>8,400** Fuel Cell Cars

Hydrogen Production Across the U.S.

- 10 million metric tons produced annually
- More than 1,600 miles of H₂ pipeline
- World’s largest H₂ storage cavern

Hydrogen Stations: Examples of Plans Across States

- **California**
  - 200 stations planned - CAFCP goal

- **Northeast**
  - 12 – 20 stations planned

Other states: HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others
R&D focus is on Affordability and Performance: DOE Targets Guide R&D

Key Goals: Reduce the cost of fuel cells and hydrogen production, delivery, storage, and meet performance and durability requirements – guided by applications specific targets

**Fuel Cell R&D**

- Fuel cell system:
  - $210/kW
  - $180/kW
  - $75/kW
  - $50/kW
  - $45/kW
  - $30/kW

- Durability adjusted (preliminary), 100k/yr

**Hydrogen R&D**

- On-board storage:
  - $21/kWh
  - $17/kWh
  - $15/kWh
  - $8/kWh

- H₂ cost at the pump:
  - $16/kg
  - $13/kg

- Electrolysis:
  - $10/kg
  - $5/kg

- NG to H₂:
  - <$4/kg

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1) Based on commercially available FCEVs
2) Based on state of the art technology

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1) Storage costs based on preliminary 2019 storage cost record

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1) For range: H₂ production from natural gas (NG), delivered dispensed at today’s (2018) stations (~180kg/day)
2) For range: Assumes high volume manufacturing in 1) H₂ production costs ranging from $2/kg to $5/kg (electrolysis manufactured at 700 MW/year), and 2) Delivery and dispensing costs ranging from $3/kg (advanced tube trailers) to $5/kg (liquid tanker or advanced pipeline technologies).
3) Range assumes >10,000 stations at 1,000 kg/day capacity, to serve 10 million vehicles
Hydrogen R&D Areas – Examples

**H₂ Production (Electrolysis) Cost Drivers:** Electrical energy and capital costs

**H₂ Onboard Storage Cost Drivers:** Carbon Fiber Precursors and Processing

**H₂ Infrastructure Cost Drivers:** Compressors and Storage

Note: Updates to be published May, 2020
Increased Activities on Hydrogen, Energy Storage, Hybrid Systems

**H₂ energy storage**

Dynamic response

Increased opportunities for nuclear and hydrogen

25 kW high-temperature electrolysis @ INL Energy Systems Laboratory

**Dynamic electrolyzer response – INL & NREL**

Multiple end use applications

DOE Industry demos

**Recentlly announced demonstrations**

**Thermal Integration**
New Project: Electrolyzer Operation at Nuclear Plant and In-House Hydrogen Supply

**Clean H₂ production enabling dispatchable, carbon-free power**

**Objectives**

- Develop an integrated hydrogen production, storage, and utilization facility at a nuclear plant site, based on a PEM electrolyzer
- Demonstration of economic supply of carbon-free hydrogen for internal nuclear site use.
- Dynamic control of the electrolyzer

**Expected Outcomes**

- Scaled-up hydrogen production in the U.S. power sector through a dynamically operable hydrogen production facility at a nuclear plant enabling nuclear units to be dispatchable.
- Demonstrated mechanism for hydrogen-based energy storage systems to improve nuclear plant participation in organized power markets.

**Program Summary**

- **Partners:** Exelon & Nel Hydrogen, INL, NREL, ANL
- **Period:** 36 months
- **Total budget:** $7.2 million

Based on original proposal submission; final project under negotiation
Collaboration & Resources
Global Government Partnerships to Accelerate Progress on Hydrogen and Fuel Cells

Hydrogen and Fuel Cells in the Economy
Enabling the global adoption of hydrogen and fuel cells in the economy

Key Activities: Working Groups on Regulations, Codes, Standards & Safety; Education & Outreach
- Develops country updates on policies, status, shares best practices
- Task force on developing H₂ production methodology to facilitate international trade
- Coordinates activities among global and regional partnerships

Mission Innovation Hydrogen Challenge
Launched 2017

Hydrogen Energy Ministerial (HEM)
Launched 2018

Clean Energy Ministerial Hydrogen Initiative
Launched 2019

Find IPHE on Facebook, Twitter and LinkedIn
Follow IPHE @The_IPHE

www.iphe.net

International Energy Agency (IEA)

