U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Hydrogen and Fuel Cells Update

Sunita Satyapal, Director – Fuel Cell Technologies Office

Transportation Research Board Subcommittee Meeting

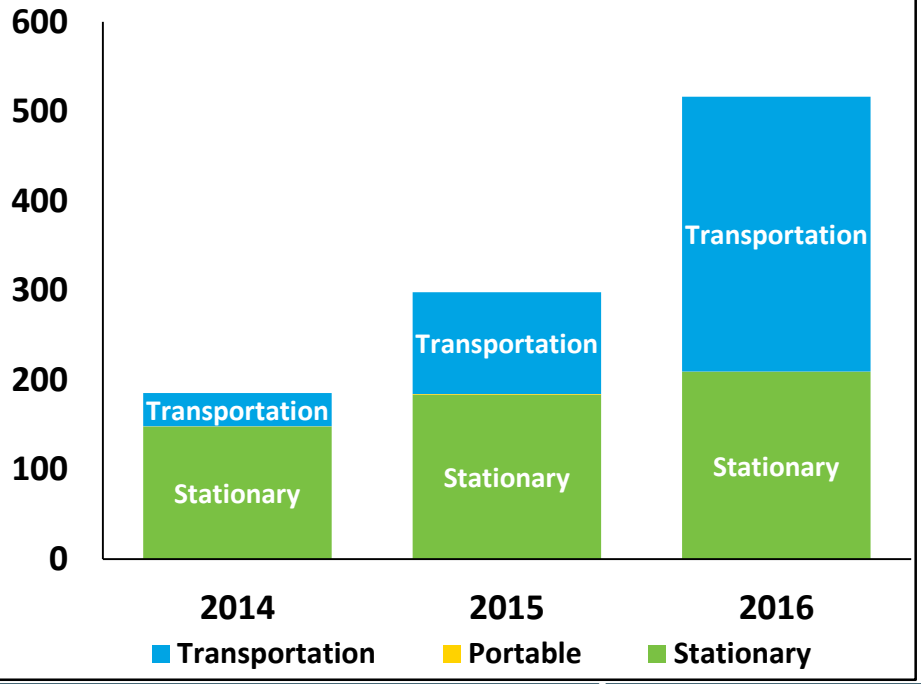
International Aspects of Transportation Energy Subcommittee, ADC70(1)

Washington DC – January 10, 2018

2016 Global Shipments – Trends

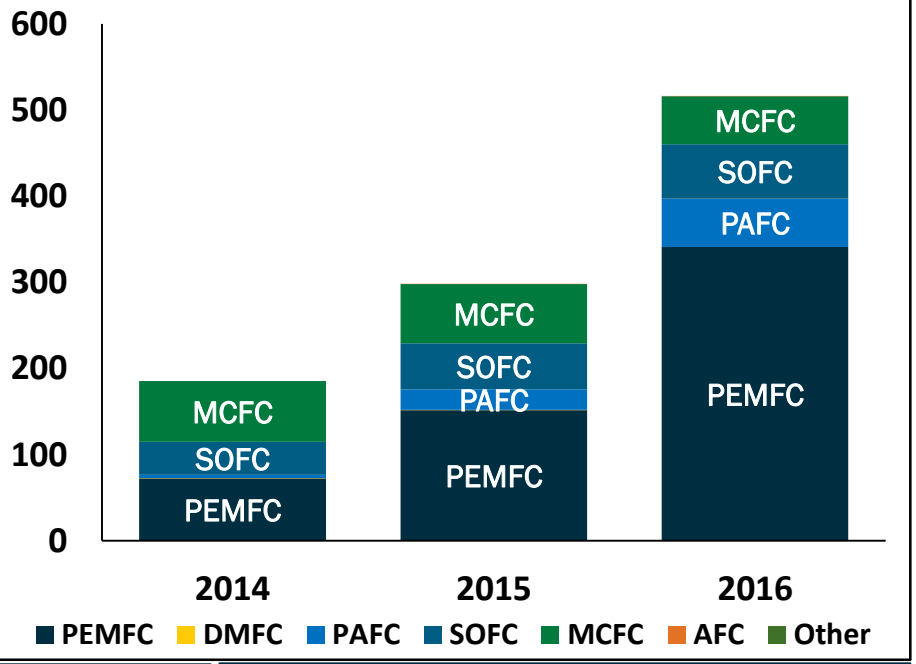
Total power (in MW) shipped by application

Growth in Transportation



Total power (in MW) shipped by fuel cell chemistry

Growth in PEMFC



500 MW fuel cell power shipped worldwide

62,000 fuel cell units shipped worldwide

Approximately **$1.6 Billion** fuel cell revenue

Source: E4tech

For the first time in history….


