Hydrogen: Fuel of the Future?

Wednesday 18 March 2020

NICE Future
Nuclear Innovation: Clean Energy Future
An Initiative of the Clean Energy Ministerial

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Agenda

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.

NICE Future NUCLEAR INNOVATION: CLEAN ENERGY FUTURE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

IPHE

HYDROGEN INITIATIVE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

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

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Advancing Clean Energy Together

FNC FLEXIBLE NUCLEAR CAMPAIGN FOR NUCLEAR-RENEWABLES INTEGRATION
A CAMPAIGN OF THE CLEAN ENERGY MINISTERIAL

LucidCatalyst

Eric Ingersoll

Managing Partner

Kirsty Gogan

Managing Partner

ENERGY OPTIONS NETWORK

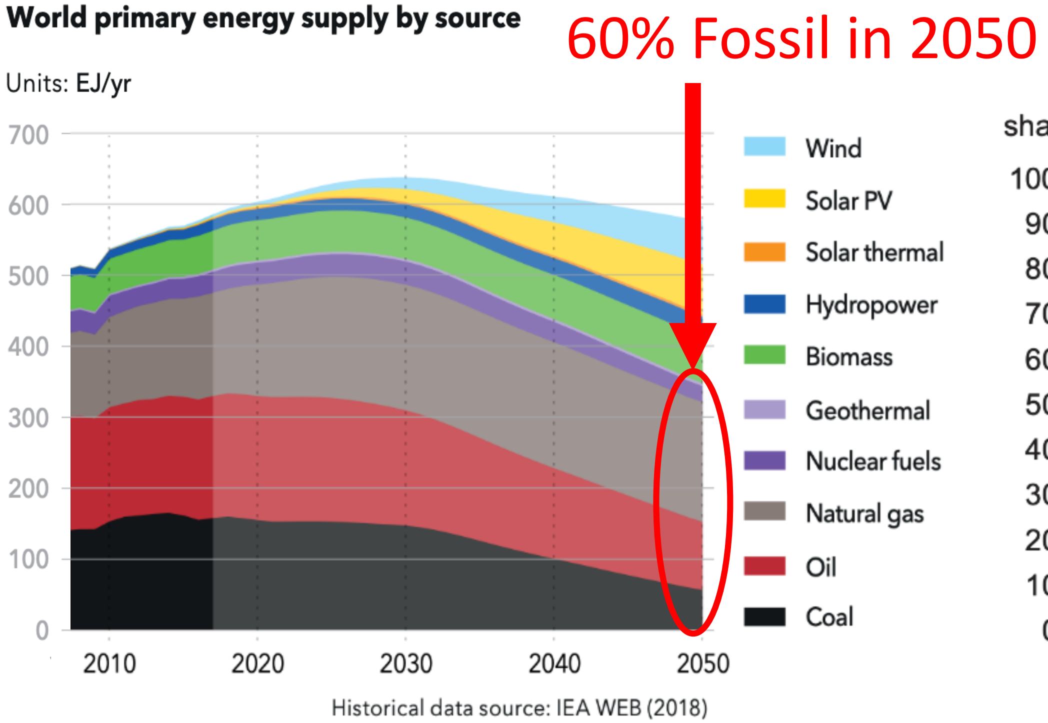
ENERGY FOR HUMANITY

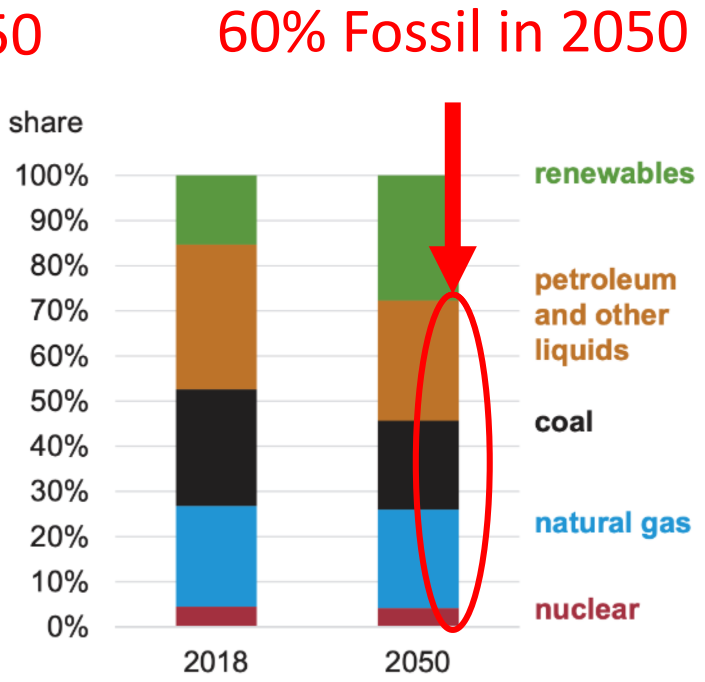
Opportunities for Hydrogen

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





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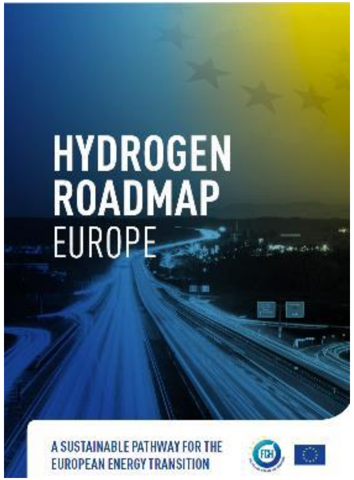
Some industries will be very difficult to decarbonize

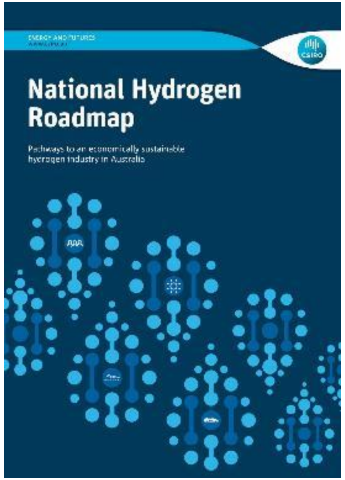
- Biofuels cannot scale to the levels necessary to decarbonize industries like air travel or marine shipping

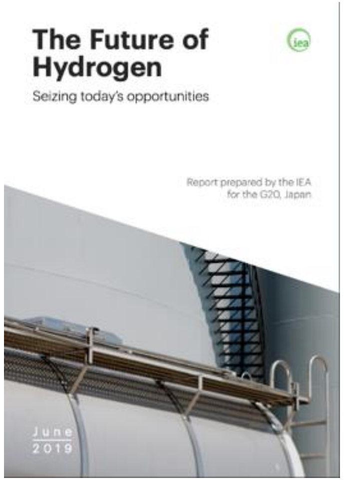
- Low-carbon options for heavy industry like steel and cement are scarce and expensive.

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)."



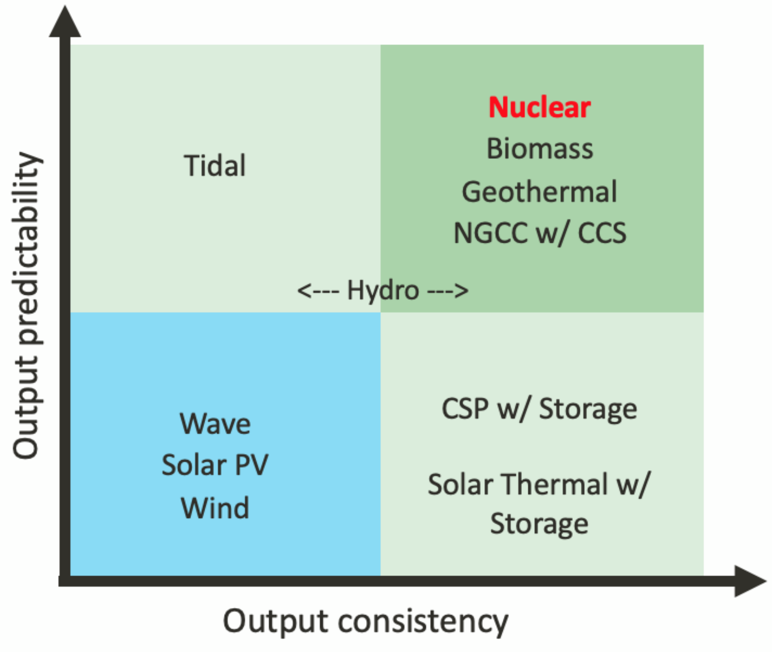




Evidence suggests that nuclear is a promising candidate for low-cost H_2 production

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.



Source: EDF (2019) “Sailing on Solar”

Four reasons why we need dedicated hydrogen production

1. The global liquid fuels market is 4x larger (in GJ) than the global electricity market. 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

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Flexible Nuclear Campaign – The Team

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FNC FLEXIBLE NUCLEAR CAMPAIGN
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Dr. Sunita Satyapal

Director of the Fuel Cell Technologies Office, Department of Energy Office of Energy Efficiency and Renewable Energy (EERE), United States International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) Chair and CEM Hydrogen Initiative (H2I) Co-Lead

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.

@The_IPHE
#HydrogenNow
#FuelCellsNow

U.S. DEPARTMENT OF
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RENEWABLE ENERGY

Hydrogen and Fuel Cell Perspectives

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

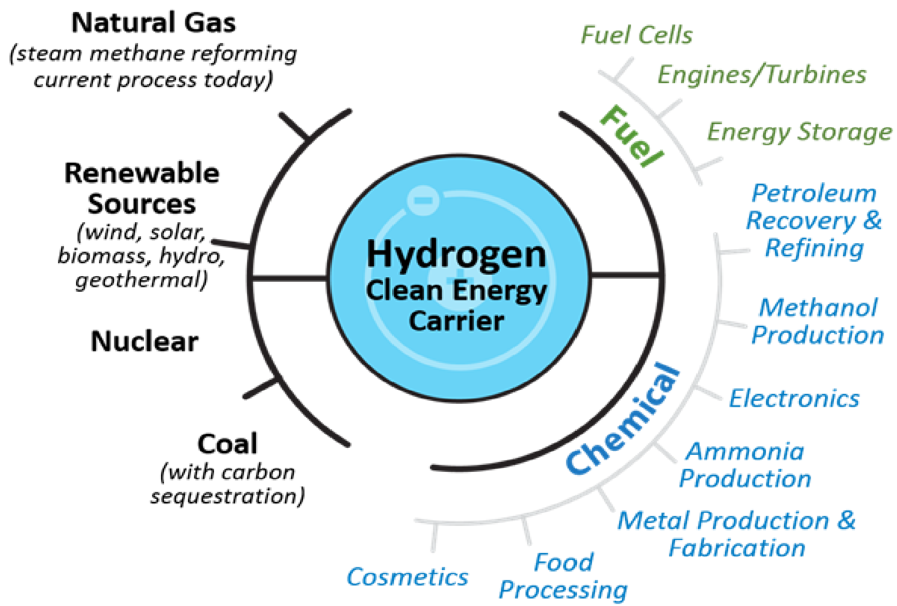
Clean Energy Ministerial’s (CEM) Nuclear Innovation: Clean Energy Future (NICE Future) Initiative, Hydrogen Initiative (H2I), International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) Joint Webinar

March 18, 2020


Hydrogen – One Part of a Comprehensive Energy Strategy

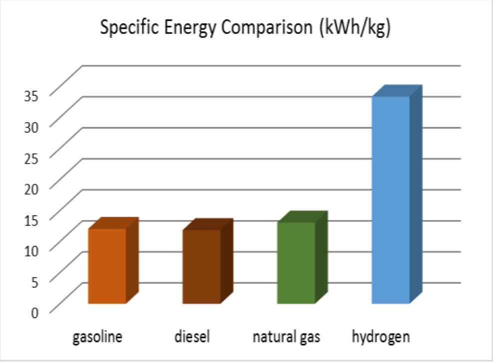
H_2 can be produced from diverse domestic sources

Many applications rely on or could benefit from H_2

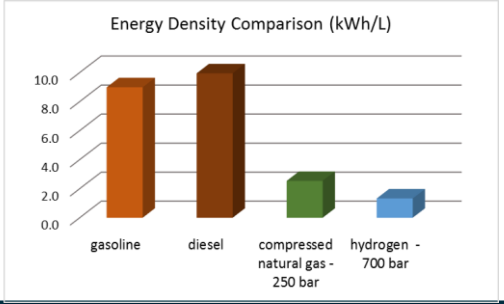


High energy content by mass

Nearly 3x more than conventional fuels



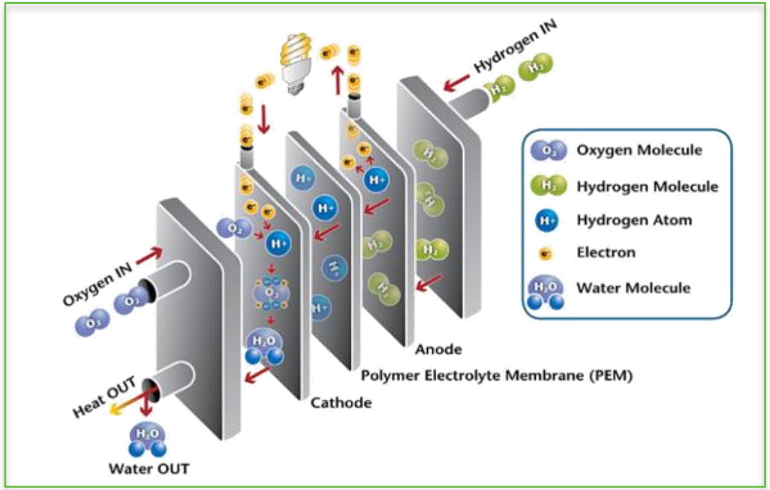
Low energy content by volume

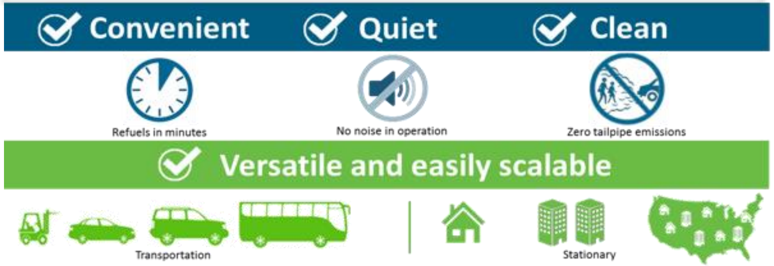


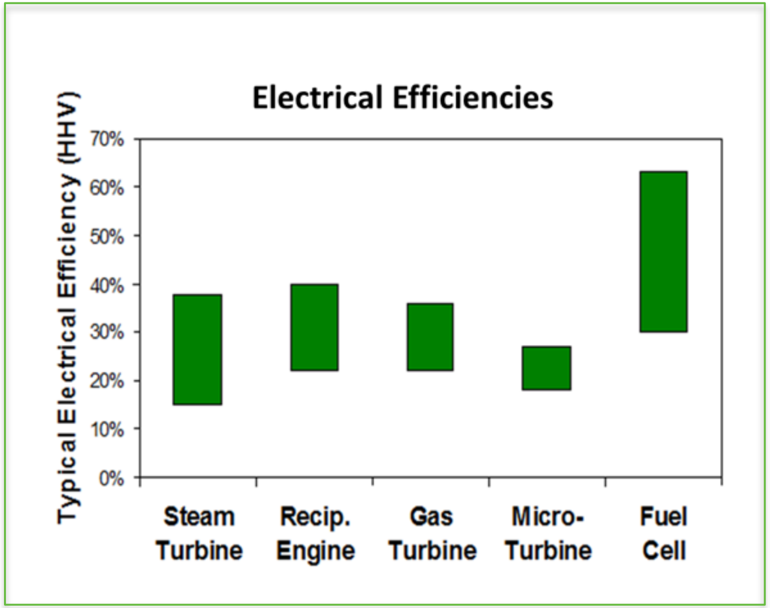
Clean , sustainable, versatile, and efficient energy carrier