Formed 2003
19 Countries and EC
Roadmaps and Plans Developing in Multiple Regions

Drivers include: Energy security, energy efficiency & resiliency, economic growth, innovation & technology leadership, environmental benefits

Aspirational Targets: “10, 10, 10”
10M systems, 10K stations, 10 years

High priority areas include: Global harmonization of codes and standards and addressing gaps, safety
More than 1/3 million stationary fuel cells, 15,000 fuel cell electric vehicles, 400 stations
Over 1 GW of fuel cells shipped in 2019
Plans developing for applications across sectors
Example of Collaboration: Global Center for H₂ Safety (CHS)

IPHE Steering Committee action: Increase awareness of safety partnership.
Promotes safe operation, handling and use of hydrogen across all applications.

www.aiche.org/CHS
Resources and Announcements

Save the Date

Oct 8 - Hydrogen and Fuel Cells Day
(Held on its very own atomic-weight-day)

Resources

Visit H2tools.org for hydrogen safety and lessons learned
https://h2tools.org/

Download the H2IQ resource for free:
energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Join monthly H2IQ hours to learn more about hydrogen and fuel cell topics
energy.gov/eere/fuelcells/fuel-cell-technologies-office-webinars

Sign up to receive hydrogen and fuel cell updates
www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

Learn more at: energy.gov/eere/fuelcells AND www.hydrogen.energy.gov
Alice Caponiti

Deputy Assistant Secretary for Reactor Fleet and Advanced Reactor Deployment, Department of Energy Office of Nuclear Energy (DOE-NE), United States

Alice Caponiti’s current responsibilities include light water reactor programs; advanced reactor development activities – including micro-reactors; innovative nuclear research in advanced modelling and simulation, manufacturing, sensors and other cross-cutting areas; competitive R&D and infrastructure investment programs; and the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative.

Ms. Caponiti previously led efforts to design, build, test, and deliver safe and reliable nuclear power systems for space exploration and national security applications and conduct detailed safety analyses for each mission. She served as the as the technical advisor to the Department of State and a United Nations working group on space nuclear power sources, as well as a risk communications spokesperson for the New Horizons mission to Pluto and the Mars Science Laboratory mission that delivered the Curiosity rover to the surface of Mars. Prior to joining DOE-NE in 2001, Ms. Caponiti worked on a nonproliferation program to reduce stockpiles of excess Russian weapons plutonium.
Clean Energy Ministerial
Nuclear Innovation: Clean Energy (NICE) Future Initiative
Webinar – March 18

Hydrogen Integration with Nuclear Power
Alice Caponiti
Deputy Assistant Secretary
Office of Reactor Fleet and Advanced Reactor Deployment
NE Mission Focus Leads to Global Competitiveness in Nuclear Technology
Current U.S. Nuclear Power Plant Fleet Provides Majority of Clean Energy

- 8 quadrillion btus total
- 8% of U.S. total energy
- 20% of all electricity
- 42% of clean energy
- 55% of clean electricity

Distribution of 98 operating nuclear power plants in the U.S.

Years of Commercial Operation | Number of Reactors
--- | ---
0-10 | 1
10-19 | 0
20-29 | 11
30-39 | 42
40-49 | 44

Note: There are no commercial reactors in Alaska or Hawaii
Source: Nuclear Regulatory Commission / Energy Information Administration
Last Updated: 10/19

energy.gov/ne
Current Nuclear Fleet Faces Economic Challenges

LWRS Enhances Performance and Ensures Continued Operation of the Light Water Reactor Fleet with transformative technologies to enable:

- Plant Modernization
- Efficiencies in workforce
- Diversity of products
## Research Pathways & Focus Areas

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td><strong>Plant Modernization</strong></td>
<td>Address replacement of existing instrumentation and control technologies and enable plant efficiency improvements through a strategy for long-term modernization</td>
</tr>
<tr>
<td><strong>Flexible Plant Operation and Generation</strong></td>
<td>Evaluate and demonstrate integrated energy systems that competitively produce electricity and non-electrical products to optimize revenue generation by nuclear power plants</td>
</tr>
<tr>
<td><strong>Physical Security</strong></td>
<td>Validate methods and tools which can be used to implement an updated physical security regime to optimize physical security at U.S. nuclear power plants</td>
</tr>
<tr>
<td><strong>Risk Informed Systems Analysis</strong></td>
<td>Develop significantly improved safety analysis methods and tools to optimize the safety, reliability, and economics of plants</td>
</tr>
<tr>
<td><strong>Materials Research</strong></td>
<td>Understand and predict long-term behavior of materials in nuclear power plants, including detecting and characterizing aging mechanisms</td>
</tr>
</tbody>
</table>
Nuclear Energy Reimagined