Hyundai Tucson Fuel Cell SUV


Toyota Mirai


Honda Clarity

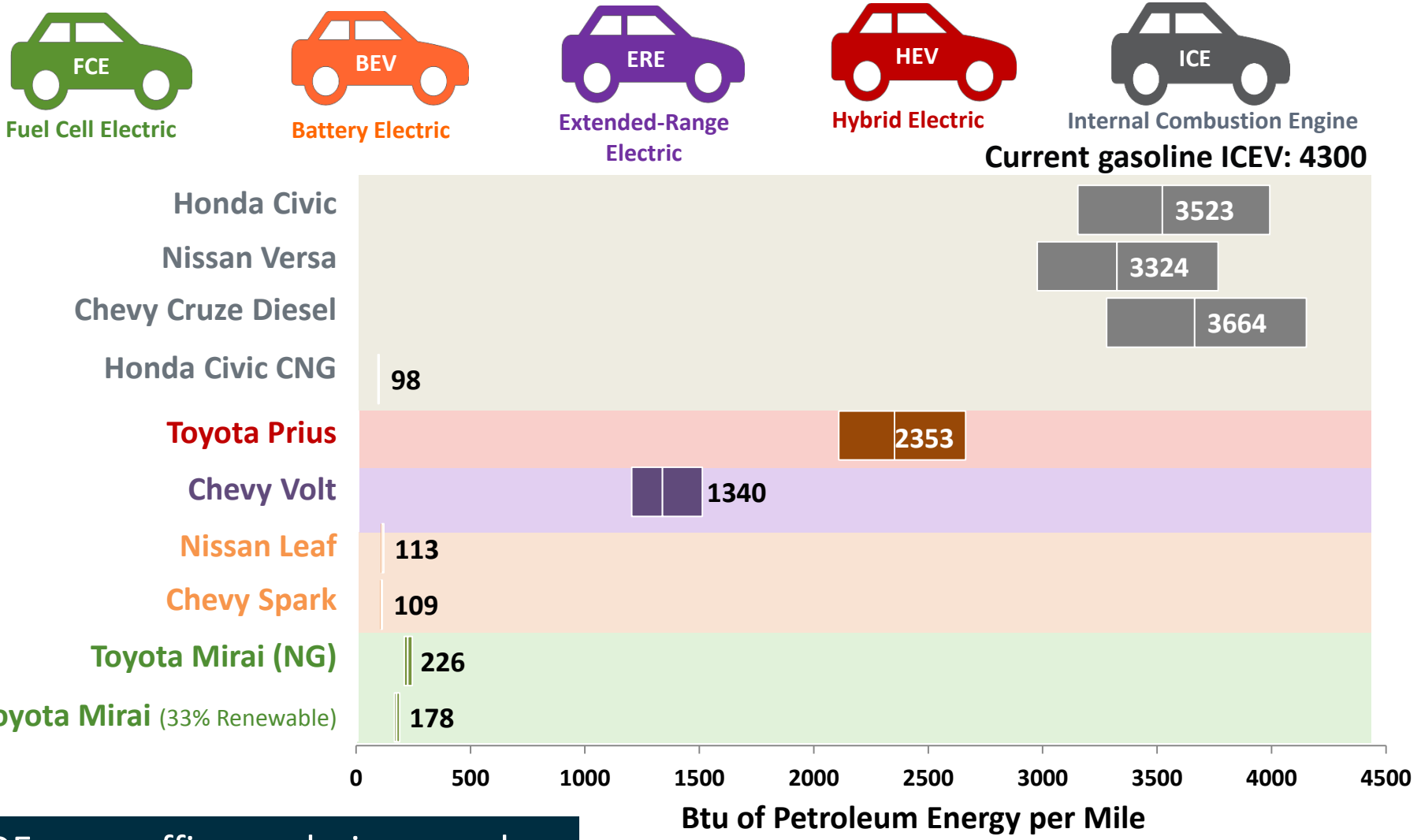
Commercial
fuel cell electric cars are here!

Nearly **3,500** | **sold or leased** in the United States

- **No petroleum, no pollution**
- **Refuels in minutes**
- **More than 360 mi driving range**
- **Over 60 mpgge**

Life-Cycle Petroleum Use- Today's Cars

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

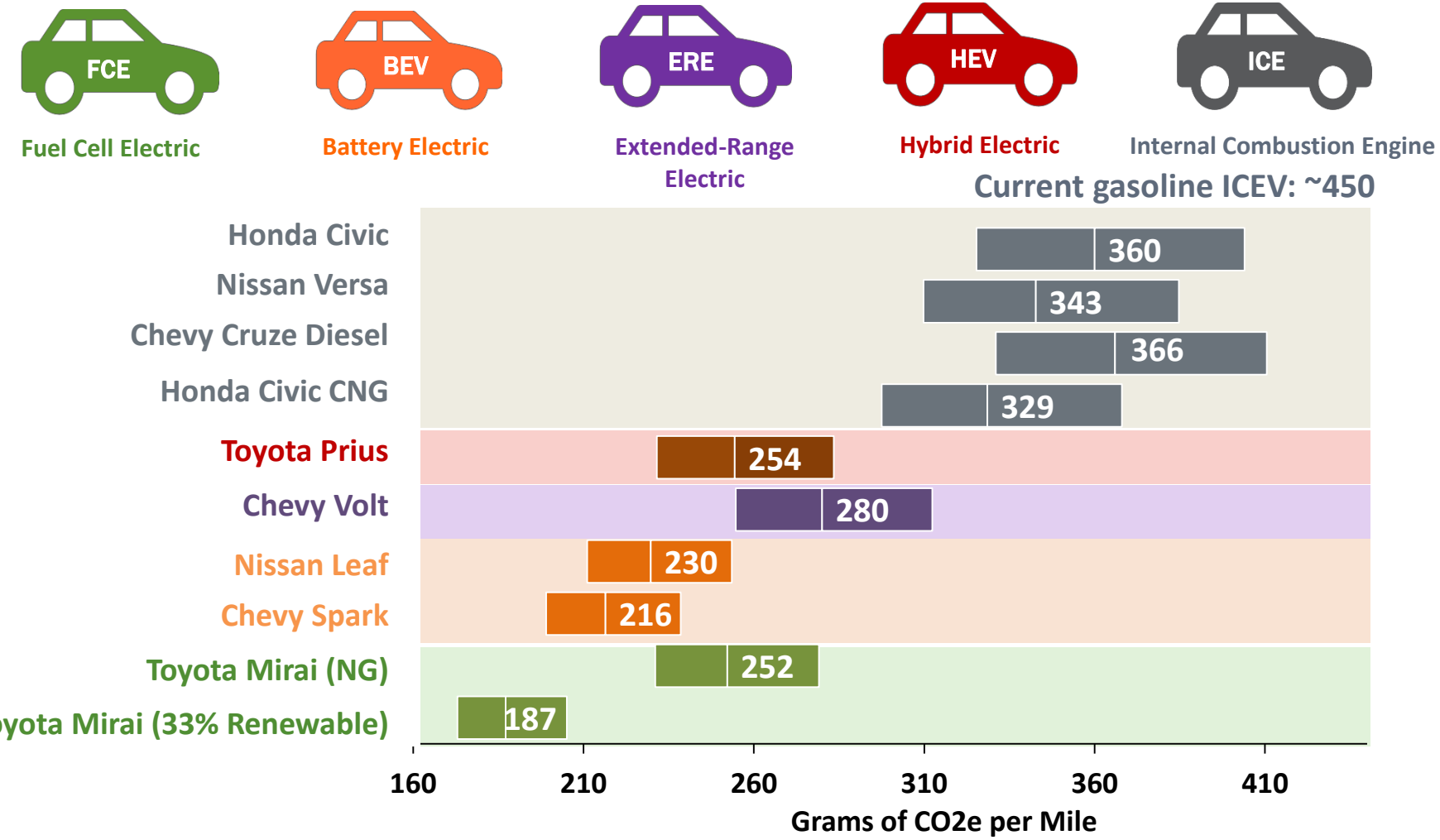


DOE cross office analysis example

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

Life-cycle Emissions- Today's Cars

Low, Medium & High Emissions/Mile for 2015 Technology



DOE cross office analysis example

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

Market Segmentation Analysis Underway

FCEVs : Lower cost for large size classes and longer driving range

Year 2040: FCEV minus BEV-X Total Cost of Ownership
Green shows where FCEVs are more cost effective