Fuel Cell Basics

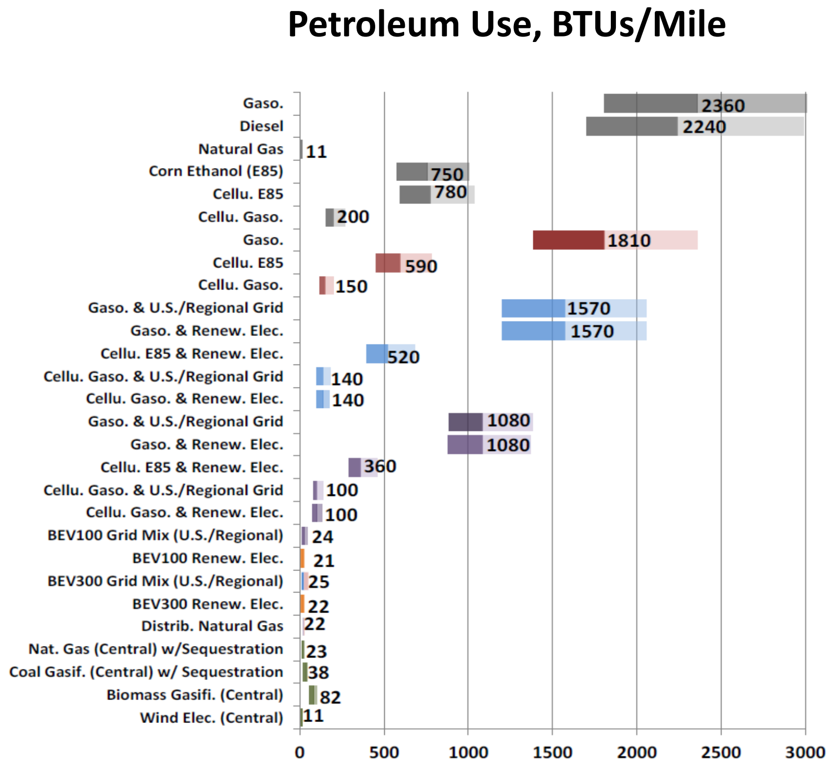
Fuel cells can operate on hydrogen or other fuels and do not involve combustion so have high electrical efficiencies

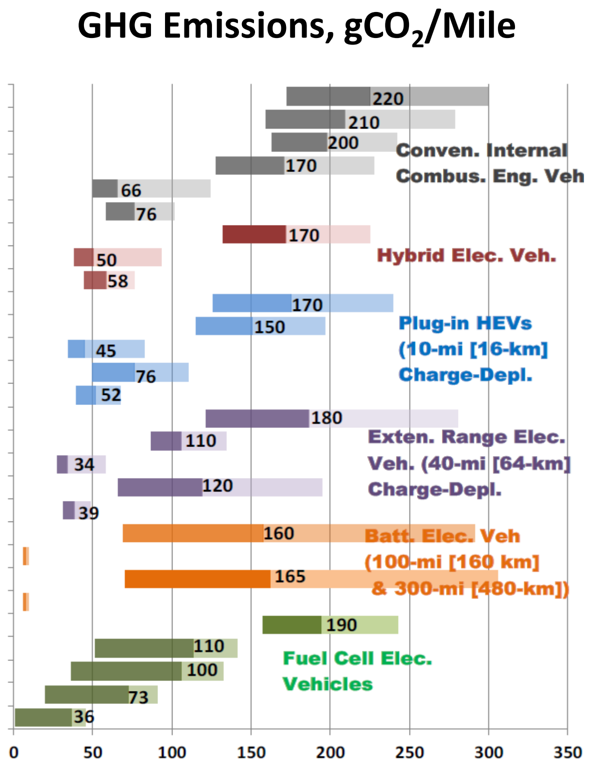






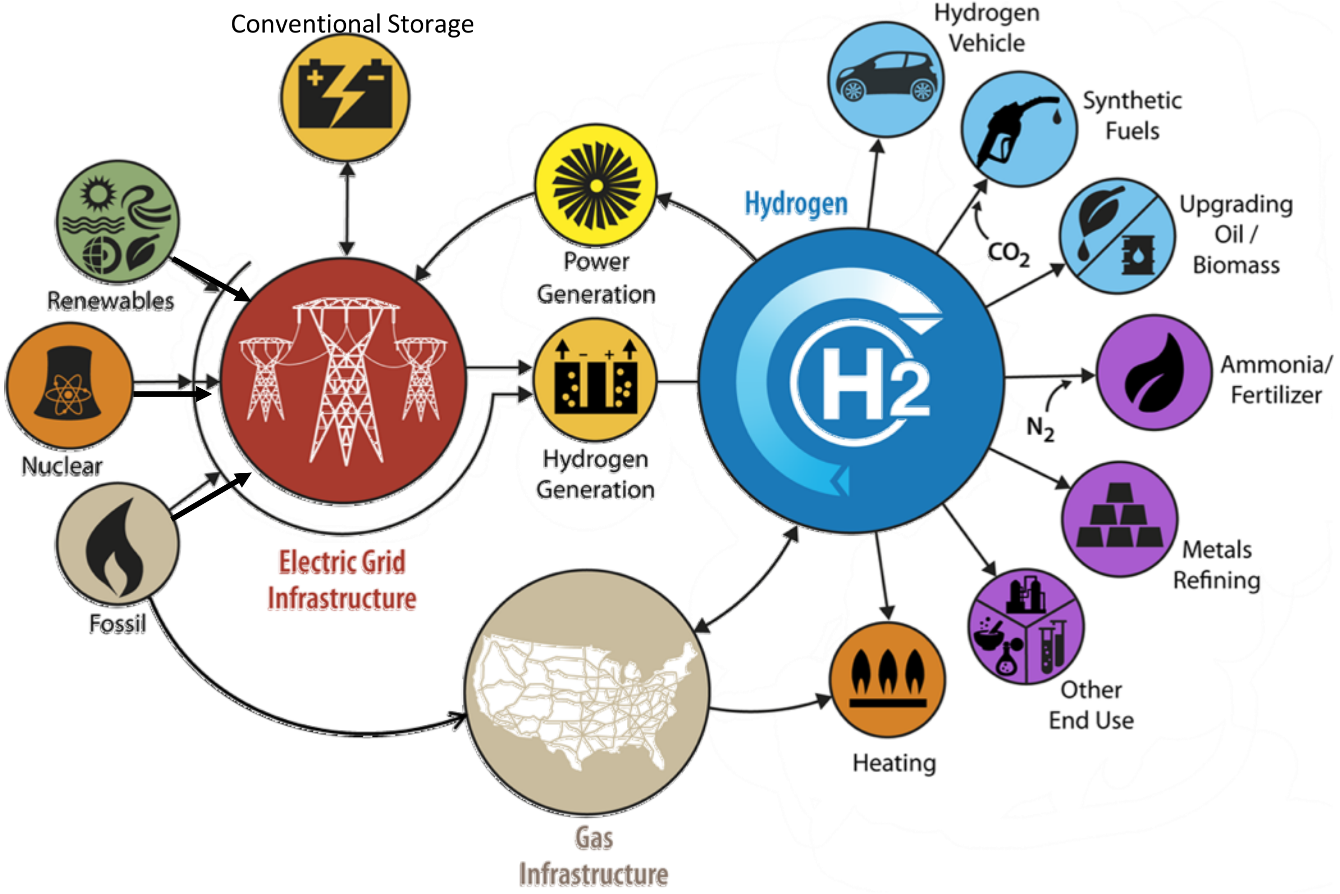
Example of Well-to-Wheels Analysis: Petroleum Use and Emissions



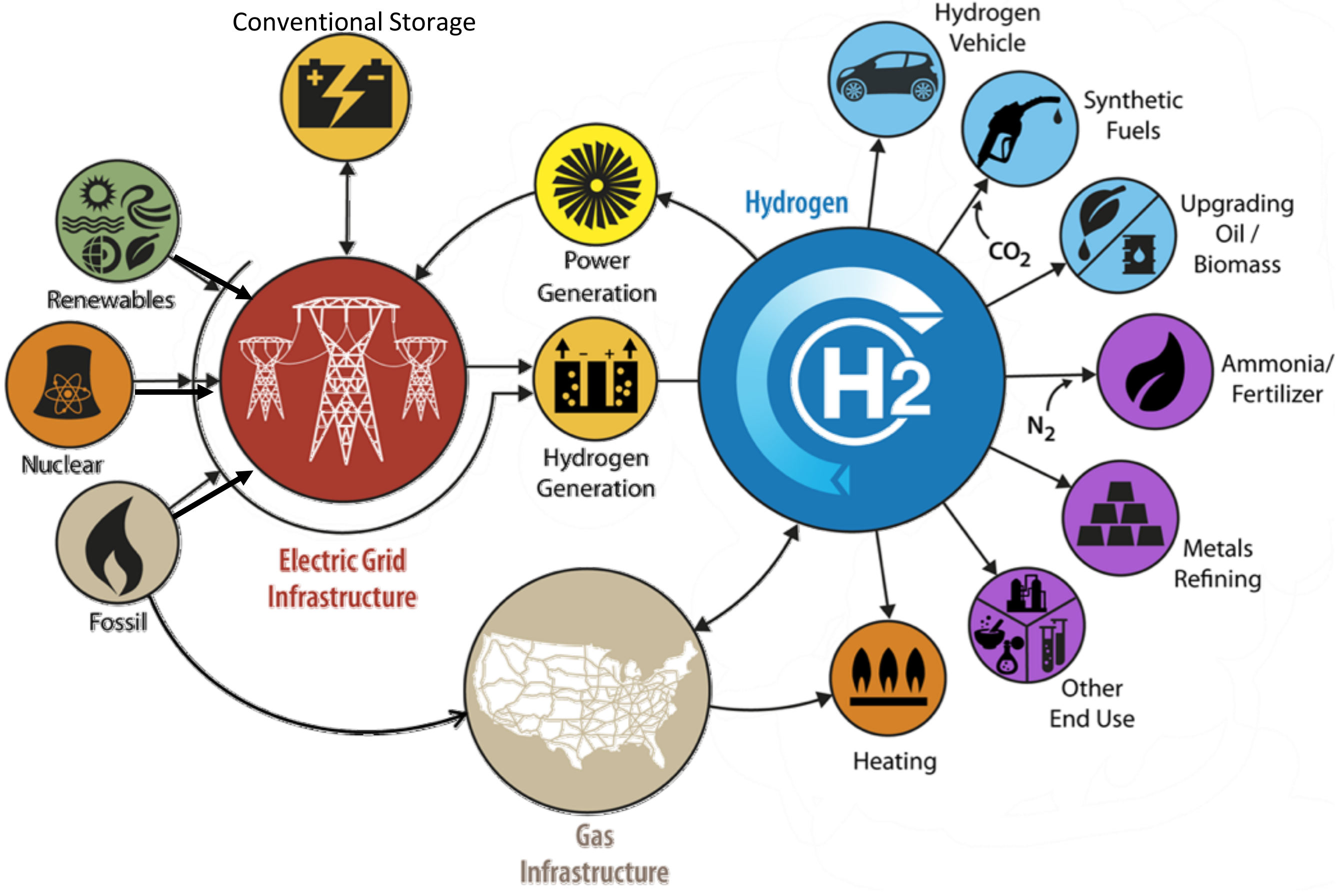


Program Record #13005: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf; updates underway will include heavy duty vehicles- focus for hydrogen fuel cells

H_2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



H_2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



Guiding Legislation and Budget

Energy Policy Act (2005) Title VIII on Hydrogen

- 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**

	FY 2018	FY 2019	FY 2020
Fuel Cell R&D	32,000	30,000	26,000
Hydrogen Fuel R&D	54,000	39,000	45,000
Hydrogen Infrastructure R&D*	-	21,000	25,000
Technology Acceleration	19,000	21,000	41,000
Safety, Codes, and Standards	7,000	7,000	10,000
Systems Analysis	3,000	2,000	3,000
Total	**$115,000**	**$120,000**	**$150,000**

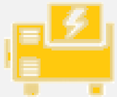
* FY20 Appropriations for nuclear to H2 demonstration project with FCTO ($10M)

DOE Office	Funding (in $K)
EERE (FCTO) - Lead	$150,000
Fossil Energy (SOFC)	$30,000
Nuclear Energy	$11,000

- EERE: Energy Efficiency and Renewable Energy Office
- FCTO: Fuel Cell Technologies Office
- SOFC: Solid Oxide Fuel Cell Office

Snapshot of Hydrogen and Fuel Cells Applications in the U.S.

Examples of Applications



>500MW

Stationary Power

>33,000

Forklifts

>30

Fuel Cell Buses

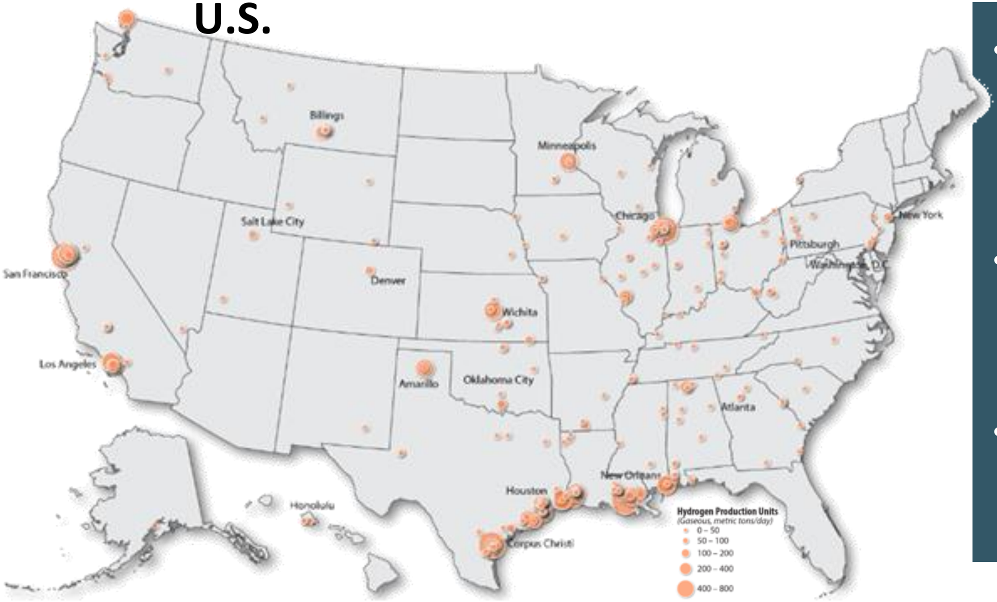
>45

H_2 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 H_2 pipeline**
- **World's largest H_2 storage cavern**