Nuclear Beyond Electricity – Advanced Reactors

NOW

Baseload Electricity Generation

FUTURE

Large Light Water Reactors

Small Modular Reactors

GEN IV Reactors

New Chemical Processes

Heating

Hydrogen Production

Clean Water

Electricity

Industrial Applications
Integrated Energy Systems

Maximizing energy utilization, generator profitability, and grid reliability and resilience through novel systems integration and process design.
Value Proposition for Nuclear Hybrid Systems

Low-cost electricity creates an opportunity to co-produce hydrogen. Direct power to hydrogen production creates a value stream for nuclear plants to supplement revenue from power generation.

Up to 80% of the year, electricity price is lower than cost to operate plant.

Price of Power

- Sell electricity to grid
- Cost to operate plant
- Re-direct power to hydrogen production @ ~$30/MWh

The challenge in some regions:

- Localized marginal price of electricity < Cost of generating electricity at nuclear plant

Sources:
1. 2017 data from PJM-NI Hub; R. Boardman, et. al. INL
Flexible Nuclear-Hybrid Plant Operation Allows Nuclear to Power Peak Electricity Demand

Example Optimized Hybrid System Performance Results, INL-Developed Toolset

- System design optimization using time histories for one year
- Results shown for a selected time history, one week period (hourly resolution)
- Optimized component capacities
  - Nuclear Reactor 300 MW<sub>e</sub>
  - Hydrogen Plant Capacity 120 MW<sub>e</sub> (shown as negative – electricity input; 70% turndown limit; H<sub>2</sub> market price ~ $1.75/kg-H<sub>2</sub>)
  - Gas turbine 200 MW<sub>e</sub>
  - Electric battery 100 MWh
  - Wind penetration 400 MW<sub>e</sub> (100% of mean demand, installed capacity, 27% capacity factor)
  - Penalty function applied for over or under production of electricity.

Rabiti and Epiney, INL, 2018
Recently Funded NE-Led Demonstration
FirstEnergy Solutions Corp., Xcel Energy, APS, INL

LWR Integrated Energy Systems Interface Technology Development & Demonstration at Davis-Besse NPP in Ohio

- $11.5M ($9.2M DOE), announced September 2019
- 2 MW Containerized “Turn-Key” Electrolysis Test Skid helps reduce project risk
- 24 month project - operation and verification planned for 2022
- Onsite and offsite uses planned

- Ensure no adverse effects on the plant, grid, or skid.
- Control software will be able to modulate H₂ output based on input variables.
- Control software will interface with Programmable Logic Computer (PLC) on vendor supplied H₂ skid.
Hydrogen Production Demonstrations
iFOA Area of Interest Announced March 9

- NE iFOA ($11M NE, $10M FCTO)
  - Current cycle applications due
    6.30.2020 5PM ET

- Possible areas of work:
  - Larger scale—5 to 20 MW (low-T)
  - Use of electricity and heat (higher efficiency) in high-T electrolysis
  - Integration of renewable resources and grid services
  - Regional market transformation

- Complexity means more attention to:
  - Regulatory engagement
  - System design and cost analysis
  - Safety and risk assessment
  - Integration with reactor operations
  - Qualification of electrolyzers

https://www.id.energy.gov/NEWS/FOA/FOA Opportunities/FOA.htm
High Temperature Improves Hydrogen Production Efficiency by up to 2.4 x