	50 mi.	100 mi.	150 mi.	200 mi.	250 mi.	300 mi.	350 mi.
Two-seaters	$0.05	$0.01	-$0.03	-$0.07	-$0.11	-$0.15	-$0.19
Minicompacts	$0.05	$0.02	-$0.01	-$0.04	-$0.07	-$0.10	-$0.13
Subcompacts	$0.05	$0.02	-$0.01	-$0.04	-$0.07	-$0.11	-$0.14
Compacts	$0.04	$0.01	-$0.02	-$0.05	-$0.09	-$0.12	-$0.15
Midsize Cars	$0.05	$0.01	-$0.03	-$0.06	-$0.10	-$0.13	-$0.17
Large Cars	$0.04	$0.01	-$0.02	-$0.06	-$0.09	-$0.12	-$0.16
Small Station Wagons	$0.05	$0.01	-$0.03	-$0.07	-$0.11	-$0.15	-$0.19
Pass Van	$0.03	-$0.01	-$0.06	-$0.11	-$0.15	-$0.20	-$0.24
SUV	$0.03	-$0.02	-$0.08	-$0.14	-$0.19	-$0.25	-$0.30
Std Pickup	$0.14	$0.11	$0.07	$0.04	$0.01	-$0.03	-$0.06
Small Pickup	$0.06	$0.02	-$0.02	-$0.07	-$0.11	-$0.15	-$0.19

Heavy Duty Vehicle Applications Emerging- Examples

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

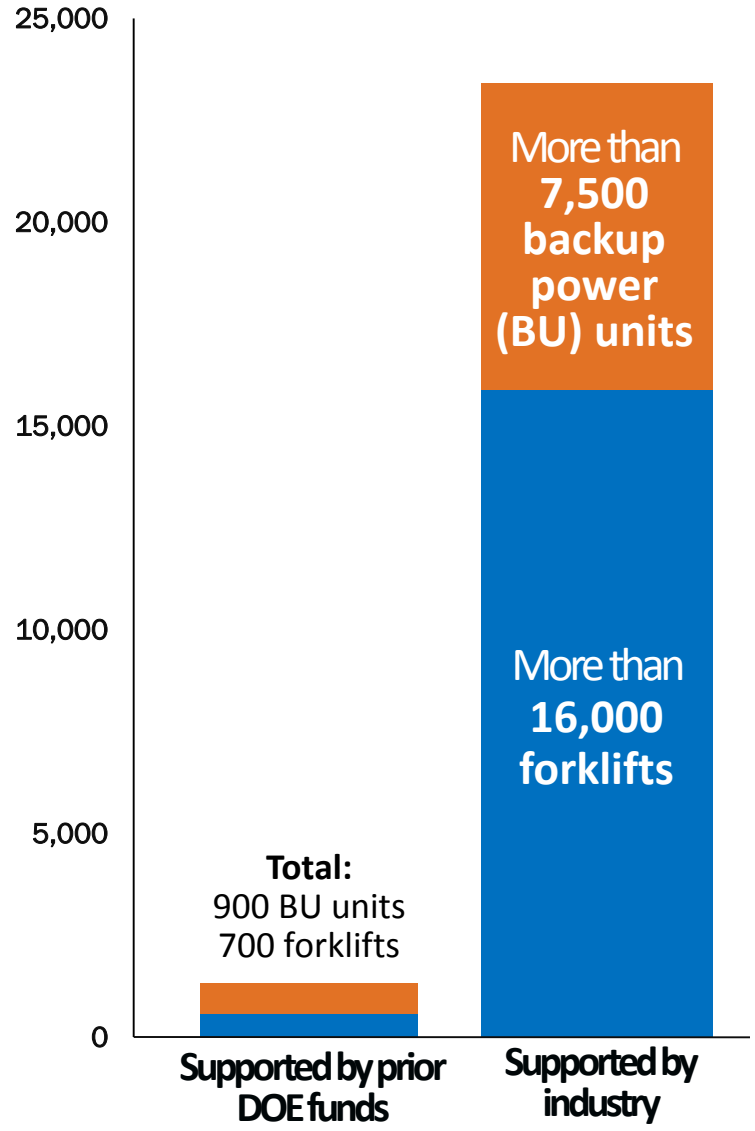
Fuel cell buses in CA surpass 17M passengers

Industry demonstrates first heavy duty fuel cell truck in CA

Catalyzing Early Markets for Fuel Cells

Credit: BMW Manufacturing


Credit: Fuel Cell Energy



New Applications Emerging- Examples

China

Eight Fuel Cell Trams

Capacity: 285 passengers
Maximum speed: 70 km/hr.

Germany

Trains to operate in Germany in 2018

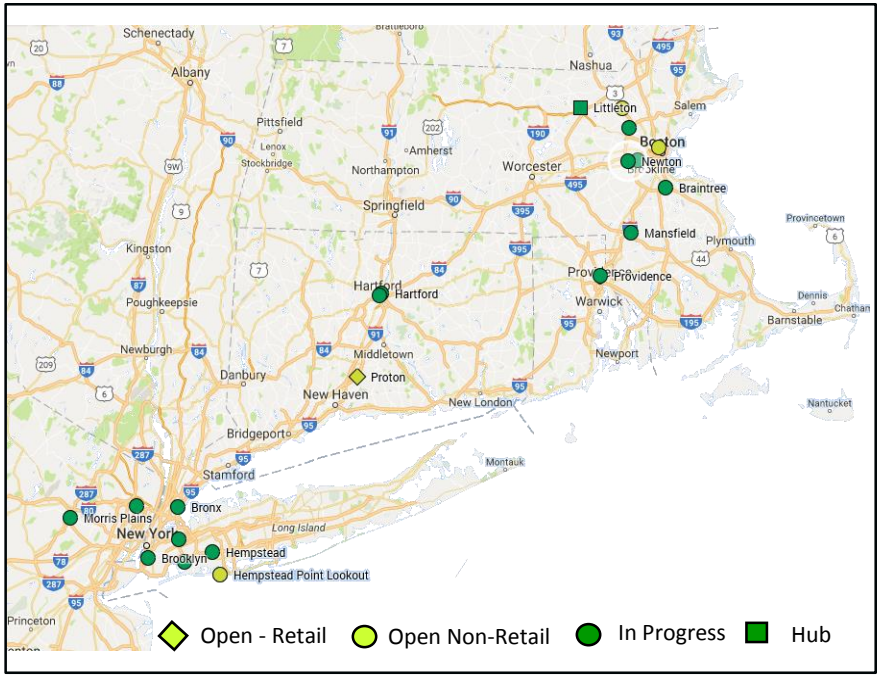
Capacity: 300 passengers
Maximum speed: 140 km/hr.