Hydrogen Stations: Examples of Plans Across States

California
200 stations planned - CAFCP goal

Northeast
12 – 20 stations planned

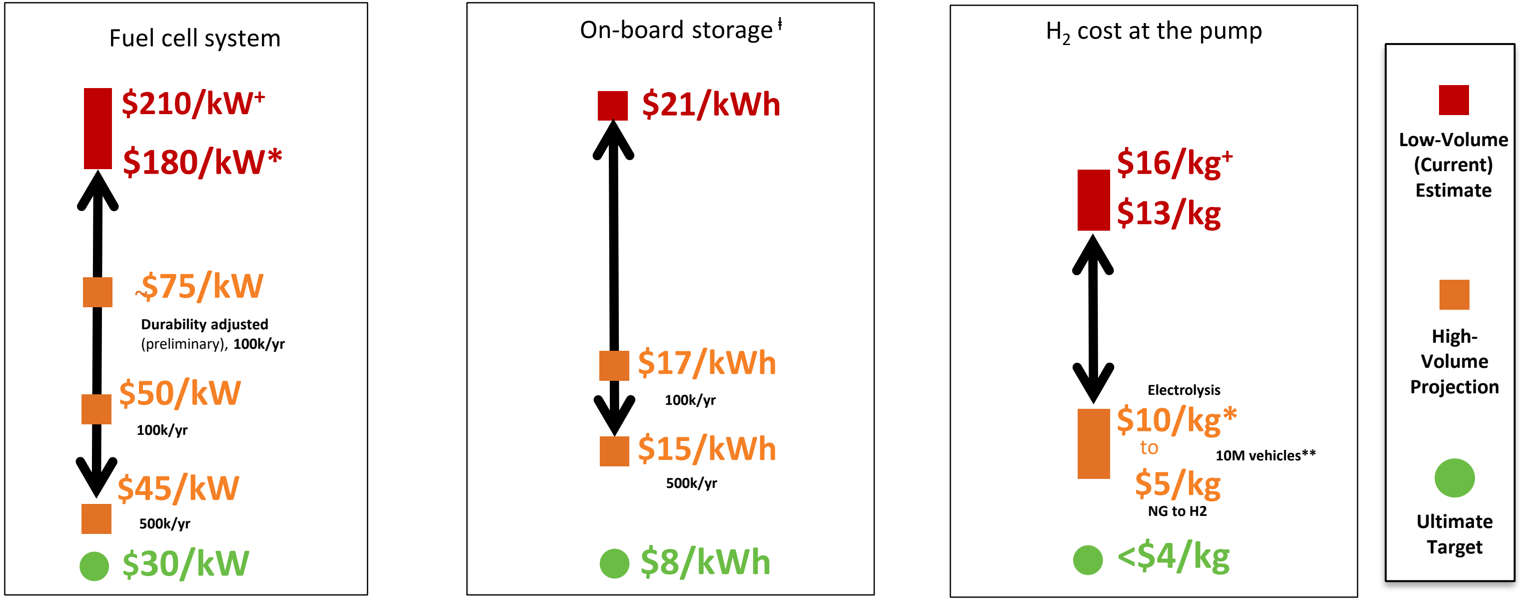
HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others

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

Hydrogen R&D



†Based on commercially available FCEVs

*Based on state of the art technology

ǂStorage costs based on preliminary 2019 storage cost record

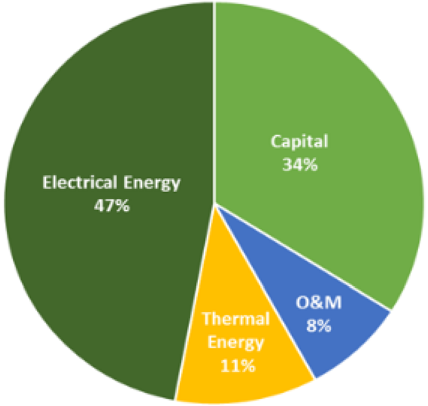
†For range: H2 production from natural gas (NG), delivered dispensed at today's (2018) stations (~180kg/d)

*For range: Assumes high volume manufacturing in 1) H2 production costs ranging from $2/kg (NG) 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).

** Range assumes >10,000 stations at 1,000 kg/day capacity, to serve 10 million vehicles

Hydrogen R&D Areas – Examples

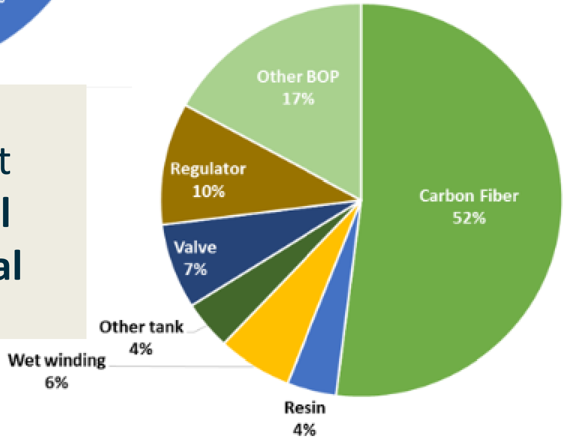
Hydrogen Production Cost
(High Temperature Electrolysis)



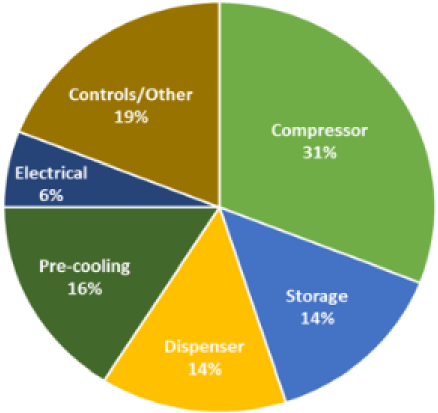
H_2 Production (Electrolysis) Cost Drivers: **Electrical energy and capital costs**

H_2 Onboard Storage Cost Drivers: **Carbon Fiber Precursors and Processing**

Hydrogen Storage Cost
(Onboard 700 Bar Hydrogen Storage Vessel)



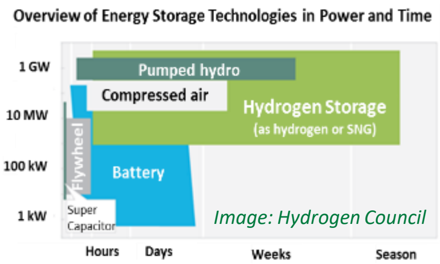
Hydrogen Infrastructure Cost
(700 Bar Hydrogen Station)



H_2 Infrastructure Cost Drivers: **Compressors and Storage**

Note: Updates to be published May, 2020

Increased Activities on Hydrogen, Energy Storage, Hybrid Systems

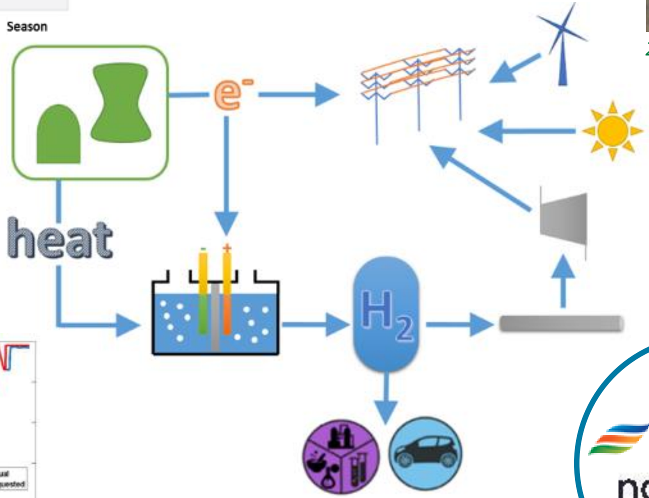


H_2 energy storage

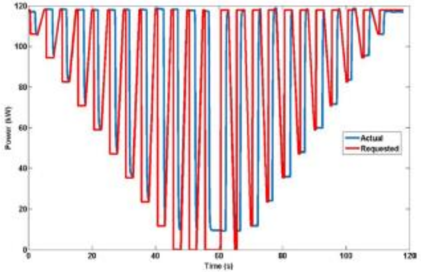
Increased opportunities for nuclear and hydrogen

25 kW high-temperature electrolysis @ INL Energy Systems Laboratory

Thermal Integration



Dynamic response



Dynamic electrolyzer response – INL & NREL

Multiple end use applications

DOE Industry demos

Recently announced demonstrations

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

Clean H_2 production enabling dispatchable, carbon-free power

Objectives

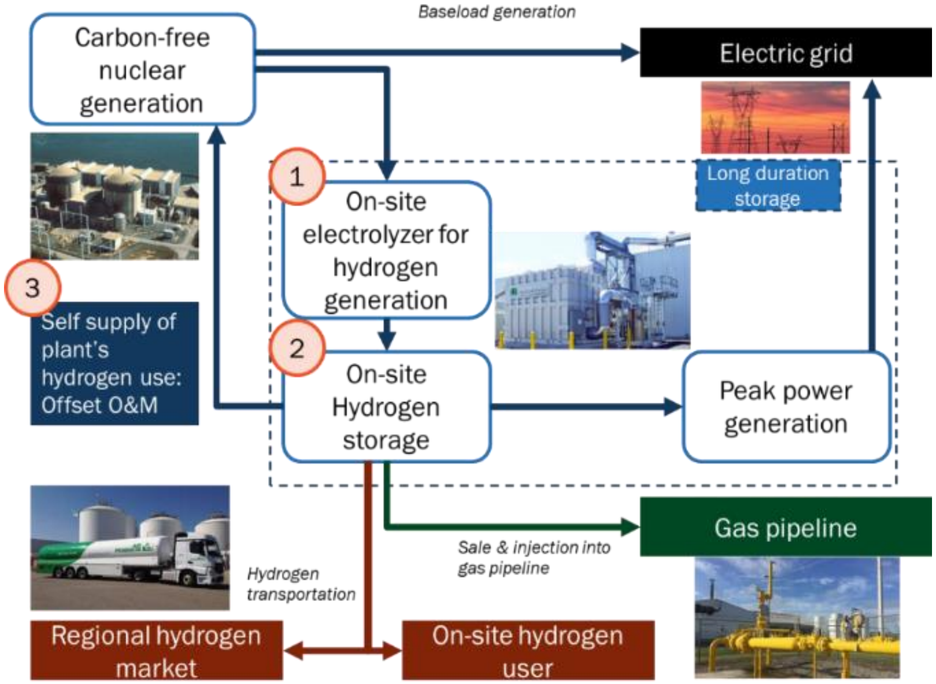
- Develop an integrated hydrogen production, storage, and utilization facility at a nuclear plant site, based on a PEM electrolyzer
- Demonstration of economic supply of carbon-free hydrogen for internal nuclear site use.
- Dynamic control of the electrolyzer

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

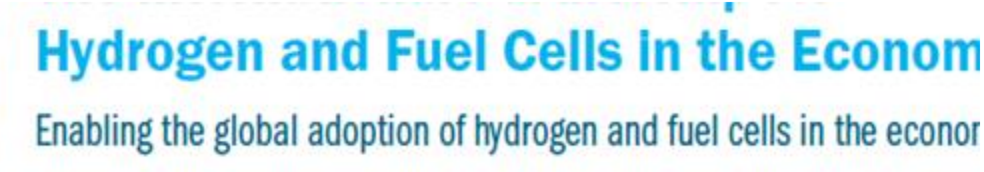
Global Government Partnerships to Accelerate Progress on Hydrogen and Fuel Cells

Elected Chair and Vice-Chair, 2018

Mission Innovation Hydrogen Challenge Launched 2017

Hydrogen Energy Ministerial (HEM) Launched 2018

Clean Energy Ministerial Hydrogen Initiative Launched2019

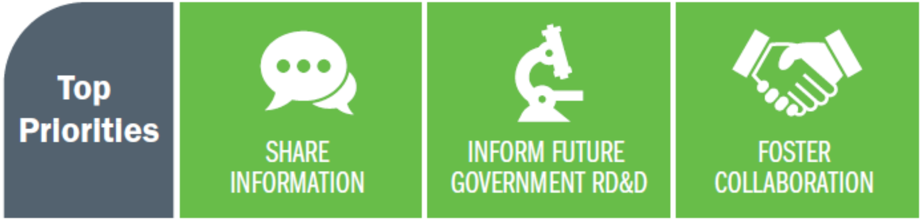


Key Activities: Working Groups on Regulations, Codes, Standards & Safety; Education & Outreach

Develops country updates on policies, status, shares best practices

Task force on developing H_2 production methodology to facilitate international trade

Coordinates activities among global and regional partnerships



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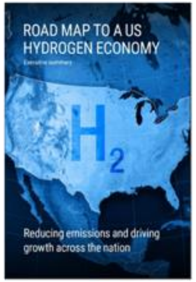
Formed 2003

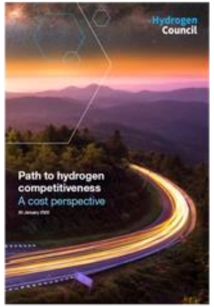
19 Countries and EC

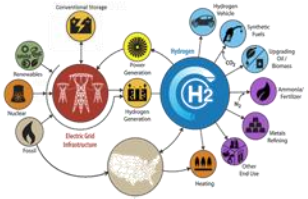
International Energy Agency (IEA)

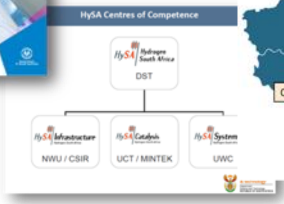
Roadmaps and Plans Developing in Multiple Regions

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

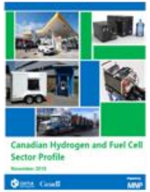






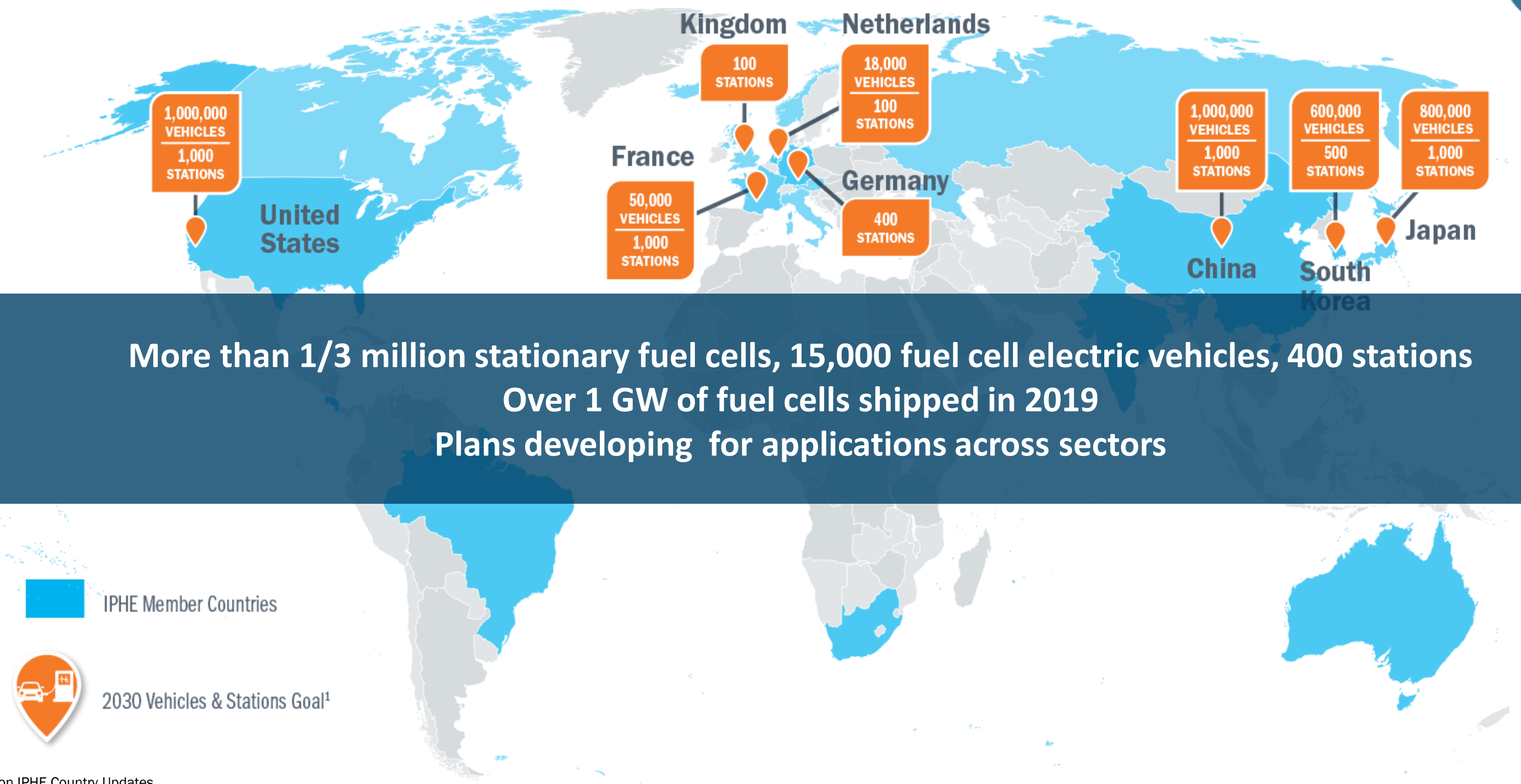


Global Action Agenda released at Hydrogen Energy Ministerial, Tokyo (9/25/2019)
Aspirational Targets: "10, 10, 10"
10M systems, 10K stations, 10 years