### Electrolysis Efficiencies vs Nuclear Reactor Type

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>T-Out (Celsius)</th>
<th>Power Cycle</th>
<th>Electrolysis Technology</th>
<th>Overall Nuclear Fuel Efficiency</th>
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</thead>
<tbody>
<tr>
<td>LWR</td>
<td>300</td>
<td>Rankine</td>
<td>LTE</td>
<td>25%</td>
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<tr>
<td>LWR</td>
<td>300</td>
<td>Rankine</td>
<td>HTSE</td>
<td>38%</td>
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<tr>
<td>SFR</td>
<td>500</td>
<td>Rankine</td>
<td>LTE</td>
<td>28%</td>
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<td>HTSE</td>
<td>38%</td>
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<td>MSR</td>
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<td>S-CO₂</td>
<td>LTE</td>
<td>40%</td>
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<td>LTE</td>
<td>37%</td>
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<td>750</td>
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<td>HTSE</td>
<td>50%</td>
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<td>VHTGR</td>
<td>950</td>
<td>He Brayton</td>
<td>LTE</td>
<td>42%</td>
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<tr>
<td>VHTGR</td>
<td>950</td>
<td>He Brayton</td>
<td>HTSE</td>
<td>59%</td>
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**Laboratory Scale**  
Experimentally Proven  
Modeled

**Light Water Reactors**  
~275 – 325 C

**Gas Reactors**  
~750 – 1000 C
# The Future: Microreactor Powered Hydrogen Fueling Station

## Notional Specs*

<table>
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<tr>
<th>Specification</th>
<th>Value</th>
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<tr>
<td>MW Total (15 MW modules)</td>
<td>60</td>
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<tr>
<td>kg / day trucks</td>
<td>50</td>
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<tr>
<td>kWh / kg hydrogen generation</td>
<td>50</td>
</tr>
<tr>
<td>kWh / truck / day</td>
<td>2500</td>
</tr>
<tr>
<td>trucks / station / day</td>
<td>576</td>
</tr>
<tr>
<td>fueling positions</td>
<td>~12</td>
</tr>
</tbody>
</table>

*not associated with images

*Image courtesy of Nikola Motor Company*

*Image courtesy of HolosGen*
Thank You

Dr. Sellathurai (Sam) Suppiah

Manager, Chemical Engineering Branch
Facility Authority – Tritium Facility, Canadian Nuclear Laboratories Ltd., Canada

Suppiah manages the Chemical Engineering Branch and the Facility Authority for the Tritium Facility Operations at Canadian Nuclear Laboratories at Chalk River. A chemical engineering graduate from University of Birmingham, UK. He has more than 35 years of expertise in the areas of Heavy Water and Tritium, Catalysis, Electrolysis Cell technologies, Fuel Cell technologies, Nuclear and non-Nuclear Battery technologies, Hydrogen Production from High and Medium Temperature Thermochemical Processes and Steam Electrolysis.

Suppiah leads collaborations in many of the above areas with industry, institutes and universities. He is the Canadian delegate for the GEN IV VHTR Hydrogen Production Project Management Board. He is also a board member of the Canadian Hydrogen and Fuel Cell Association (CHFCA). He has been a regular presenter at IAEA’s technical meetings on Hydrogen Production and other national and international meetings.

His branch consists of chemical and mechanical engineers, electrochemists and chemical technologists working in technology developments and commercial activities in the above areas.
Hydrogen: Fuel of the Future?

Nuclear Innovation: Clean Energy Future Webinar, 2020 March 18

Sam Suppiah

Canadian Nuclear Laboratories Ltd.

Chalk River ON, Canada
Hydrogen - A Critical Energy Carrier For Future

A. Zuttel et.al., Phil. Trans. R. Soc. A(2010), 368, 3329-3342
Current Demand & Use of Hydrogen

Global annual demand for hydrogen since 1975

Future Use of Hydrogen

- Transportation
  - Heavy vehicles
  - Trains
  - Ships
  - Aviation

Examples of Canadian (Transport Canada) Initiatives for Marine Operations in Canada:
1) Techno-Economic Assessment of Zero-Emission Hydrogen Fuel for Marine Vessels in the Great Lakes Saint Lawrence System
2) Marine-Zero Fuel Assessment Tool to Analyse Marine Fleets for Emission-Free Fuel
Hydrail System- Deployment Perspectives

Electrification of heavy-duty rail
Ontario, Canada
A hydral deployment would accompany industrial-scale growth in regional trade and jobs creation

- Hydrogen for transport gets established as an industry
- Equipment production would grow to industrial scale

Integrated System that leverages contributions from nuclear beyond electricity sector