U.S. Hydrogen Refueling Stations

California

Over 30 open retail

Funding for 100

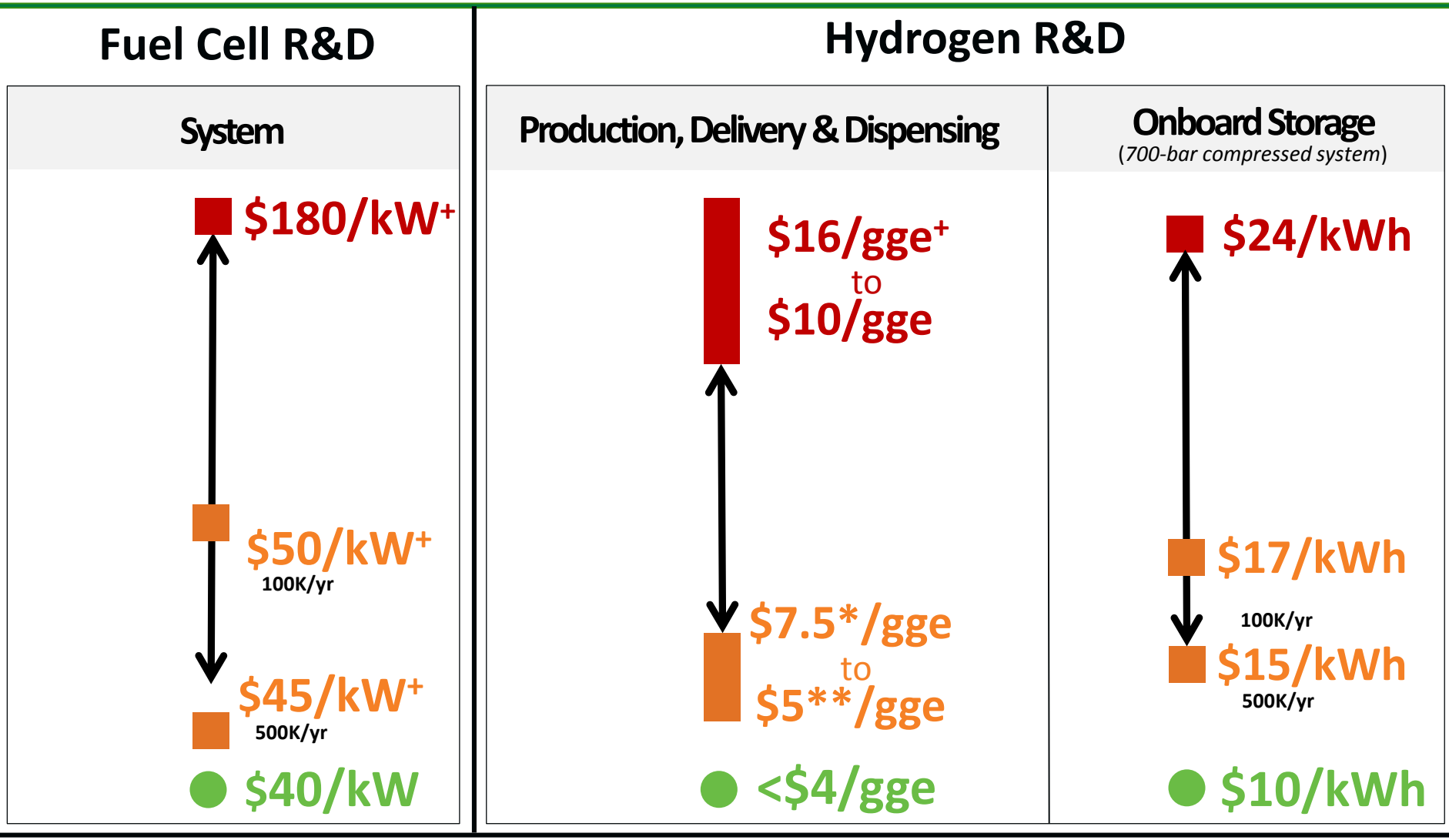


Northeast

Approx. 12 to 25 stations planned

Others with interest: Hawaii, Ohio, Texas, Colorado, South Carolina, and others

DOE Cost Status and Targets for R&D



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

Note: Graphs not drawn to scale and are for illustration purposes only.

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

Provides a forum to share information and advance collaborative initiatives to accelerate the cost-effective transition to the integrated use of fuel cells and hydrogen in the economy.

Member partners are undertaking significant RDD&D and/or implementing policy initiatives to increase the use of fuel cells and hydrogen.


Australia


Austria


Brazil


Canada


China


European Commission


France


Germany


Iceland


India


Italy


Japan


Republic of Korea


Netherlands


Norway


Russian Federation


South Africa


United Kingdom


United States

www.iphe.net

International Status and Targets- updates ongoing

	CARS		STATIONS*	
Country	Status	Target	Status	Target
CHINA	**~60**	**5,000 by 2020 50,000 by 2025 1M by 2030**	**~10**	**100 by 2020 300 by 2025 1000 by 2030**
EUROPEAN COMMISSION	~640 in Europe		~130	
FRANCE	**~200**	**1,000 by 2020**	**~18**	**100 by 2019**
GERMANY	~205		~42	100 by 2019 400 by 2023
JAPAN	**~2,200**	**40,000 by 2020 200,000 by 2025 800,000 by 2030**	**~100**	**160 by 2020 (70 MPa) 320 by 2025 (70 MPa) 100 additional at 35 MPa**
NETHERLANDS	~37	2,000 by 2020	~5	40 by 2020
SOUTH KOREA	**~500**	**10,000 by 2020 630,000 by 2030**	**~25**	**100 by 2020 520 by 2030**
UNITED STATES	~3,500 purchased or leased		~80	
TOTAL	**~6,900**		**~345**	