High priority areas include: Global harmonization of codes and standards and addressing gaps, safety

Global Snapshot of Status and Goals



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

Based on IPHE Country Updates

US: CA Fuel Cell Partnership goal

Example of Collaboration: Global Center for H_2 Safety (CHS)

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

IPHE

AIChE

Hydrogen Council

hySafe

Pacific Northwest NATIONAL LABORATORY

Includes over 40 partners from industry, government and academia

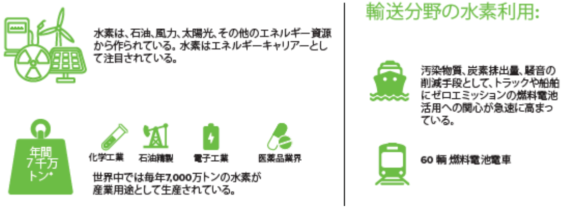
CENTER FOR Hydrogen SAFETY
Connecting a Global Community

HYDROGEN Safety Panel

HYDROGEN Emergency Response Training Resources

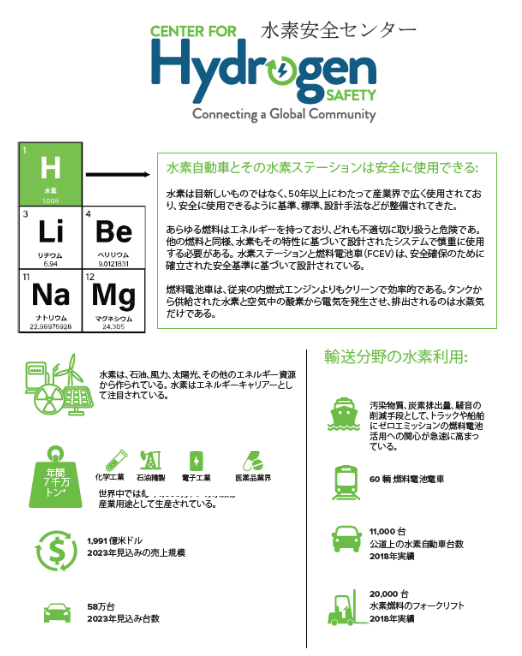
Access to >110 countries, 60,000 members

CENTER FOR Hydrogen SAFETY 水素安全センター
Connecting a Global Community



www.aiche.org/CHS

Information to be available in multiple languages



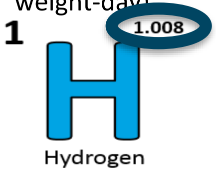
Resources and Announcements

Save the Date

May 19 – 21, 2020 Annual Merit Review and Peer Evaluation Meeting for the Hydrogen and Fuel Cells Program in Washington D.C.

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/

INCREASE YOUR H2IQ

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
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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.

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Clean. Reliable. Nuclear.

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

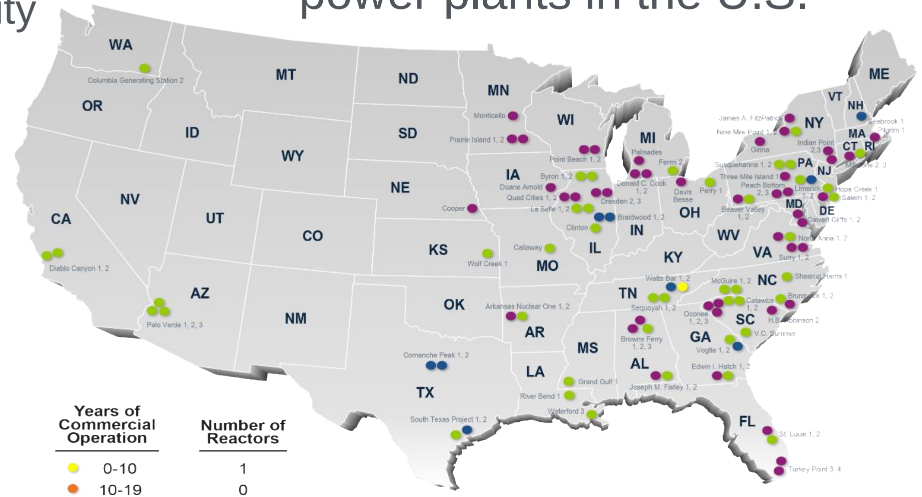
NE Mission Focus Leads to Global Competitiveness in Nuclear Technology

Existing Fleet → Advanced Reactor Pipeline → Fuel Cycle Infrastructure → Global Competitiveness

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: 10/18

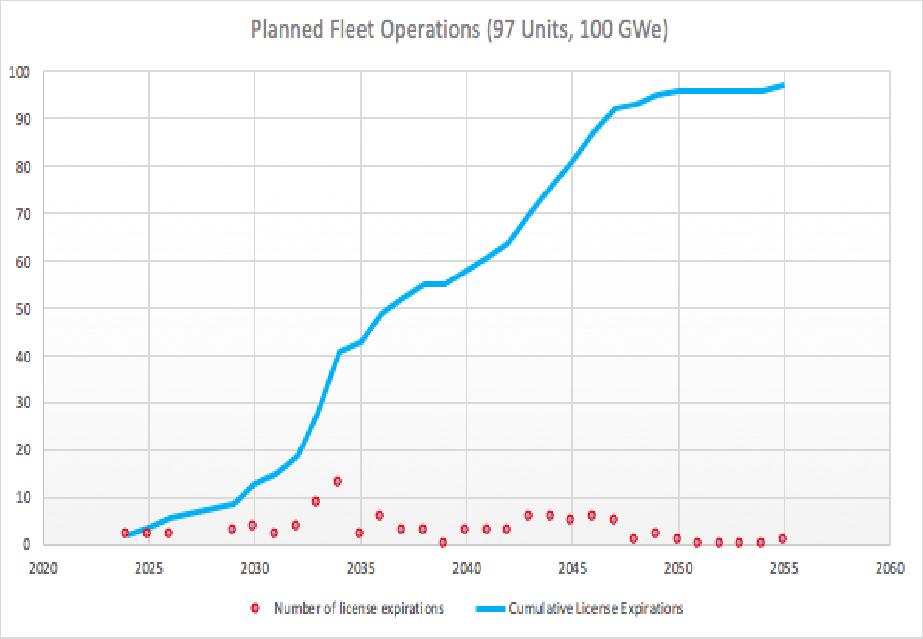
18-50141-03

3

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



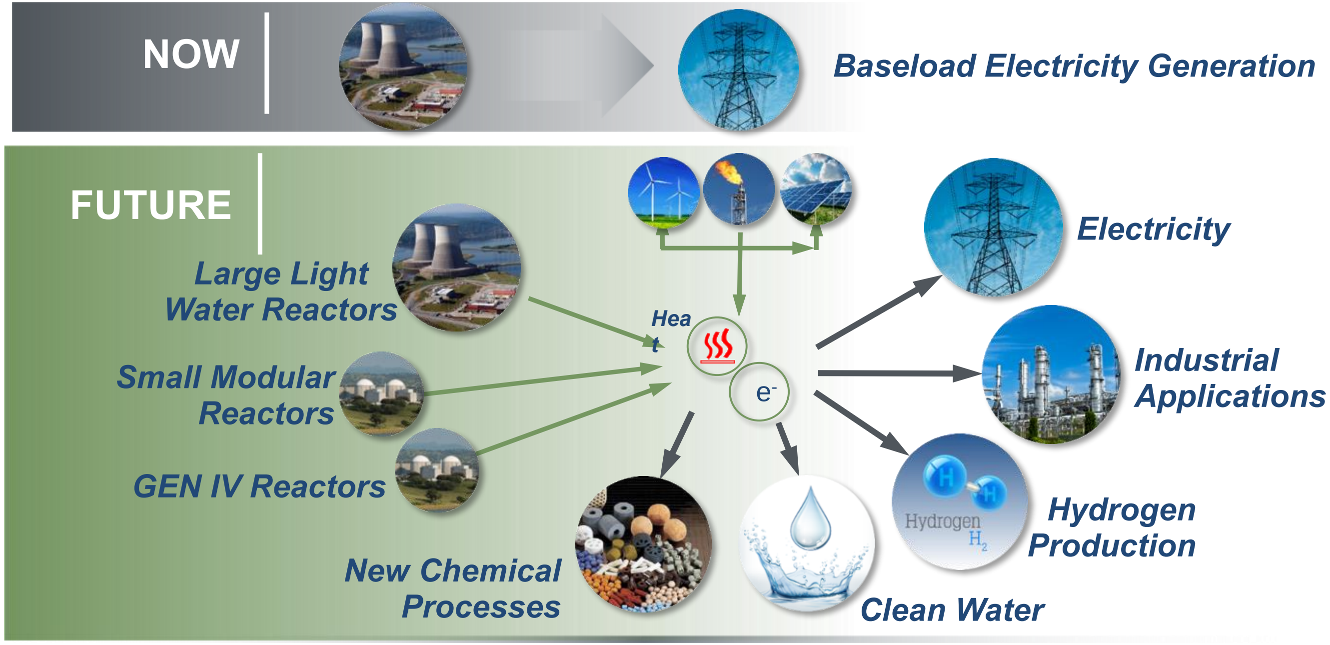
Light Water Reactor Sustainability (LWRS) Program

Research Pathways & Focus Areas

Plant Modernization	Address replacement of existing instrumentation and control technologies and enable plant efficiency improvements through a strategy for long-term modernization
Flexible Plant Operation and Generation	Evaluate and demonstrate integrated energy systems that competitively produce electricity and non-electrical products to optimize revenue generation by nuclear power plants
Physical Security	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
Risk Informed Systems Analysis	Develop significantly improved safety analysis methods and tools to optimize the safety, reliability, and economics of plants
Materials Research	Understand and predict long-term behavior of materials in nuclear power plants, including detecting and characterizing aging mechanisms

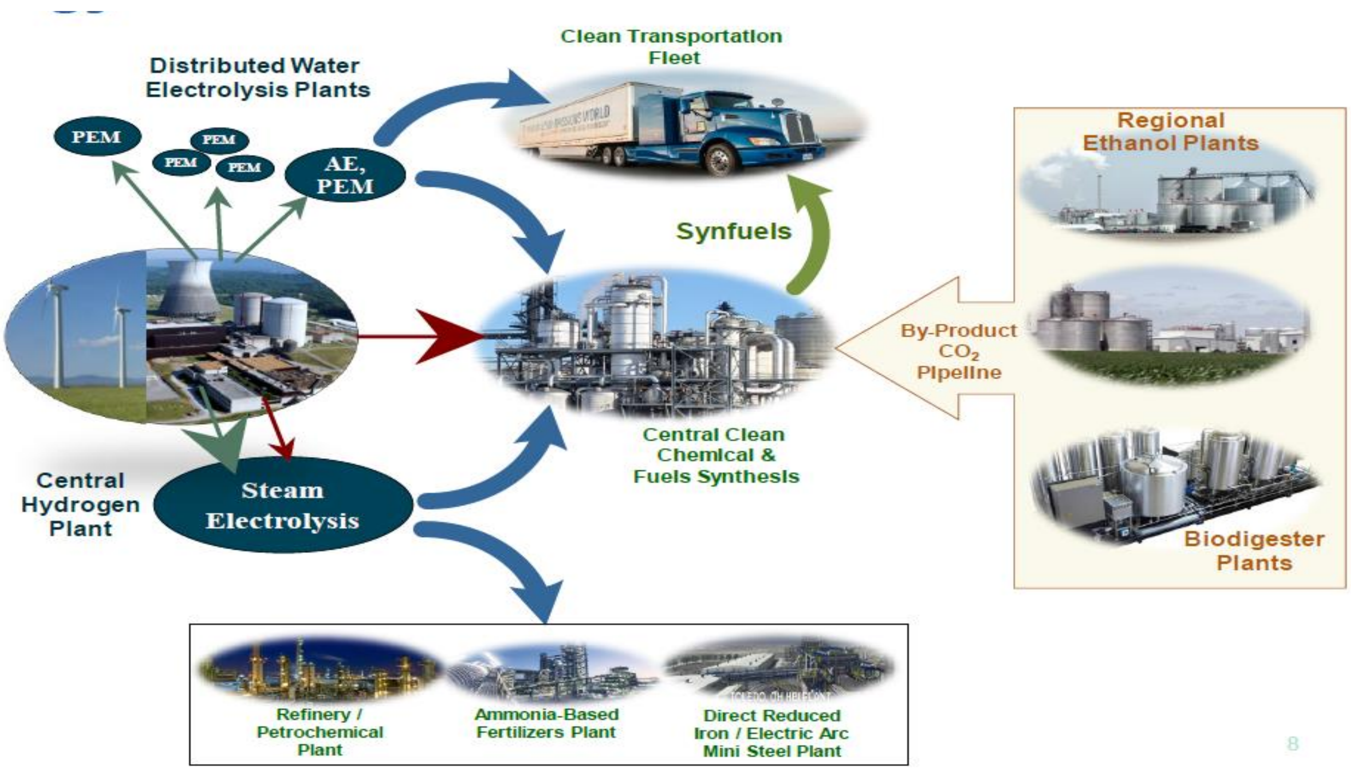
Nuclear Energy Reimagined

Nuclear Beyond Electricity – Advanced Reactors



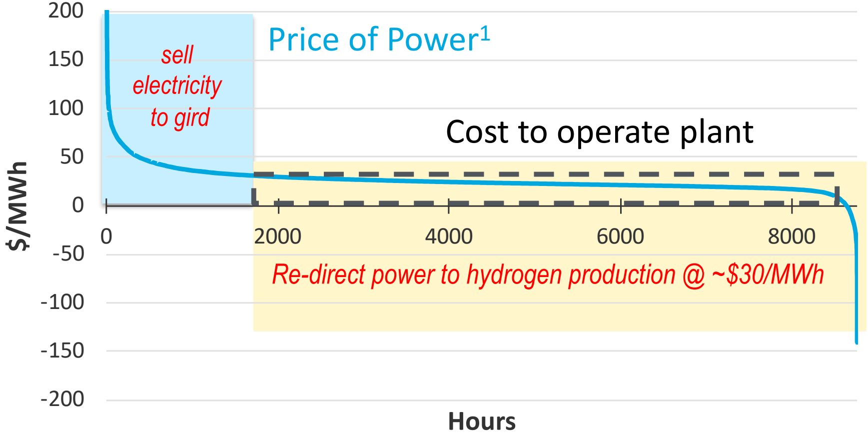
Integrated Energy Systems

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 nuclear

The challenge in some regions:

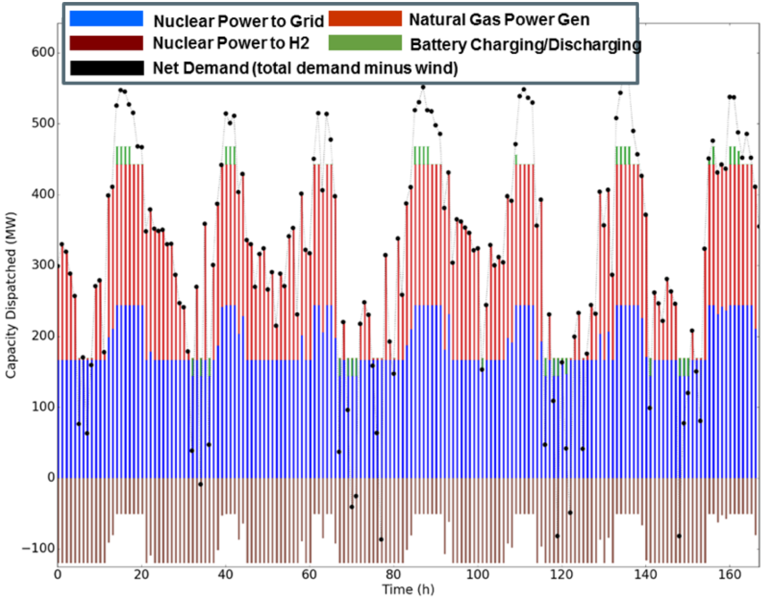
Localized marginal price of electricity < Cost of generating electricity at nuclear plant

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_e
  - Hydrogen Plant Capacity 120 MW_e
    (shown as negative – electricity input; 70% turndown limit; H_2 market price - \$1.75/kg-H_2)
  - Gas turbine 200 MW_e
  - Electric battery 100 MWh
  - Wind penetration 400 MW_e
    (100% of mean demand, installed capacity, 27% capacity factor)
  - Penalty function applied for over or under production of electricity.