Current Nuclear Reactors

Advanced Reactors

Small Modular Reactors

Heat

e-

District Heating

Chemical Processes

Clean Water

Hydrogen for Transportation and Industry

Industry

Hydrogen
Current Hydrogen Production

• Fossil source
  – Steam Methane Reforming
  – Biomass
  – Others

• Non-fossil energy source
  – Advanced Alkaline Electrolysis
  – PEM Electrolysis
Nuclear Innovation - An Impetus for the Hydrogen Economy

- Highly Economical
- Enhanced Safety
- Minimize Wastes
- Proliferation Resistant

Gen I | Gen II | Gen III | Gen III+ | Gen IV
-----|-------|--------|--------|-----
Generation IV Nuclear Reactor Systems

- Sodium Fast Reactor
- Lead Fast Reactor
- Very High Temperature Reactor
- Gas Cooled Fast Reactor
- Supercritical Water Cooled Reactor
- Molten Salt Cooled Reactor
Nuclear Innovation in Canada

Canada has:
- Longstanding leadership in nuclear science and technology
- A full-spectrum industry with a supply chain primed for growth
- Revitalized labs with new capabilities for research and innovation.

SMRs may be located on sites that differ from where traditional nuclear power plants have been built. For example, SMRs may be established:

- on small grids where power generation needs are usually less than 300 megawatt electric (MWe) per facility
- at edge-of-grid or off-grid locations where power needs are small – in the range of 2 to 30 MWe

Electrical utilities, industry groups and government agencies throughout the world are investigating alternative uses for SMRs beyond electricity generation such as:

- producing steam supply for industrial applications and district heating systems
- making value-added products such as hydrogen fuel and desalinated drinking water
Hydrogen from Nuclear GEN IV Technology

- Sulphur-Iodine Process

\[ \text{Heat up to 850°C} \]
\[ \text{Heat up to 360°C} \]

\[ \text{Bunsen Reaction} \]
\[ \text{120°C} \]

\[ \text{SO}_2 + \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{SO}_4 \]
\[ \text{H}_2 + 4 \rightarrow 2 \text{H}_2 + 2 \text{O}^+ \]

\[ \text{Porous Cathode} \]
\[ \text{Gastight Electrolyte} \]
\[ \text{Porous Anode} \]

\[ 90\% \text{H}_2\text{O} + 10\% \text{H}_2 \]
\[ 10\% \text{H}_2\text{O} + 90\% \text{H}_2 \]

- Copper-Chlorine Process

- High Temperature Steam Electrolysis

\[ \text{Heat} \quad 800-1200°C \]

\[ \text{H}_2\text{SO}_4 \rightleftharpoons \frac{1}{2} \text{O}_2 + \text{H}_2\text{O} + \text{SO}_2 \]
\[ \text{SO}_2 + 2 \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{SO}_4 + \text{H}_2 \]

- Hybrid-Sulphur Process

\[ \text{Hydrogen from Nuclear GEN IV Technology} \]

UNRESTRICTED / ILLIMITÉ
Current Status
Sulphur-Iodine Process

- Countries Actively Developing: Japan, China, South Korea, India
- Status: Integrated System Demonstration - China 1 Nm3/h, Japan – 30 L/h
Current Status - continued

High Temperature Steam Electrolysis

- Countries Actively Developing: France, EU, US, China
- Status: Demonstrations in progress

25 kW HTSE Test Facility at INL

CEA’s First Commercial System
Current Status - continued

Copper-Chlorine Hybrid Cycle

- Countries Actively Developing: Canada, India
- Status: Preparation for integrated lab demonstration @ in 100g/d Canada
Hydrogen: Fuel of the Future?

YES
Thank You
Toshiyuki Shirai

*Director of Hydrogen Program, Ministry of Economy, Trade and Industry, Japan* International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) *Vice Chair and CEM Hydrogen Initiative (H2I) Co-Lead*

Toshiyuki Shirai is Director in Advanced Energy System Division, METI, where he leads hydrogen policy and strategy. He covered various policy areas, including industry, trade, and energy policies. He also worked as senior energy analyst in the IEA based in Paris and now serves as Vice-Chair of IPHE.
Vision and actions towards
“Hydrogen society”

Hydrogen and Fuel Cell Strategy Office,
Ministry of Economy, Trade and Industry (METI), Japan
Japan’s approach toward “Hydrogen Society”