*Note - not all stations are retail

International Status and Targets- updates ongoing

Country	Bus Status	Bus Target	OTHER
CHINA	**~100**	**Foshan City plans for 300 by 2018**	**~500 FC Trucks**
EUROPEAN COMMISSION	~47		
FRANCE	**0**	**0**	**~100 Forklifts**
GERMANY			
JAPAN	**~2**	**>100 by 2020**	**Small Stationary: over 223,000 (current) 5.3 million by 2030 (target)**
NETHERLANDS	~12	100 by 2020	500 vans and 20 trucks by 2020 (target)
SOUTH KOREA			**By 2030, 20% of energy will come from renewables**
UNITED STATES	~26		>16,000 FC forklifts purchased
TOTAL	~175		

Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

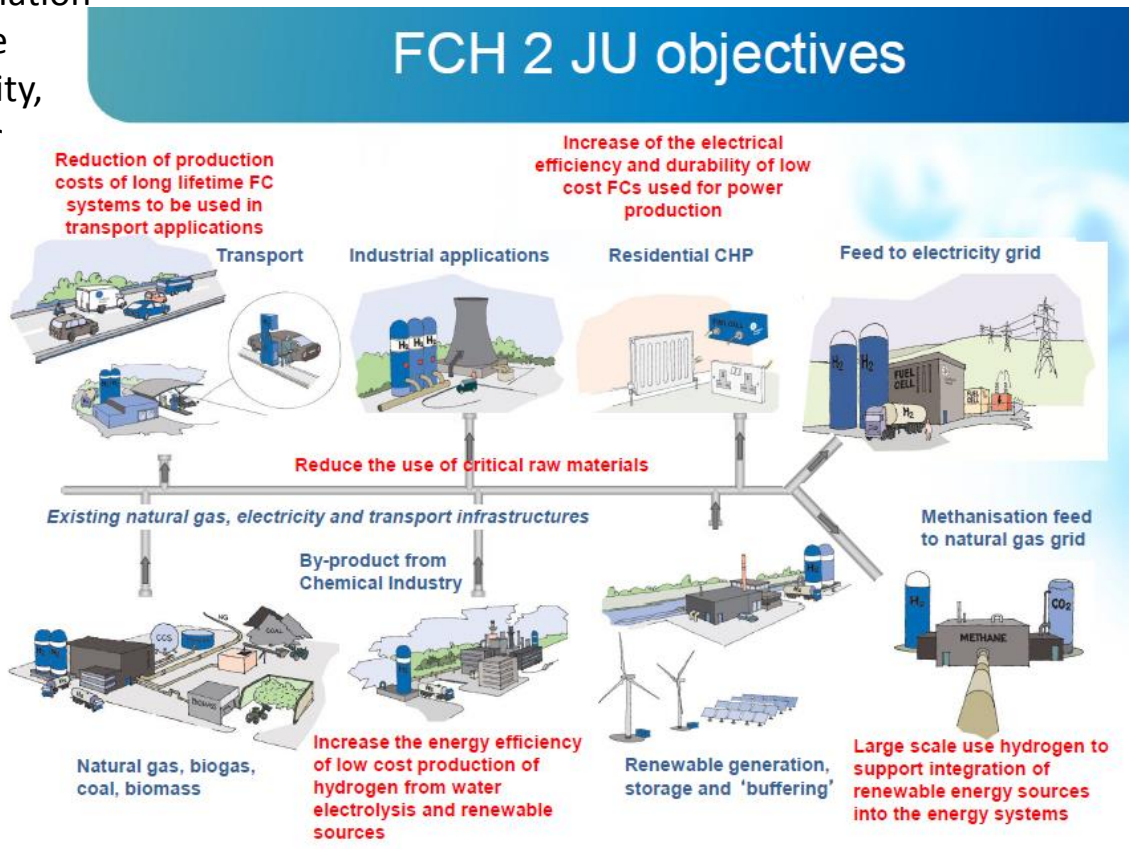
***FCH JU** - public private partnership supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies.*

Budget: 1.3B from gov't and industry contribution

Objective: demonstrate role of FCH technology in Europe's future energy and transport systems

1. **Transport:** vehicles, train, maritime, & aviation
2. **Energy:** H_2 production for energy storage & grid balancing from renewable electricity, FC systems for combined heat and power
3. **Crosscutting Research:** Standards, consumer awareness, manufacturing methods

(See: http://www.fch.europa.eu/page/vision-objectives)

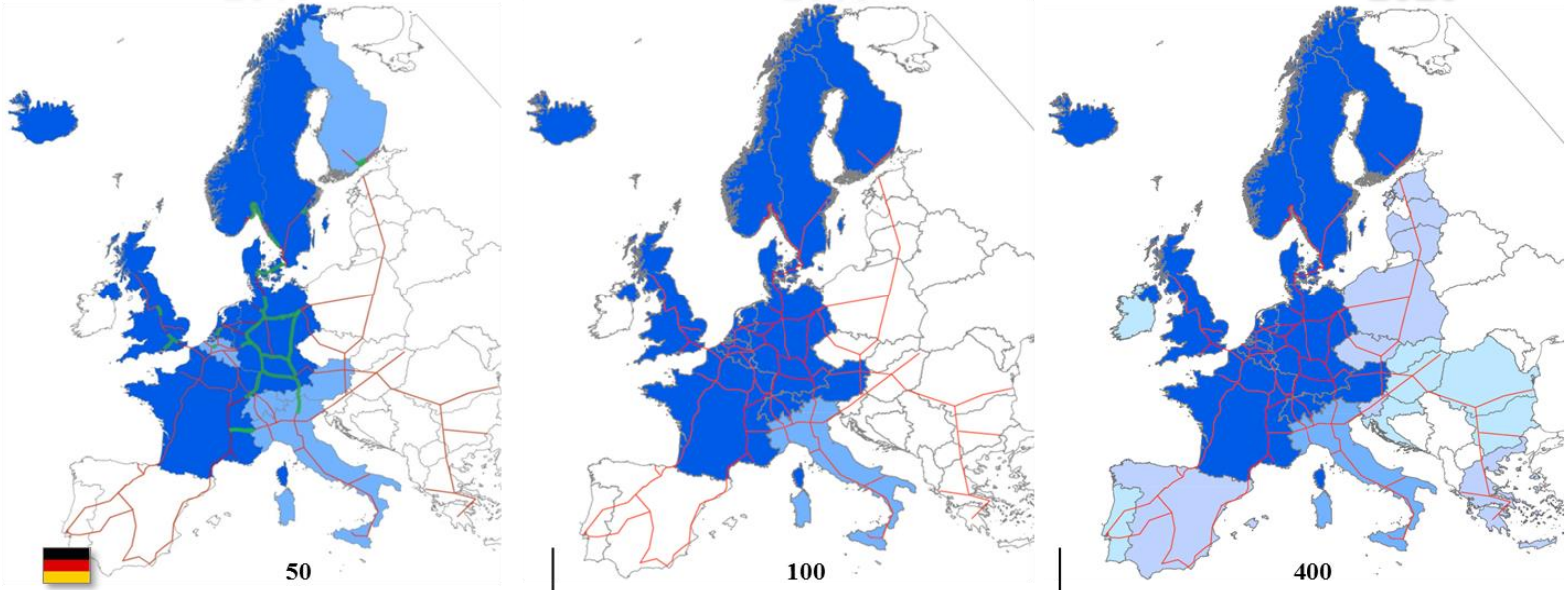


Directive 2014/94/EU on Deployment of Alternative Fuel Infrastructure:
Establishes a common framework of measures for the deployment of alternative fuels infrastructure in the EU