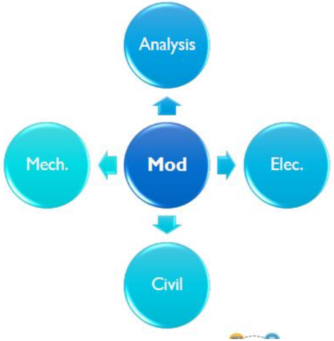
Rabiti and Epiney, INL, 2018

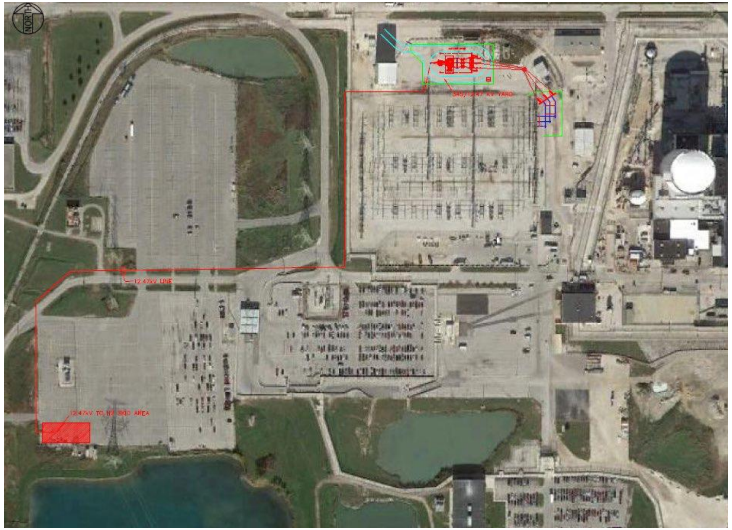
Recently Funded NE-Led Demonstration

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





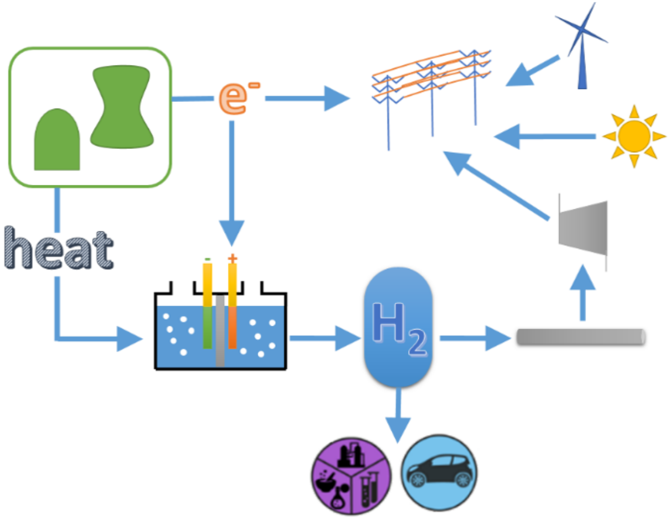
– Ensure no adverse effects on the plant, grid, or skid.
– Control software will be able to modulate H_2 output based on input variables.
– Control software will interface with Programmable Logic Computer (PLC) on vendor supplied H_2 skid.

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/FOAOpportunities/FOA.htm

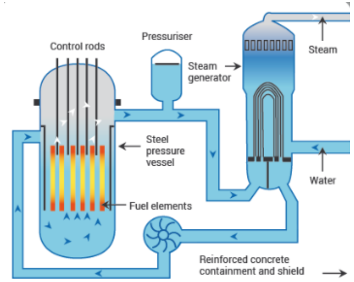
High Temperature Improves Hydrogen Production Efficiency by up to 2.4 x

Electrolysis Efficiencies vs Nuclear Reactor Type

Reactor Type	T-Out (Celsius)	Power Cycle	Electrolysis Technology	Overall Nuclear Fuel Efficiency
LWR	300	Rankine	LTE	25%
LWR	300	Rankine	HTSE	38%
SFR	500	Rankine	LTE	28%
SFR	500	Rankine	HTSE	38%
MSR	700	S-CO_2	LTE	40%
MSR	700	S-CO_2	HTSE	52%
HTGR	750	He Brayton	LTE	37%
HTGR	750	He Brayton	HTSE	50%
VHTGR	950	He Brayton	LTE	42%
VHTGR	950	He Brayton	HTSE	59%

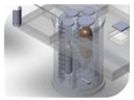
Laboratory Scale
Experimentally Proven
Modeled

Light Water Reactors
~275 – 325 C



Gas Reactors
~750 – 1000 C

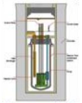

X-Energy Xe-100


Framatome SC-HTGR

~480 – 625 C
Fast Reactors


GE Hitachi PRISM


TerraPower TWR

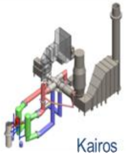

Advanced Reactor Concepts LLC ARC-100

~600-775 C
Molten Salt Reactors


Terrestrial Energy USA IMSR


TerraPower MCFR


Elysium USA MCSFR


Kairos Power UCB PB-FHR

The Future: Microreactor Powered Hydrogen Fueling Station

Notional Specs*

MW Total (15 MW modules)	60
kg / day trucks	50
kWh / kg hydrogen generation	50
kWh / truck / day	2500
trucks / station / day	576
fueling positions	~12

***not associated with images**

Image courtesy of Nikola Motor Company

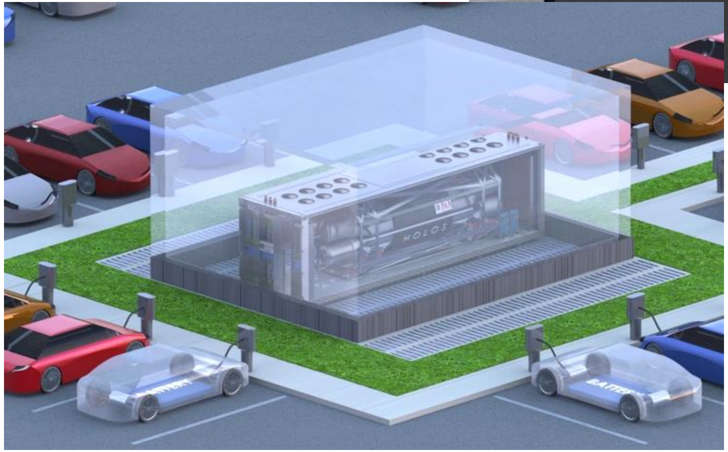


Image courtesy of HolosGen

Thank You

Clean. Reliable. **Nuclear.**

Dr. Sellathurai (Sam) Suppiah

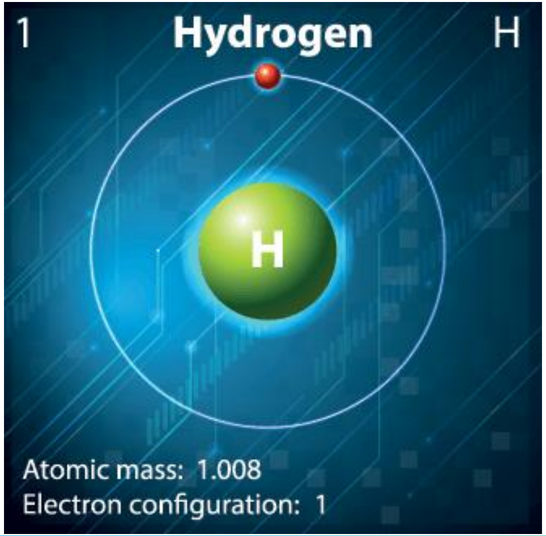
Manager, Chemical Engineering Branch
Facility Authority – Tritium Facility, Canadian Nuclear Laboratories Ltd., Canada

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?

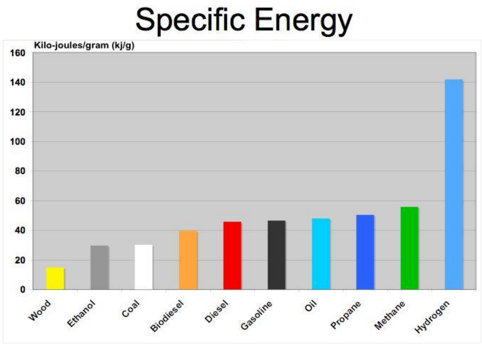
Nuclear Innovation: Clean Energy Future Webinar, 2020 March 18

Sam Suppiah

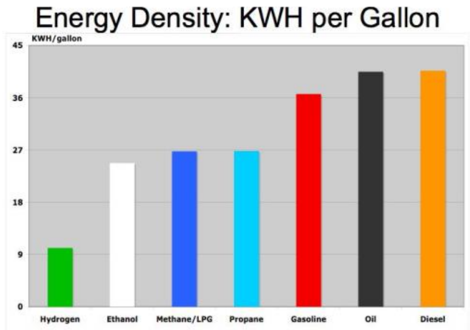
Canadian Nuclear Laboratories Ltd.

Chalk River ON, Canada

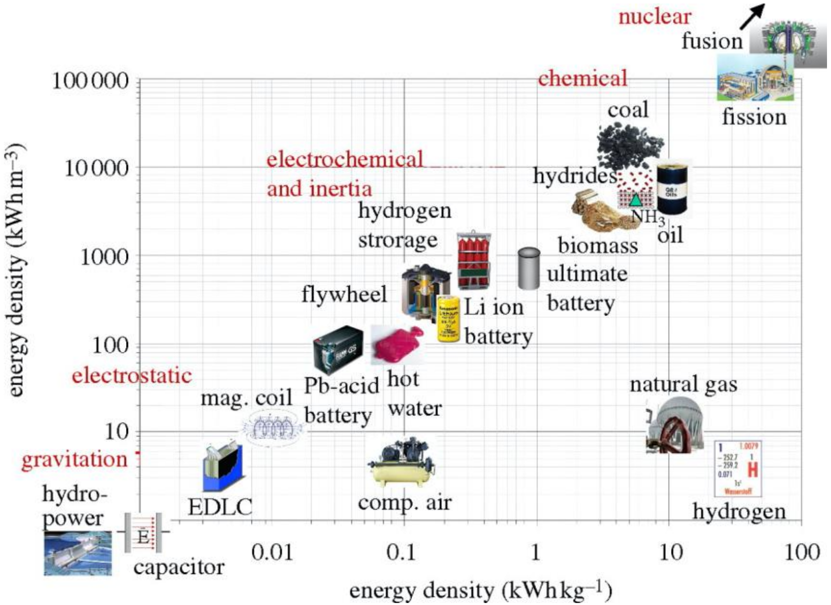
Hydrogen – A Critical Energy Carrier For Future



Source: DOE, Green Econometrics research

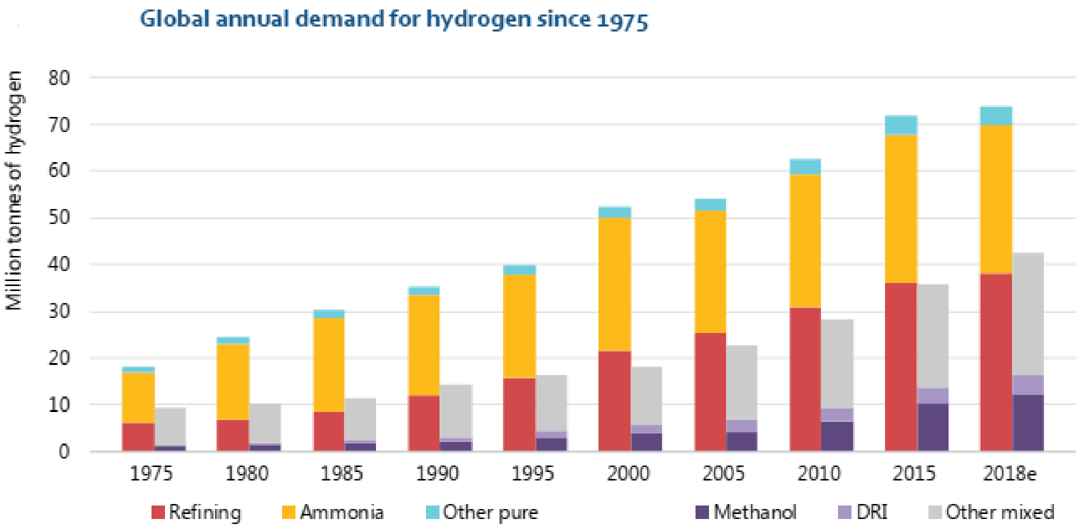


Source: DOE, Green Econometrics research



A. Zuttel et.al., Phil. Trans. R. Soc. A(2010), 368, 3329-3342

Current Demand & Use of Hydrogen



IEA (2019), "The Future of Hydrogen", IEA, Paris https://www.iea.org/reports/the-future-of-hydrogen

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

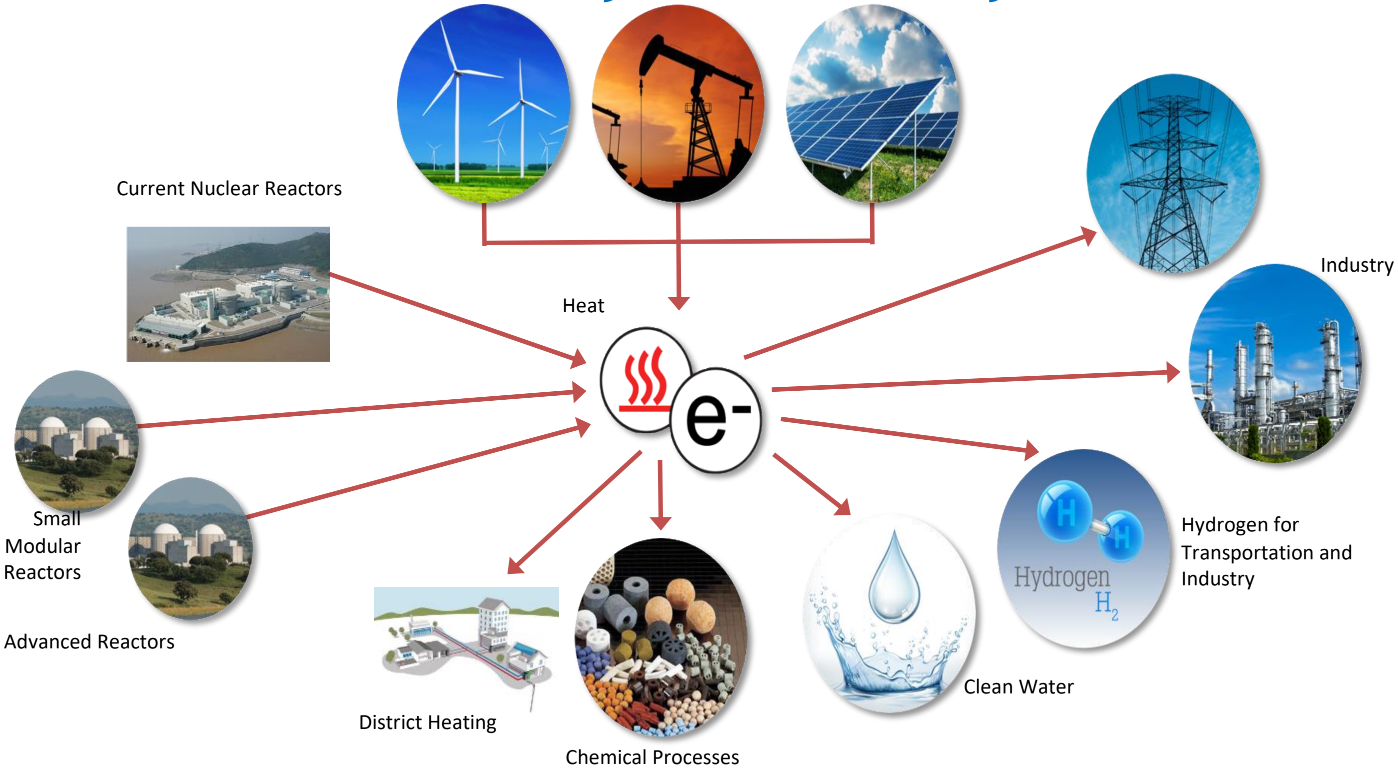
Ontario, Canada

A hydrail 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**

http://www.metrolinx.com/en/news/announcements/hydrail-resources/CPG-PGM-RPT-245_HydrailFeasibilityReport_R1.pdf