**Basic Energy Plan**

Hydrogen as a key contributor to:
- Decarbonization
- Energy security
- Industrial competitiveness

**Basic Hydrogen Strategy** (Prime Minister Abe’s Initiative)

- First comprehensive national strategy
- H$_2$ as a future energy option toward 2050
- Detailed strategy with numerical targets
  ($3$/kg by 2030 $\Rightarrow$ $2$/kg by 2050)

**Strategic Roadmap for Hydrogen and Fuel Cells**

**Hydrogen and Fuel Cells Technology Development Strategy**
# Numerical targets toward hydrogen society

<table>
<thead>
<tr>
<th>Supply</th>
<th></th>
<th>Current</th>
<th>2025</th>
<th>2030</th>
<th>2050</th>
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<tbody>
<tr>
<td>Domestic H₂</td>
<td>International H₂ Supply Chains</td>
<td>CO₂-free H₂</td>
<td>Domestic Power-to-gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($/kg)</td>
<td>~10</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>Volume (t/y)</td>
<td>200</td>
<td>300k</td>
<td>5 ~10M</td>
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<table>
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<tr>
<th>Generation</th>
<th>Demand</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Power Plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC CHP*</td>
<td>300k</td>
<td>5.3m</td>
</tr>
<tr>
<td>*Primary energy: natural gas.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRS</td>
<td>113</td>
<td>320</td>
</tr>
<tr>
<td>FCV</td>
<td>3.6k</td>
<td>200k</td>
</tr>
<tr>
<td>FC Bus</td>
<td>33</td>
<td>1.2k</td>
</tr>
<tr>
<td>FC FL</td>
<td>250</td>
<td>10k</td>
</tr>
<tr>
<td>Industry Use</td>
<td>(RD&amp;D)</td>
<td></td>
</tr>
</tbody>
</table>
The Strategic Road Map for Hydrogen and Fuel Cells

Discussed among experts on how to achieve goals in the strategy

- A set of technical milestones
- A set of policy actions

- Price difference between FCV and HV: $28K → $6.5K
- Main FCV System cost, FC: $190/kW → $47/kW
- HRS Construction cost: $3.3m → $1.9m
- HRS Operating cost: $320,000/year → $140,000/year
- Production cost from brown coal gasification: several dollars/Nm³ → $0.1/Nm³
- Electrolyzer Cost: $1900/kW → $470/kW
The Strategic Road Map for Hydrogen and Fuel Cells ~ Industry-academia-government action plan to realize Hydrogen Society ~(overall)

- In order to achieve goals set in the Basic Hydrogen Strategy,
  1. **Set of new targets to achieve** (Specs for basic technologies and cost breakdown goals), establish approach to achieving target.
  2. **Establish expert committee to evaluate and conduct follow-up for each field.**

<table>
<thead>
<tr>
<th>Goals in the Basic Hydrogen Strategy</th>
<th>Set of targets to achieve</th>
<th>Approach to achieving target</th>
</tr>
</thead>
</table>
| **FCV** 200k b y 2025 800k by 2030 | - Price difference between FCV and HV (¥3m → ¥0.7m)  
- Cost of main FCV system  
  - Hydrogen Storage ¥0.7m → ¥0.3m  
  - Cost of fuel cell system ¥20k/kW → ¥5k/kW | - Regulatory reform and developing technology  
- Consideration for creating nationwide HRS network  
- Extending hours of operation |
| **HRS** 320 by 2025 900 by 2030 | - Construction and operating costs  
  - Construction cost ¥350m → ¥200m  
  - Operating cost ¥34m → ¥15m  
- Costs of components for HRS  
  - Compressor ¥90m → ¥50m  
  - Accumulator ¥50m → ¥10m | - Increasing HRS for FC bus  
- Developing of high efficiency combustor etc.  
- Developing FC cell/stack technology |
| **Bus** 1,200 by 2030 Early 2020s | - Vehicle cost of FC bus (¥105m → ¥52.5m) | - Scaling-up and improving efficiency of brown coal gasifier  
- Scaling-up and improving thermal insulation properties |
| **Commercialize by 2030** | - Efficiency of hydrogen power generation (26%→27%)  
  *1MW scale | - Developing of high efficiency combustor etc.  
- Developing FC cell/stack technology |
| **FC** Early realization of grid parity | - Realization of grid parity in commercial and industrial use | - Developing of high efficiency combustor etc.  
- Developing FC cell/stack technology |
| **Supply** Hydrogen Cost  30/Nm³ by 2030 20/Nm³ in future | - Production: Production cost from brown coal gasification  
  *several hundred/Nm³ → ¥12/Nm³  
- Storage/Transport: Scale-up of liquefied hydrogen tank  
  *thousands m³→50,000m³  
  *Higher efficiency of liquefaction  
  *13.6kWh/kg→6kWh/kg | - Developing of high efficiency combustor etc.  
- Developing FC cell/stack technology  
- Demonstrating model regions for social deployment utilizing the achievement |
Policies to Realize a “Hydrogen Society”