Source http://www.iphe.net/events/meetings/SC_24.html

Example: Scenario Planning in Europe

Scenario for EU Hydrogen Refueling Infrastructure



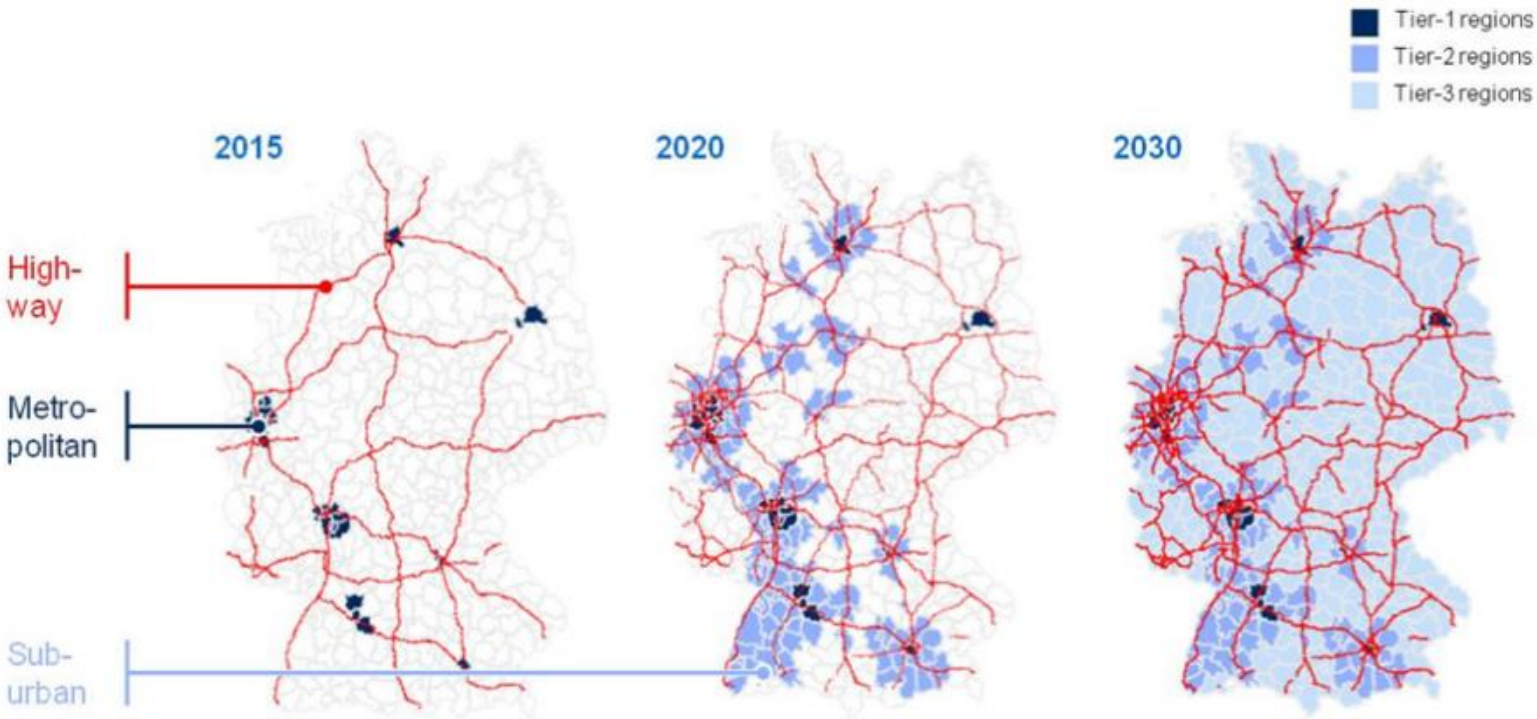
	2015	2018	> 2020
	50	100	400
	2 – 4	10	20
	9	100	355
	9	30	70
	10	30	40

Source: NOW GmbH
Source: Hydrogen Mobility France

- Nations with H_2Mobility initiatives
- Nations with some activity and/or H2Mobility initiatives starting
- Nations without H_2Mobility initiatives

Mobilité Hydrogène France
H_2 Mobility
UK H_2 Mobility
Scandinavian Hydrogen Highway Partnership
Hydrogen mobility grouping in Benelux
Hydrogen mobility grouping in Austria
Hydrogen Europe

Germany- Cluster Strategy Example



	2015	2020	2030
No. of FCEVs Thousands	~ 5	~ 150	~ 1,800
No. of HRS	~ 100	~ 400	~ 1,000
Total population covered by HRS Percent	~ 20	~ 60	~ 100