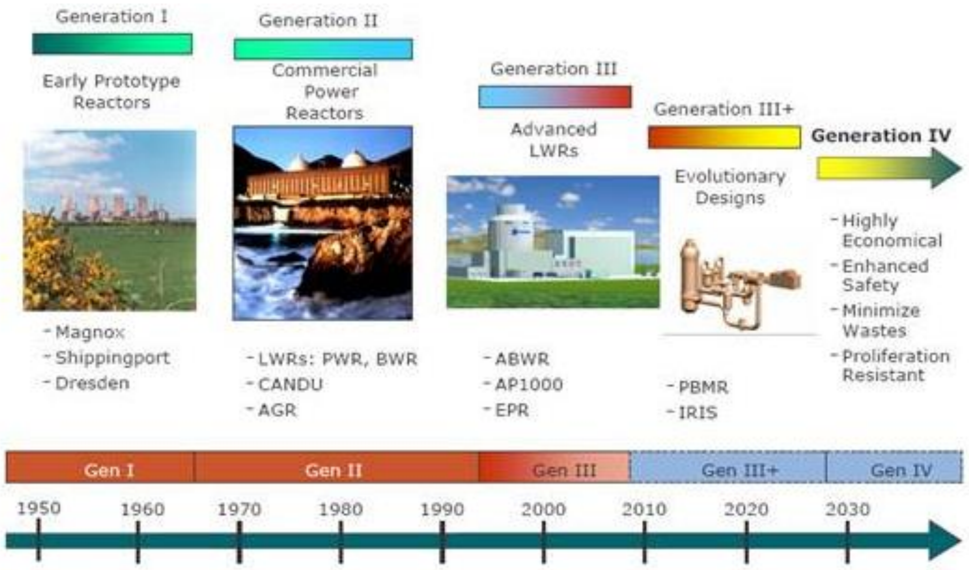
Integrated System that leverages contributions from nuclear beyond electricity sector



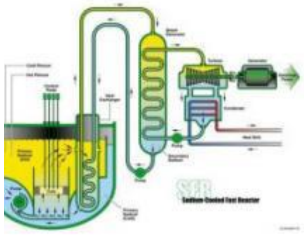
Current Hydrogen Production

- Fossil source
  - Steam Methane Reforming
  - Biomass
  - Others
- Non-fossil energy source
  - Advanced Alkaline Electrolysis
  - PEM Electrolysis

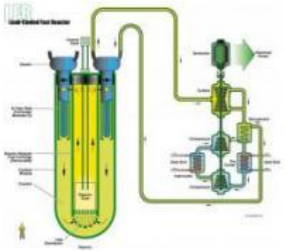
Nuclear Innovation - An Impetus for the Hydrogen Economy



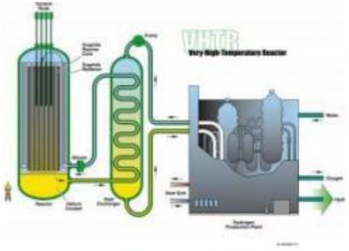
Generation IV Nuclear Reactor Systems



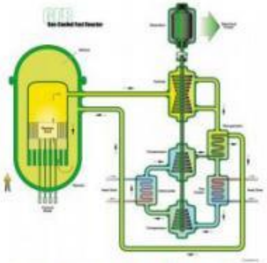
Sodium Fast Reactor



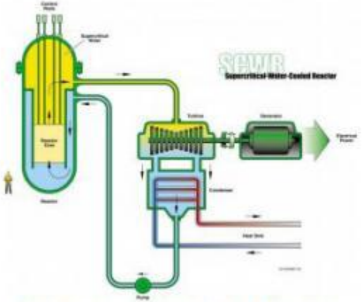
Lead Fast Reactor



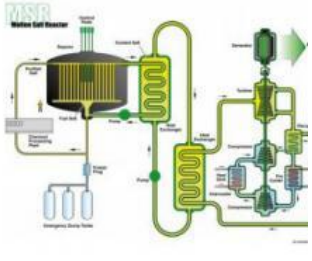
Very High Temperature Reactor



Gas Cooled Fast Reactor

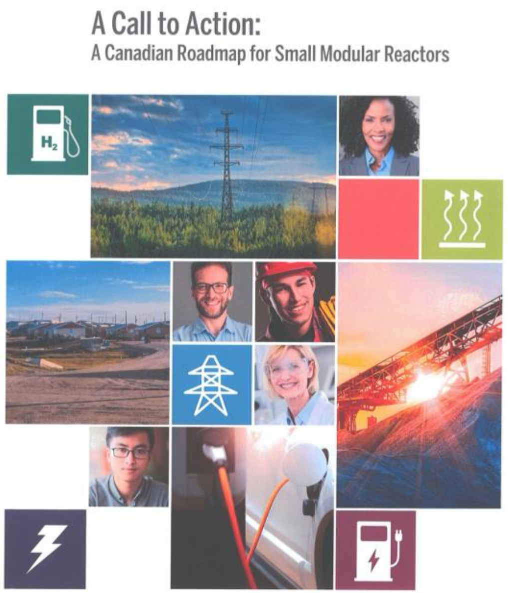


Supercritical Water Cooled Reactor



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.

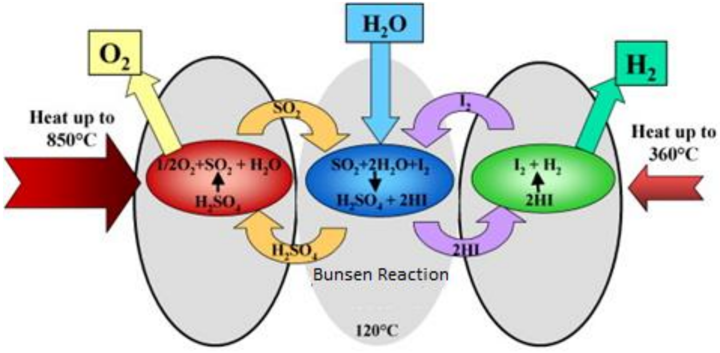
SMRs may be located on sites that differ from where traditional nuclear power plants have been built. For example, SMRs may be established:

•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

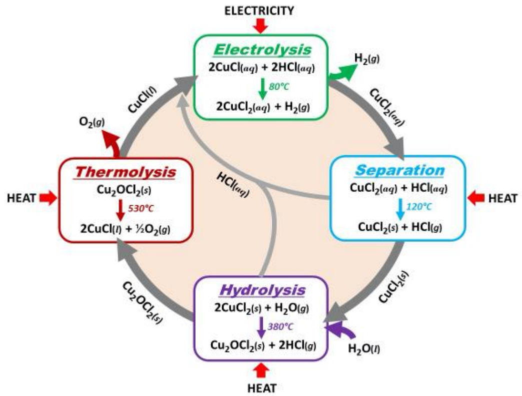
Electrical utilities, industry groups and government agencies throughout the world are investigating alternative uses for SMRs beyond electricity generation such as:

•producing steam supply for industrial applications and district heating systems
•making value-added products such as hydrogen fuel and desalinated drinking water

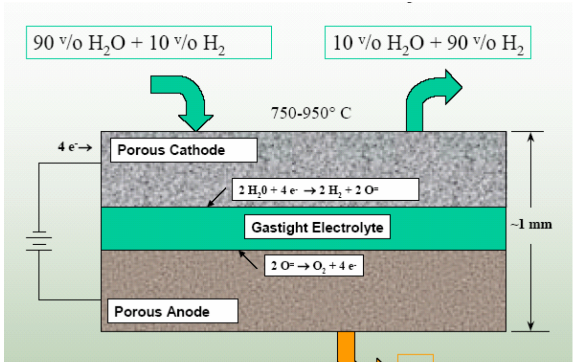
Hydrogen from Nuclear GEN IV Technology



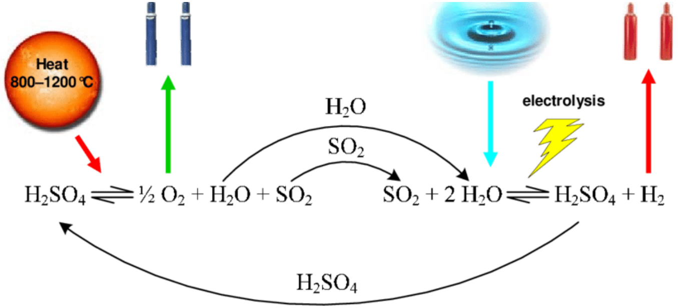
Sulphur-Iodine Process



Copper-Chlorine Process

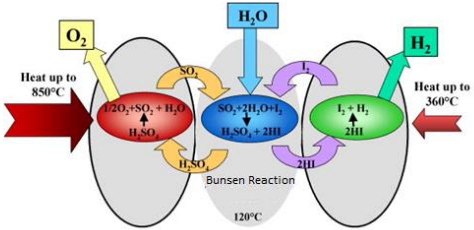


High Temperature Steam Electrolysis



Hybrid-Sulphur Process

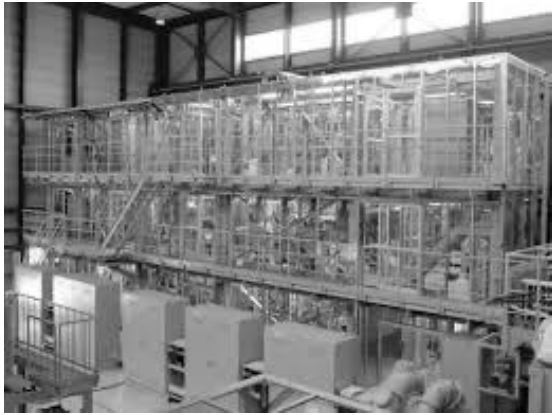
Current Status



Sulphur-Iodine Process

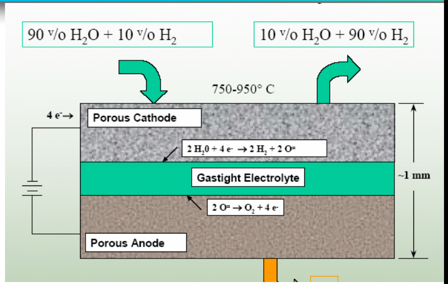
- Countries Actively Developing: Japan, China, South Korea, India
- Status: Integrated System Demonstration - China 1 Nm3/h, Japan – 30 L/h

China



Japan

Current Status - continued



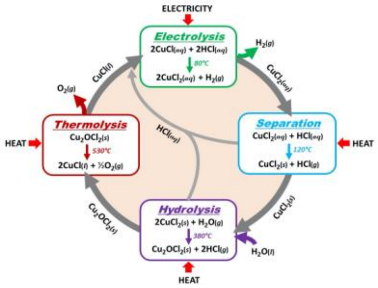
High Temperature Steam Electrolysis

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

25 kW HTSE Test Facility at INL

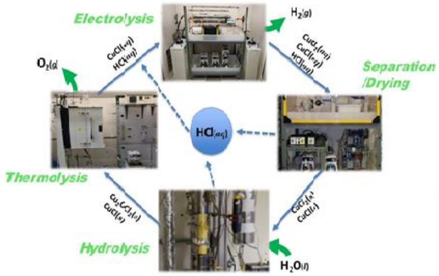
CEA's First Commercial System

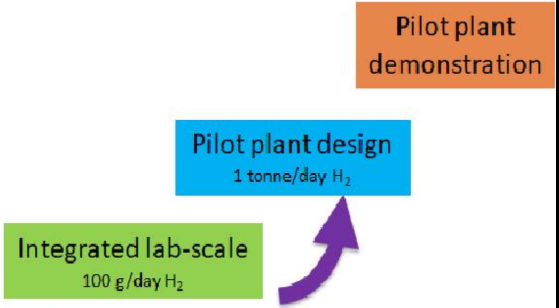
Current Status - continued



Copper-Chlorine Hybrid Cycle

- Countries Actively Developing: Canada, India
- Status: Preparation for integrated lab demonstration @ in 100g/d Canada





Laboratory Process Development	Pilot Plant Design	Pilot Plant Demonstration
2018-2021	2022-2023	2024-2026

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

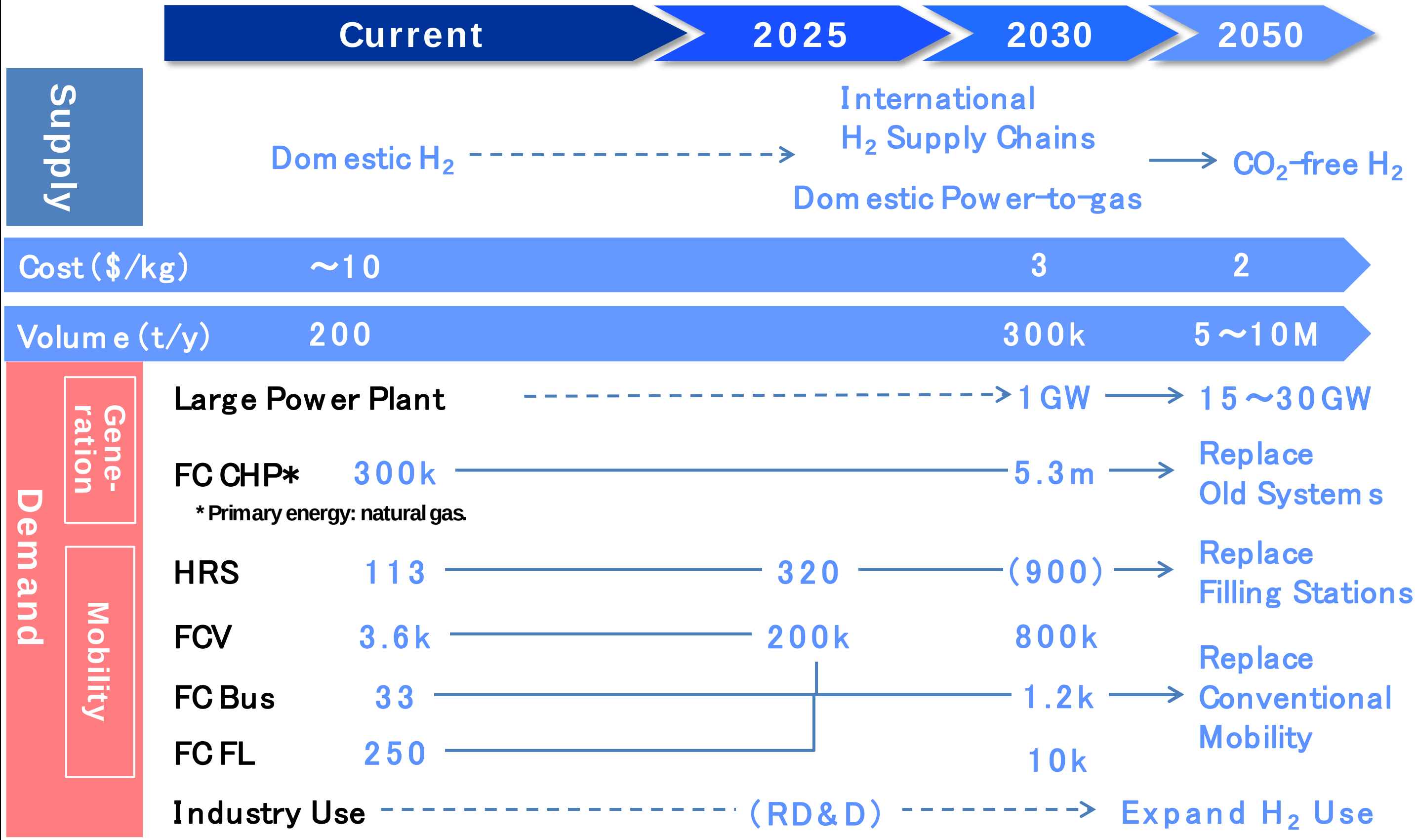
Basic Hydrogen Strategy (Prime Minister Abe's Initiative)