- Produce hydrogen from unused, affordable resources, such as brown coal and renewable energy
  - A demonstration project in Fukushima (10M electrolyzer with 20M solar PV)
  - Demonstration projects overseas in Australia and Brunei

Production

Transportation and supply
(supply chain)

Use

Power-to-Gas Plant

Gasification from Brown Coal + CCS

natural gas
Policies to Realize a “Hydrogen Society”

- Promote deployment of hydrogen stations (113 stations)
- Promote regulatory reforms to allow unmanned H2 stations and lower operation cost
- The world’s first international hydrogen supply chain project, with the LH2 carrier ship launched in December 2019
Policies to Realize a “Hydrogen Society”③

- Promote deployment of hydrogen technologies in a variety of sectors
  - Fuel cell vehicles (FCV, FC bus, etc.)
  - Combined heat and power supply using hydrogen-powered cogeneration
  - Feasibility study and R&D for hydrogen power generation
  - R&D to use hydrogen in steel making process

H₂ Co-generation Demonstration Project
Growing momentum of hydrogen and fuel cells around the world

Netherlands: Plan for hydrogen power generation, etc.
Norway: Hydrogen supply project
Russia: Interest in Hydrogen Production
Canada: FC development
UK: Hydrogen injection into pipelines
France: FCV, etc.
China: FC bus
U.S.A: Lead R&D on hydrogen and FC
Germany: Hydrogen Train
Japan: FCV, Hydrogen Supply Chain Project, Hydrogen Production
Brunei: Hydrogen Production, Hydrogen Supply Chain Project with Japan
Korea: FCV
Oman: Interest in Hydrogen
Australia: Hydrogen production from brown coal and renewable energy. Hydrogen Supply Chain project with Japan
NZ: Hydrogen production project
Argentina: Interest in Hydrogen production

Multi-lateral initiatives on hydrogen
G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth

G20 Communiqué (excerpt)
The G20 Energy Ministers will step up existing international efforts to unlock the potential of hydrogen as a clean, reliable and secure source of energy including cooperation in research and development, evaluating hydrogen’s technical and economic potential, cost reduction pathways and addressing the various challenges including regulations and standards.

G20 Karuizawa Innovation Action Plan (excerpt)
<Hydrogen and other synthetic fuels>
We support the acceleration of our work that will lead to concrete actions which were summarized in the chair’s summary at Hydrogen Energy Ministerial Meeting (HEM) 2018, including exchange of best practices, international joint research, evaluation of hydrogen’s potential, e.g. for power to x, outreach and addressing regulatory barriers, codes and standards. We promote further international cooperation and discuss concrete actions through frameworks such as HEM 2019 (autumn), the Clean Energy Ministerial (CEM), Mission Innovation (MI) and the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), and ask relevant international and regional organizations such as the IEA, IRENA and the ERIA to develop the analysis of potential pathways to a hydrogen-enabled clean energy future, including the use of methanol and ethanol as hydrogen carriers in fuel cells. We note that hydrogen as well as other synthetic fuels can play a major role in the clean energy future with a view to long-term strategies.
Hydrogen Energy Ministerial Meeting

2018
21 countries, region and organizations
300 attendees

2019
35 countries, region and organizations
600 attendees

TOKYO STATEMENT
• Harmonization of Regulation, Codes and Standards
• Joint Research and Development
• Study and Evaluation of Hydrogen’s Potential
• Education & Outreach

GLOBAL ACTION AGENDA

The 3rd Meeting will be held in Tokyo on Oct 12nd and 13rd
Global Action Agenda

- **Mobility**
  - Sharing aspirational goals such as “10 million hydrogen powered systems” and “10 thousand Hydrogen Refueling Stations (HRS)” in 10 years (“Ten, Ten, Ten”)