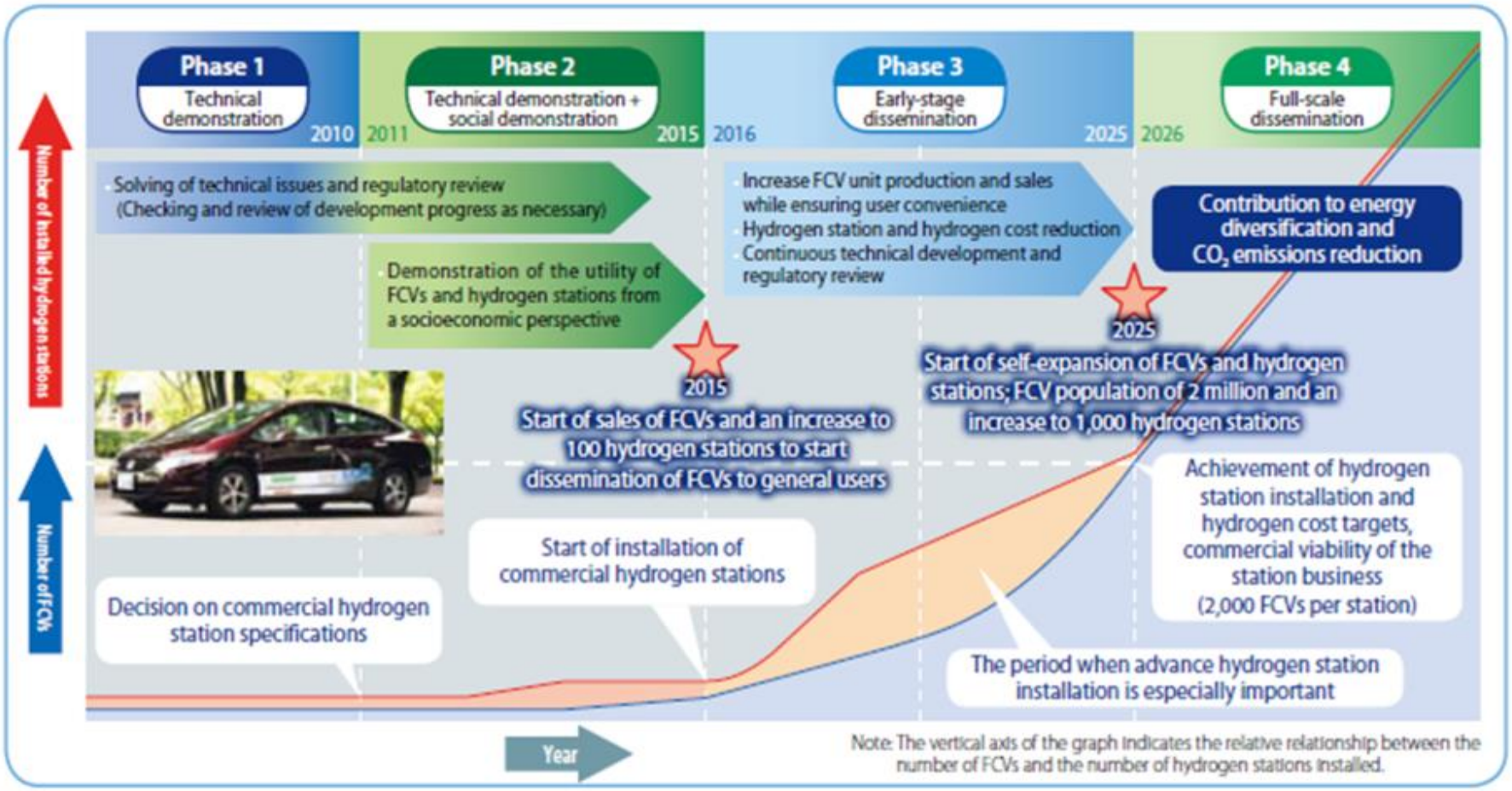
Photo Credit: Office of Prime Minister of Japan and His Cabinet

Photo Credit: Office of Prime Minister of Japan and His Cabine

Iwatani Hydrogen Fueling Station Opening with Japan's Prime Minister (Apr, 2015)

1st station in the heart of Tokyo

Japan Example- Stations before FCEVs



*Assumption: FCV user benefits (price, convenience, etc.) have been secured, and dissemination proceeds steadily.

Source: Fuel Cell Commercialization Conference of Japan

The Hydrogen Council formed in 2017

Investment

Over $10 billion

towards hydrogen and fuel cells

Members

Over 20 companies

Representing over $1.3T in revenues and 2M jobs

Estimated Impact

$2.5 trillion

in global revenues

30 million jobs

potentially created

18% of total global

energy demand

More information: hydrogeneurope.eu

Developments in Other Countries- Examples

Canada:

- 20 FCEVs and 1 Bus
- One semi-public station (Powertech Labs in Surrey) + three under development (1 in Vancouver, 2 in the greater Toronto area)
- Over 500 forklifts in operation
- Transport Canada commissioned a study of the deployment of Fuel Cell trains in Canada to interview experts in industry, government, and academia, and to identify prerequisites to deploying hydrogen-powered railways ("hydrail") in Canada

India:

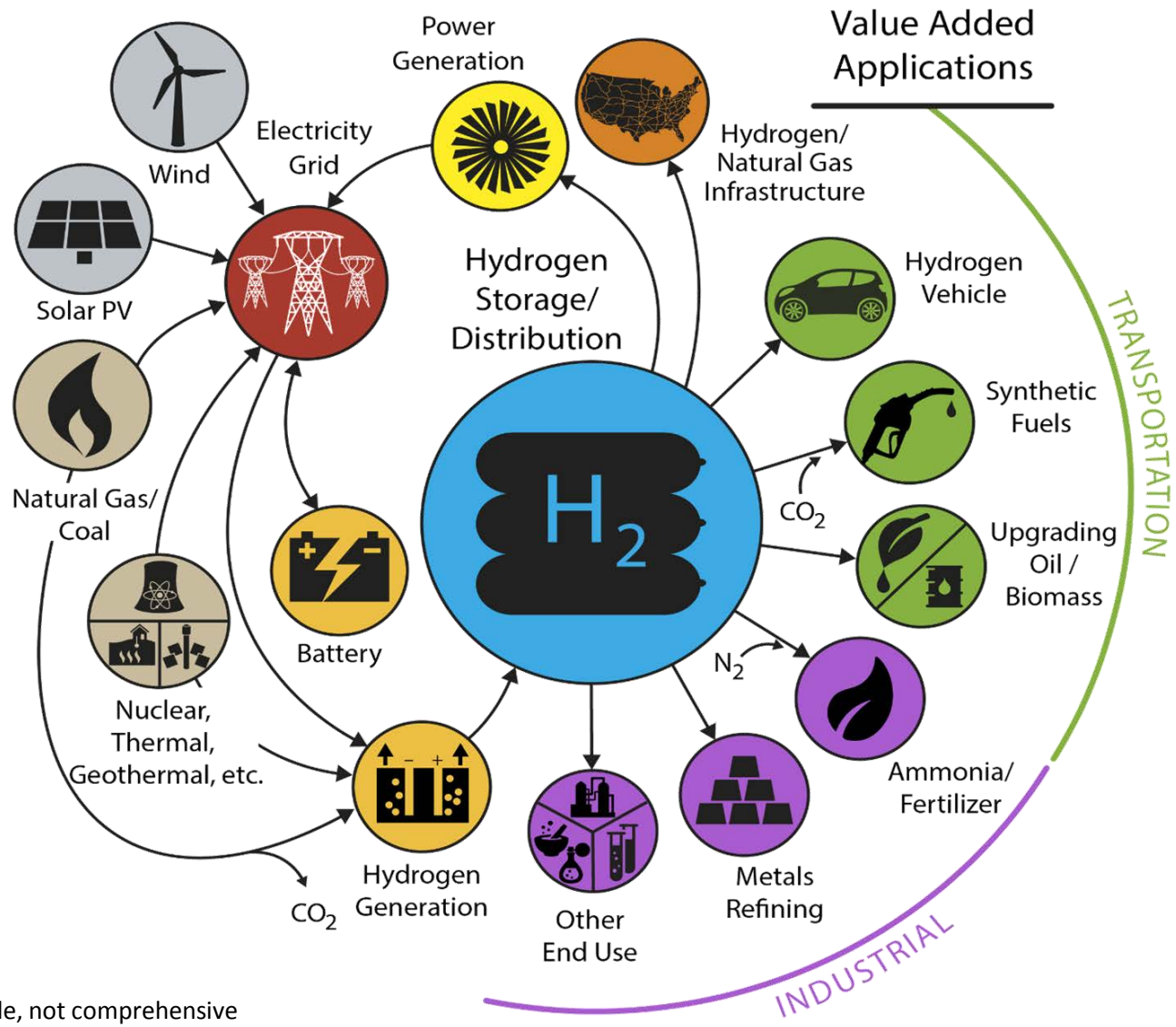
- Ministry of New & Renewable Energy has provided funding for Rs.59.5 Million ($US 0.89 M) for R&D related activities in the area of hydrogen energy & fuel cells for FY 2015-16
  - *FY 2016-17 funding:* Rs.200 Million ($US2.985Million) for hydrogen energy and fuel cell related activities
- 5 HRS are in operation; stationary PEM Fuel Cells being deployed to provide backup power for telecommunications towers; transportation focus on 3 wheelers