- First comprehensive national strategy
- H_2 as a future energy option toward 2050
- Detailed strategy with numerical targets
  ($3/kg by 2030 ⇒ $2/kg by 2050)

Strategic Roadmap for Hydrogen and Fuel Cells

Hydrogen and Fuel Cells Technology Development Strategy

Numerical targets toward hydrogen society



The Strategic Road Map for Hydrogen and Fuel Cells

METI Ministry of Economy, Trade and Industry

- 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.**

		Goals in the Basic Hydrogen Strategy		Set of targets to achieve	Approach to achieving target
Use	Mobility	FCV 200k by 2025 800k by 2030	2025	● Price difference between FCV and HV (¥3m → ¥0.7m) ● Cost of main FCV system (FC ¥20k/kW → ¥5k/kW; Hydrogen Storage ¥0.7m → ¥0.3m)	• Regulatory reform and developing technology
		HRS 320 by 2025 900 by 2030	2025	● Construction and operating costs (Construction cost ¥350m → ¥200m; Operating cost ¥34m →¥15m) ● Costs of components for HRS (Compressor ¥90m → ¥50m; Accumulator ¥50m → ¥10m)	• Consideration for creating nation wide network of HRS • Extending hours of operation
		Bus 1,200 by 2030	Early 2020s	● Vehicle cost of FC bus (¥105m → ¥52.5m)	• Increasing HRS for FC bus
				※In addition, promote development of guidelines and technology development for expansion of hydrogen use in the field of FC trucks, ships and trains.	
	Power	Commercialize by 2030	2020	● Efficiency of hydrogen power generation (26%→27%) ※1MW scale	• Developing of high efficiency combustor etc.
	FC	Early realization of grid parity	2025	● Realization of grid parity in commercial and industrial use	• Developing FC cell/stack technology
Supply	Fossil Fuel + CCS	Hydrogen Cost ¥30/Nm3 by 2030 ¥20/Nm3 in future	Early 2020s	● 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)	• Scaling-up and improving efficiency of brown coal gasifier • Scaling-up and improving thermal insulation properties
	Green H2	System cost of water electrolysis \ 50,000/kW in future	2030	● Cost of electrolyzer (¥200,000/kW →¥50,000/kW) ● Efficiency of water electrolysis (5kWh/Nm3→4.3kWh/Nm3)	• Demonstration in model regions for social deployment utilizing the achievement in the demonstration of Namie, Fukushima • Development of electrolyzer with higher efficiency and durability

Policies to Realize a “Hydrogen Society”①

Production → Transportation and supply (supply chain) → Use

Power-to-Gas Plant

Gasification from
Brown Coal + CCS

- **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**

natural gas

Policies to Realize a "Hydrogen Society"②

Production → **Transportation and supply (supply chain)** → **Use**

Hydrogen station

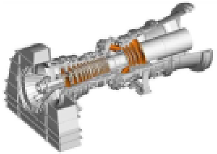
Liquefied hydrogen carrier ship

MCH plant

- **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

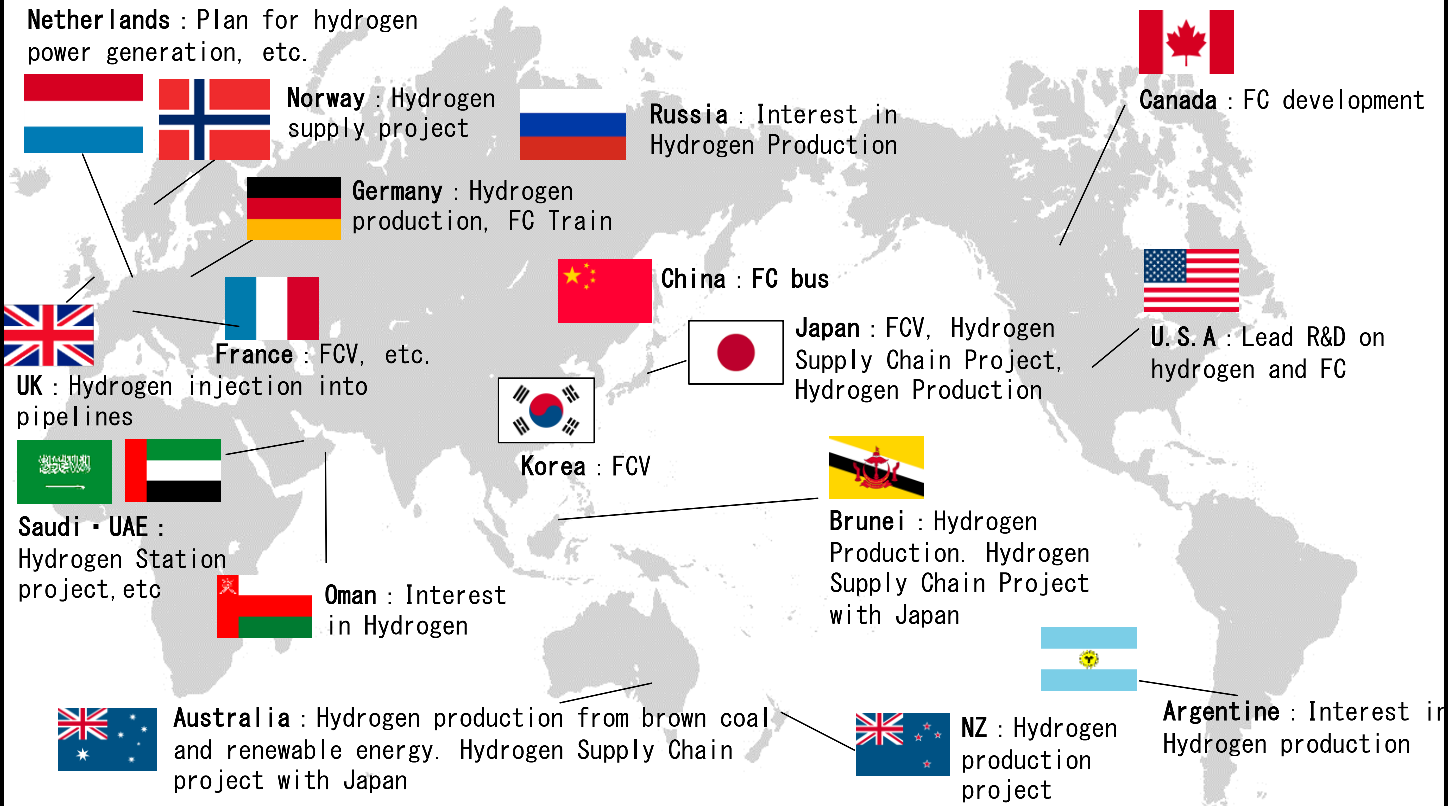
Production → Transportation and supply (supply chain) → **Use**



H_2 Co-generation Demonstration Project

- **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

Growing momentum of hydrogen and fuel cells around the world



Multi-lateral initiatives on hydrogen

HYDROGEN INITIATIVE – AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

H₂EM 2019

IPHE

MISSION INNOVATION

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

METI
Ministry of Economy, Trade and Industry

2018

21 countries, region and organizations
300 attendees

TOKYO STATEMENT

- Harmonization of Regulation, Codes and Standards
- Joint Research and Development
- Study and Evaluation of Hydrogen's Potential
- Education & Outreach

2019

35 countries, region and organizations
600 attendees

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.

International Energy Agency

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?

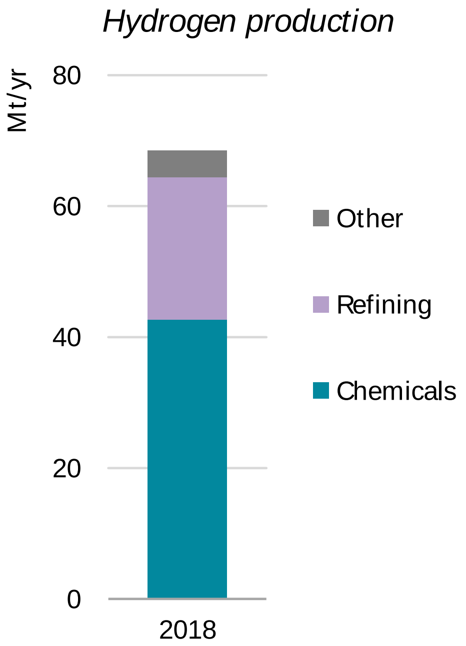
- Momentum currently behind hydrogen is unprecedented, with more and more policies, projects and plans by governments & companies in all parts of the world

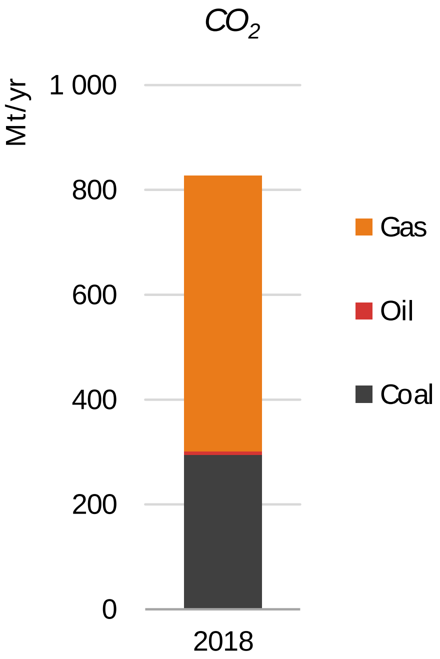
- Hydrogen can help overcome many difficult energy challenges

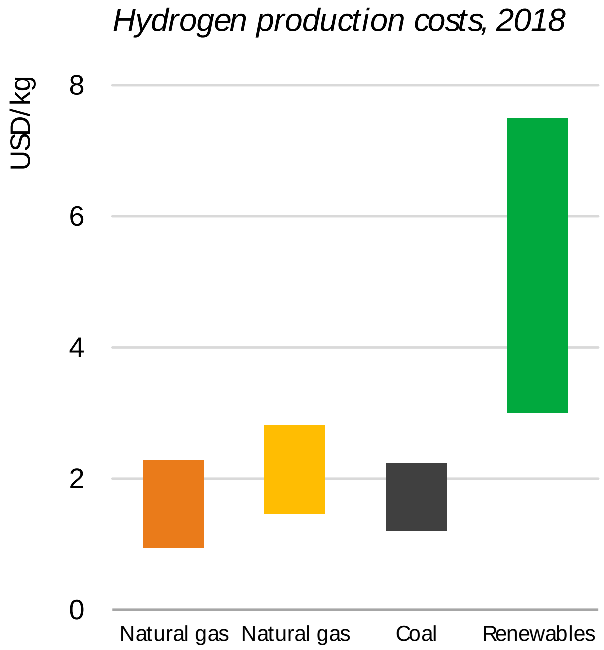
  - ***Integrate more renewables***, including by enhancing storage options & tapping their full potential
  - ***Decarbonise hard-to-abate sectors*** such as steel, chemicals, trucks, ships & planes
  - ***Enhance energy security*** by diversifying the fuel mix & providing flexibility to balance grids

- 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

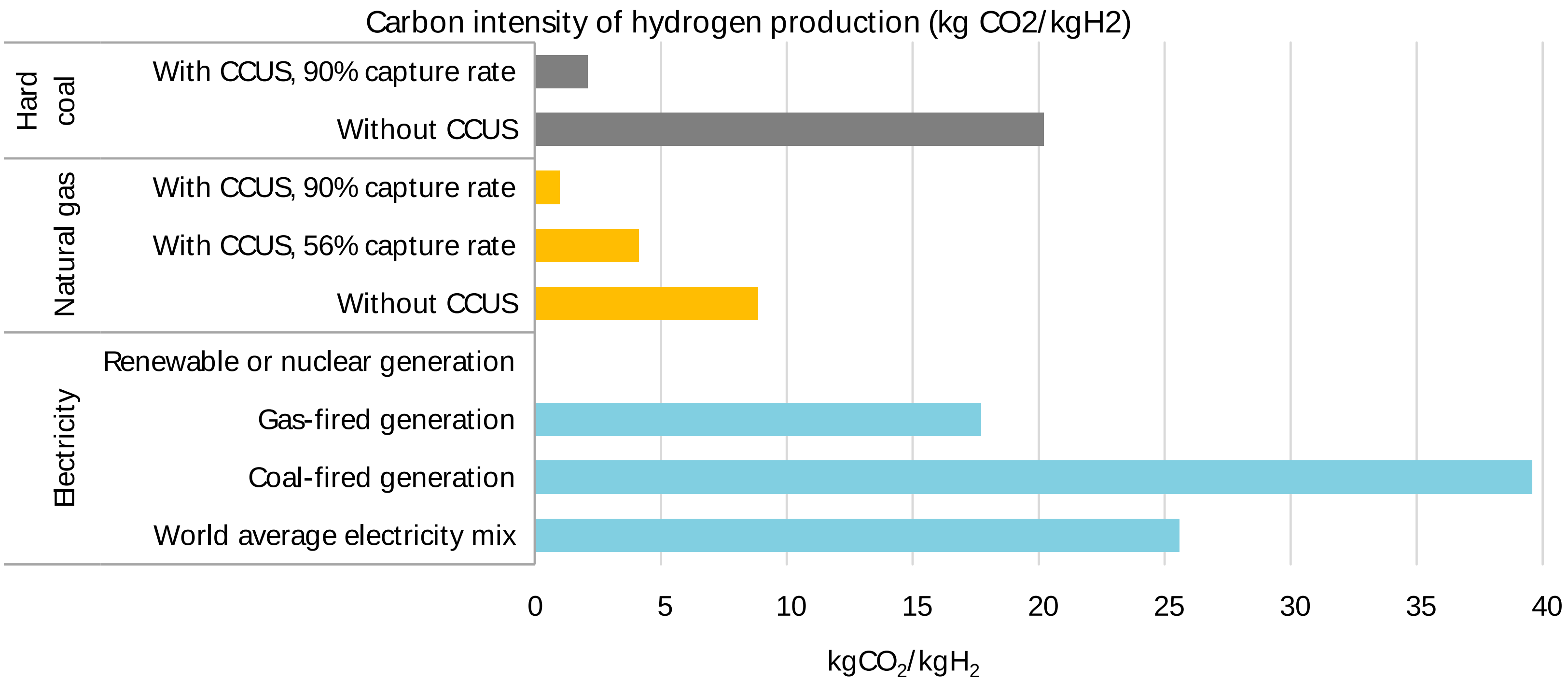






Dedicated hydrogen production is concentrated in very few sectors today, using fossil fuels and responsible for 2.4% of global energy-related CO2. If replaced by electrolysis would require 3600 TWh of electricity and 617 Mm3 of water.