- **Hydrogen Supply Chains**
  - R&D and Sharing Information
  - Promote investment

- **Sector Integration**
  - Expand the use of hydrogen in various sectors

- **Study and Evaluation of Hydrogen’s Potential**
  - Further analysis and study by IEA, IRENA, ERIA

- **Communication, Education and Outreach**
  - Disseminate information
  - Conduct campaign
Peter Fraser

*Head of Division for Gas, Coal and Power markets, International Energy Agency*

Peter Fraser rejoined the International Energy Agency in December 2016 as Head of the Gas, Coal and Power Markets Division. This is his second sojourn with the IEA, having been a Senior Electricity Policy Advisor there from 1998-2004. Trained in astrophysics, Peter has spent most of his career in energy policy in Canada.
Carbon, Uranium, Hydrogen

Some insights on relative economics from The Future of Hydrogen study

NICE Future Webinar, 18 March 2020
Hydrogen – A common element of our energy future?

- Momentum currently behind hydrogen is unprecedented, with more and more policies, projects and plans by governments & companies in all parts of the world.

- Hydrogen can help overcome many difficult energy challenges:
  - **Integrate more renewables**, including by enhancing storage options & tapping their full potential
  - **Decarbonise hard-to-abate sectors** such as steel, chemicals, trucks, ships & planes
  - **Enhance energy security** by diversifying the fuel mix & providing flexibility to balance grids

- But there are challenges: **costs** need to fall; **infrastructure** needs to be developed; **cleaner hydrogen** is needed; and **regulatory barriers** persist.
Hydrogen is already part of the energy mix

Dedicated hydrogen production is concentrated in very few sectors today, using fossil fuels and responsible for 2.4% of global energy-related CO2. If replaced by electrolysis would require 3600 TWh of electricity and 617 Mm3 of water.
### Low carbon hydrogen production

#### Carbon intensity of hydrogen production (kg CO2/kgH2)

<table>
<thead>
<tr>
<th>Source</th>
<th>Hard coal</th>
<th>Natural gas</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With CCUS, 90% capture rate</td>
<td>With CCUS, 90% capture rate</td>
<td>Renewable or nuclear generation</td>
</tr>
<tr>
<td></td>
<td>Without CCUS</td>
<td>With CCUS, 56% capture rate</td>
<td>Gas-fired generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Without CCUS</td>
<td>Coal-fired generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>World average electricity mix</td>
</tr>
<tr>
<td></td>
<td>Expensive</td>
<td>Low cost</td>
<td>World average electricity mix</td>
</tr>
</tbody>
</table>

While electrolysis with low carbon electricity is lowest, gas/coal with CCUS has relatively moderate emissions intensity.
Producing low carbon hydrogen – gas vs. electricity

Comparison of natural gas (steam reforming) with CCS and electrolysis (USD 450/kW)

Electricity prices below USD 40/MWh are needed to be competitive with SMR/CCS
Price of electricity dominates electrolyser economics

Cost of hydrogen as a function of electrolyser CAPEX (left) and electricity price (right)

Electrolyser capital costs are already low enough that moderate load factors are sufficient
Many markets have cheap electricity available

Wholesale market prices have been low in several markets creating incentives to use electricity e.g., by diverting supply from an existing nuclear power plant.
Solar and wind will provide most of the new capacity

Global power capacity by source in the Stated Policies Scenario

- Solar PV
- Gas
- Coal
- Wind
- Hydro
- Nuclear

The growth in solar and wind in many markets will create more low price hours.
Wind + Solar hydrogen costs are set to decline

Best resources may not be near the main demand centres; necessitating transportation
Offshore wind may also become an attractive approach

A feasibility study for the NortH2 project in the Netherlands has been announced.
Some concluding thoughts

1. Hydrogen is already an important chemical with great potential as a low carbon energy carrier.

2. Hydrogen production can be decarbonised by using low carbon electricity for electrolysis.

3. The cost of the electricity (below USD 40/MWh) is more important than the cost of the electrolyser, meaning midload operation is a “sweet spot”.

4. Grid electricity can be cheaper than this with intriguing possibilities for offshore wind or wind/solar combinations.
Question & Answer
Thank you