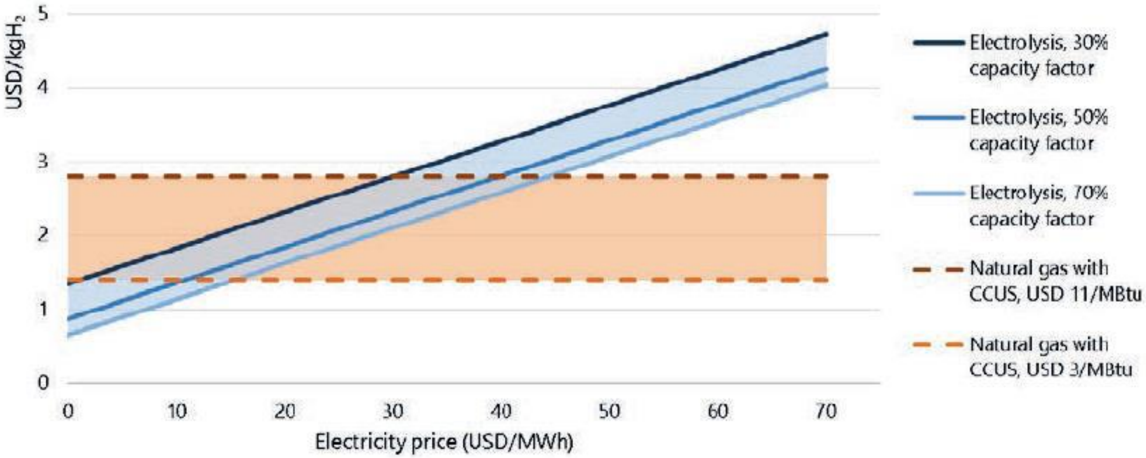
Low carbon hydrogen production



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

Producing low carbon hydrogen – gas vs. electricity

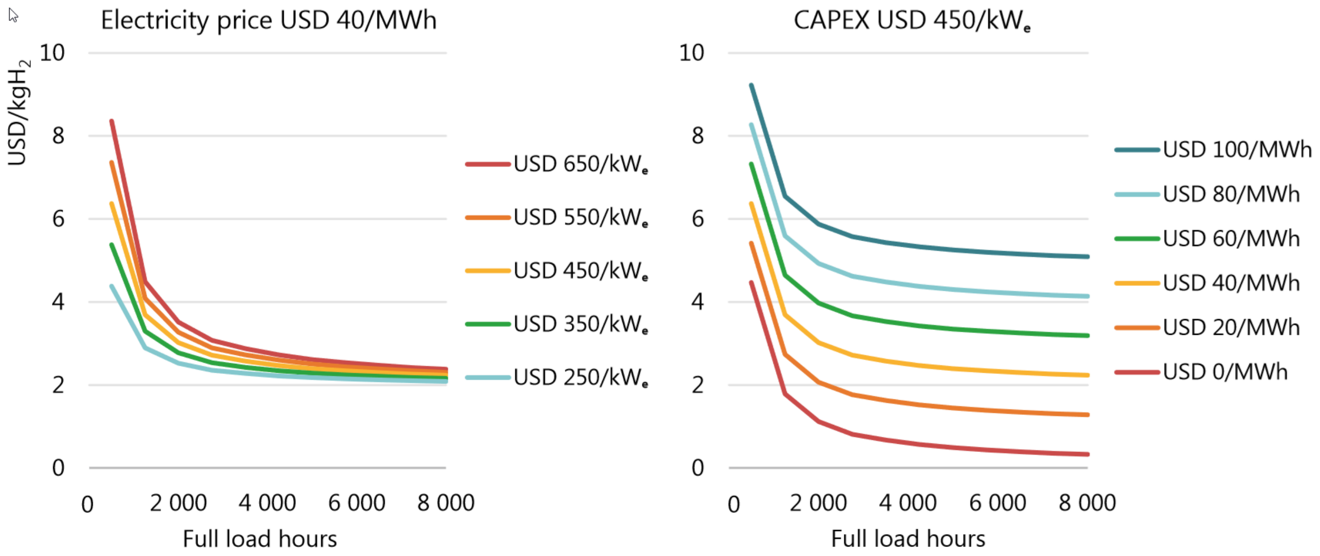
Comparison of natural gas (steam reforming) with CCS and electrolysis (USD 450/kW)



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)

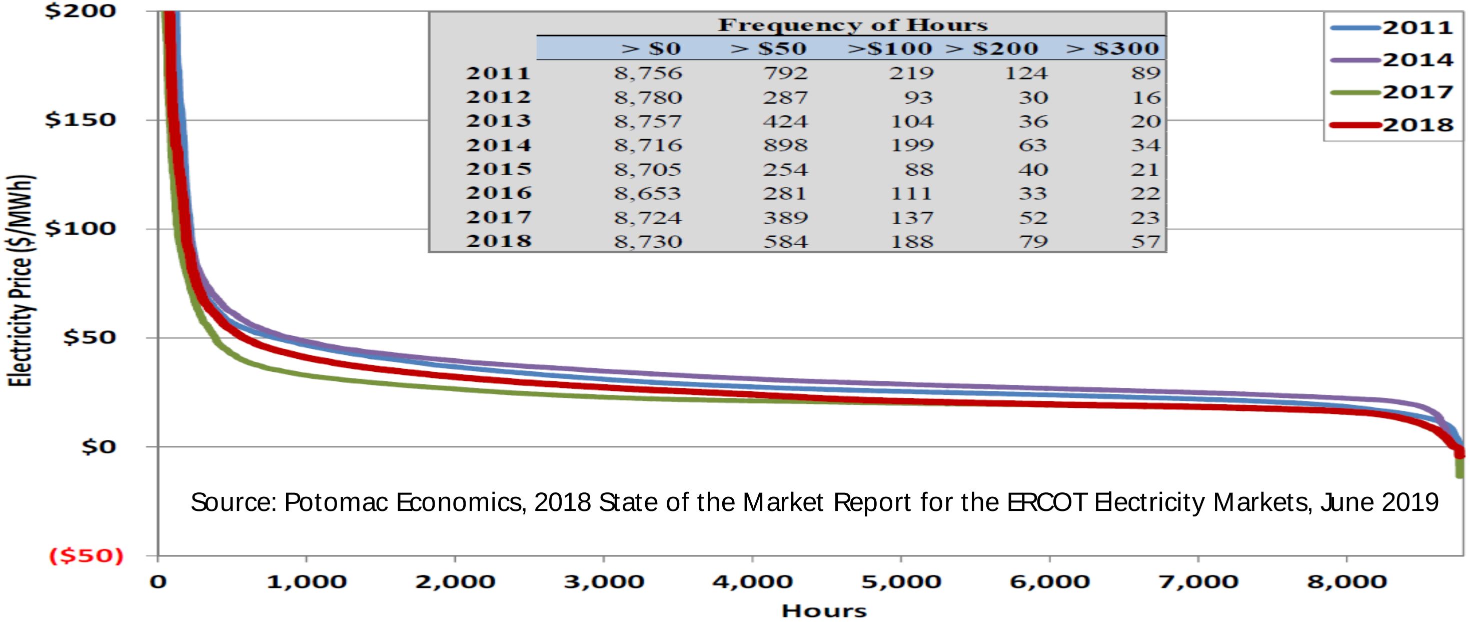


Electrolyser capital costs are already low enough that moderate load factors are sufficient

Many markets have cheap electricity available

ERCOT Price Duration Curves (2011, 2014, 2017, 2018)

Figure 8: ERCOT Price Duration Curve

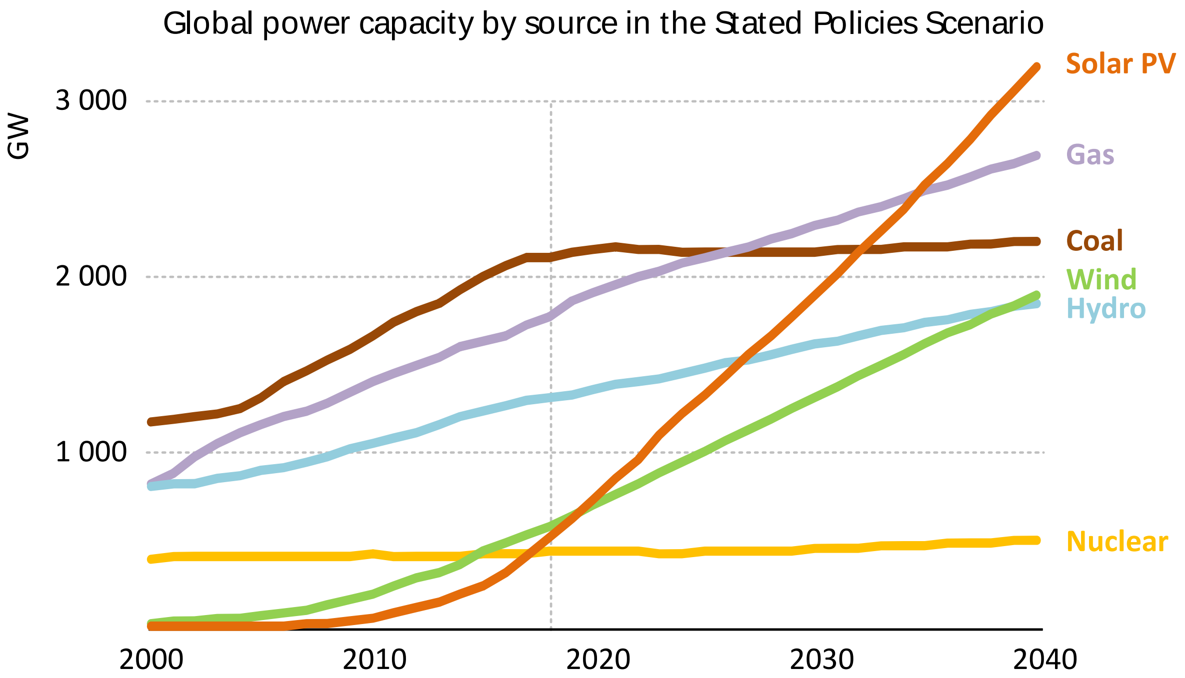


	> $0	> $50	>$100	> $200	> $300
2011	8,756	792	219	124	89
2012	8,780	287	93	30	16
2013	8,757	424	104	36	20
2014	8,716	898	199	63	34
2015	8,705	254	88	40	21
2016	8,653	281	111	33	22
2017	8,724	389	137	52	23
2018	8,730	584	188	79	57

Source: Potomac Economics, 2018 State of the Market Report for the ERCOT Electricity Markets, June 2019

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

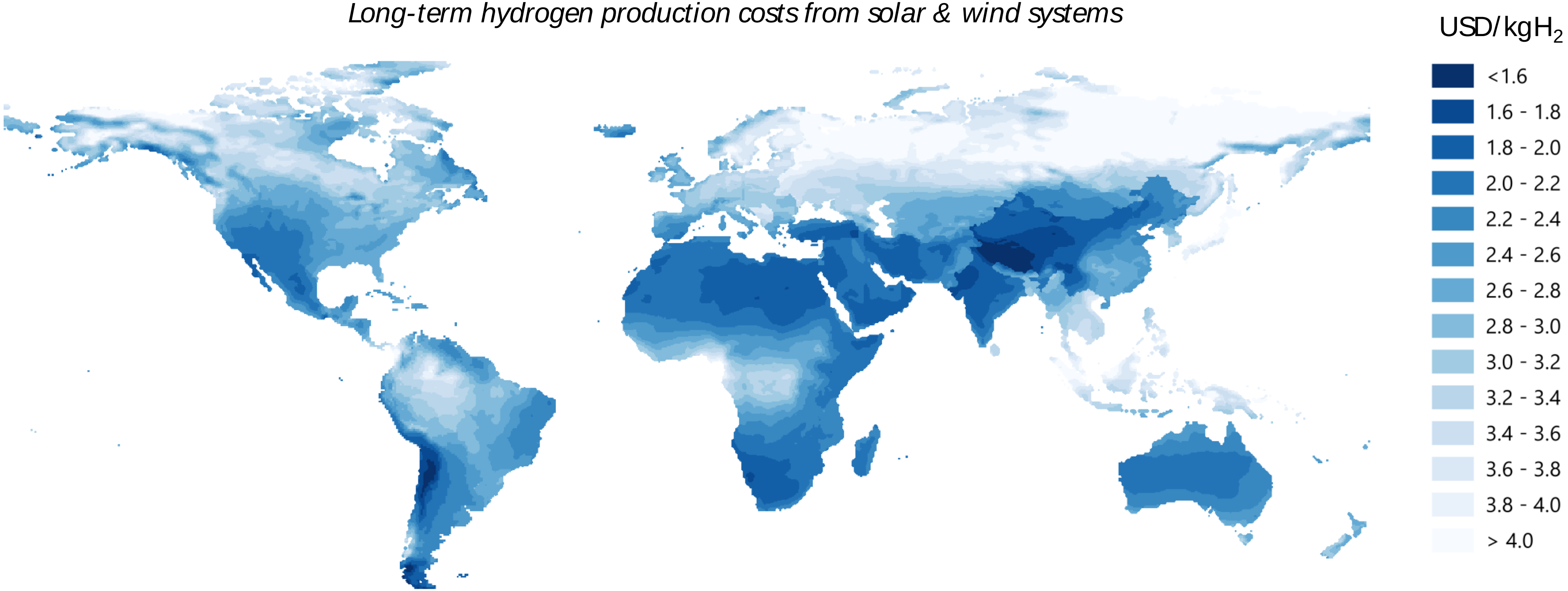
Solar and wind will provide most of the new capacity



The growth in solar and wind in many markets will create more low price hours.

Wind + Solar hydrogen costs are set to decline

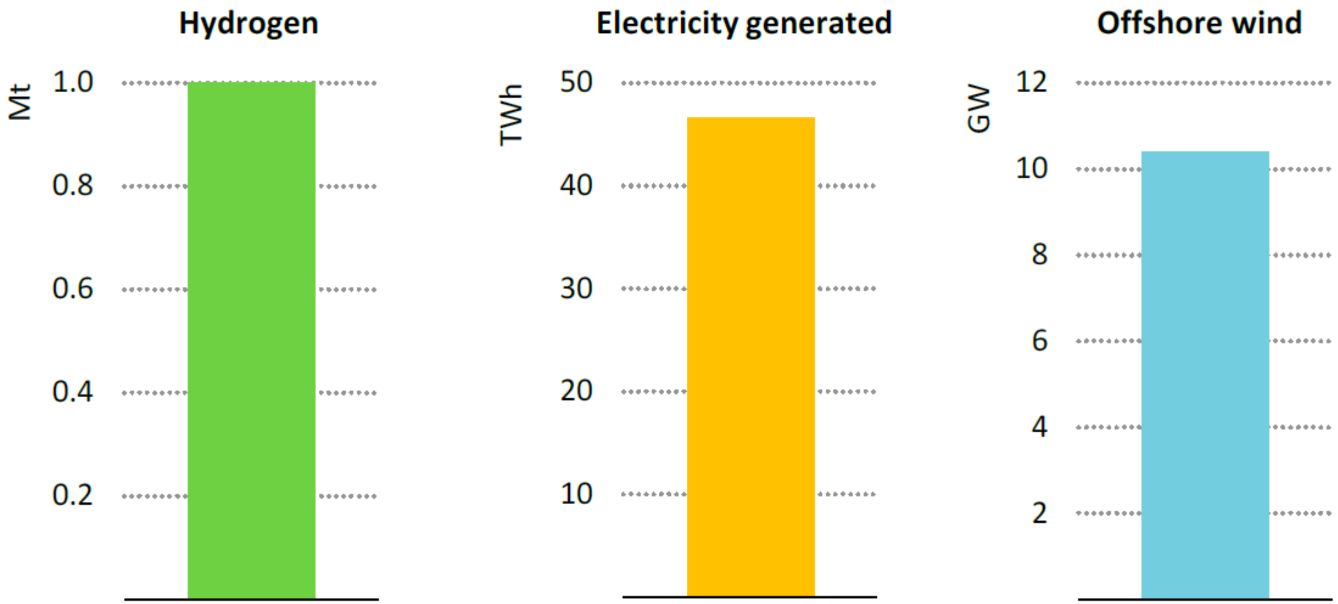
Long-term hydrogen production costs from solar & wind systems



Best resources may not be near the main demand centres; necessitating transportation

Offshore wind may also become an attractive approach

Offshore wind capacity and electricity required to produce 1 Mt of hydrogen



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

NICE Future

Nuclear Innovation: Clean Energy Future

An Initiative of the Clean Energy Ministerial

Thank you

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