South Africa:

- HySA Programme received funding of R81.4 million (~USD5.4 million) from government through the Department of Science and Technology. An additional amount of R34 million (USD2.2 million) was leveraged from other Programmes within the Department; combined total of USD7.6 million.
- First fuel cell powered forklift deployed in 2016.
- A multi-stakeholder forum involving government, industry, and the mining sector has been set up to develop a fuel cell roadmap for South Africa.

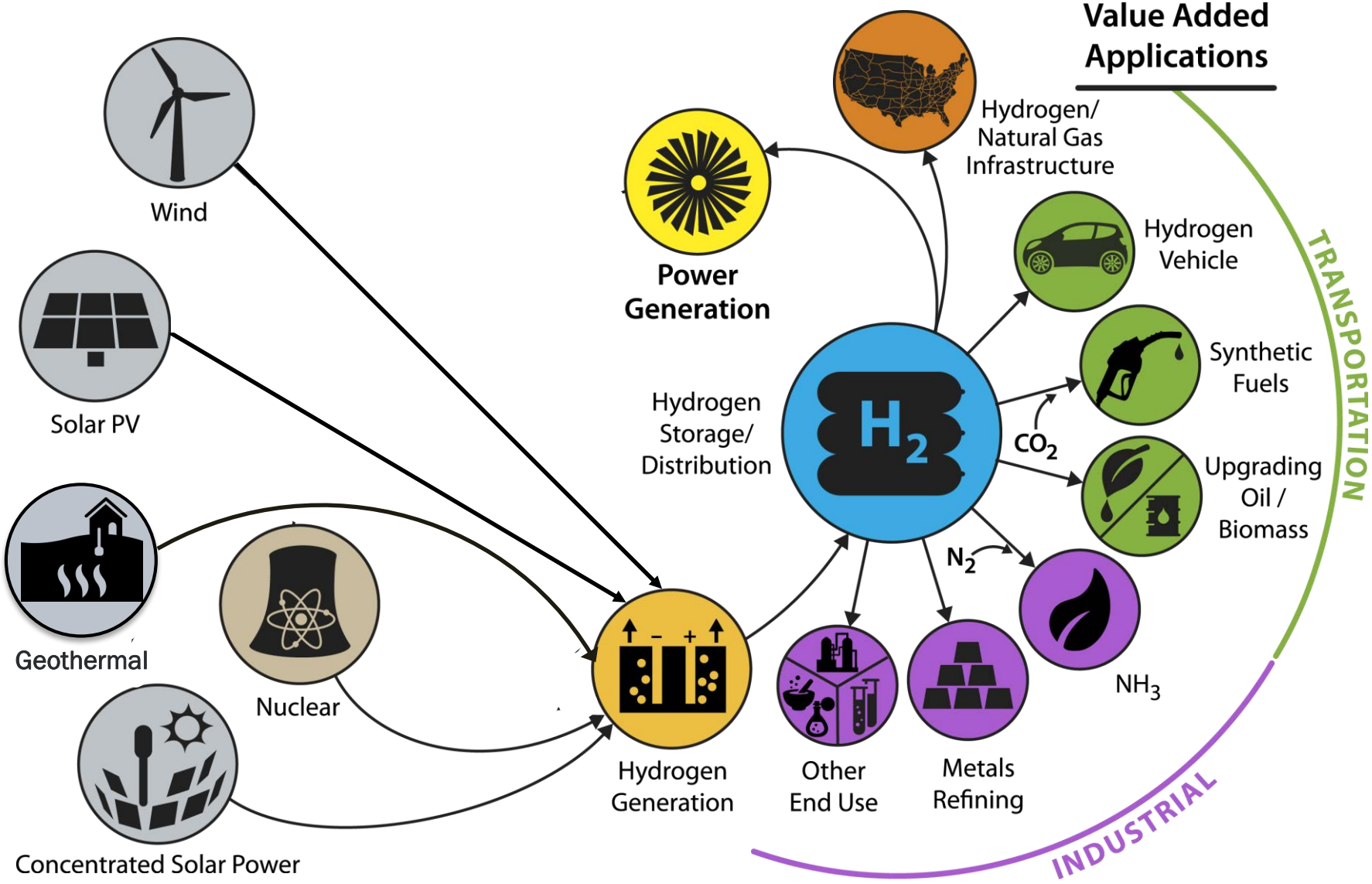
Sources: **http://www.iphe.net/partners.html**; http://www.nationaalwaterstofplatform.nl

H_2 at Scale Energy System



*Illustrative example, not comprehensive
Source: NREL

H_2 at Scale Energy System



Hydrogen Energy Storage is Scalable

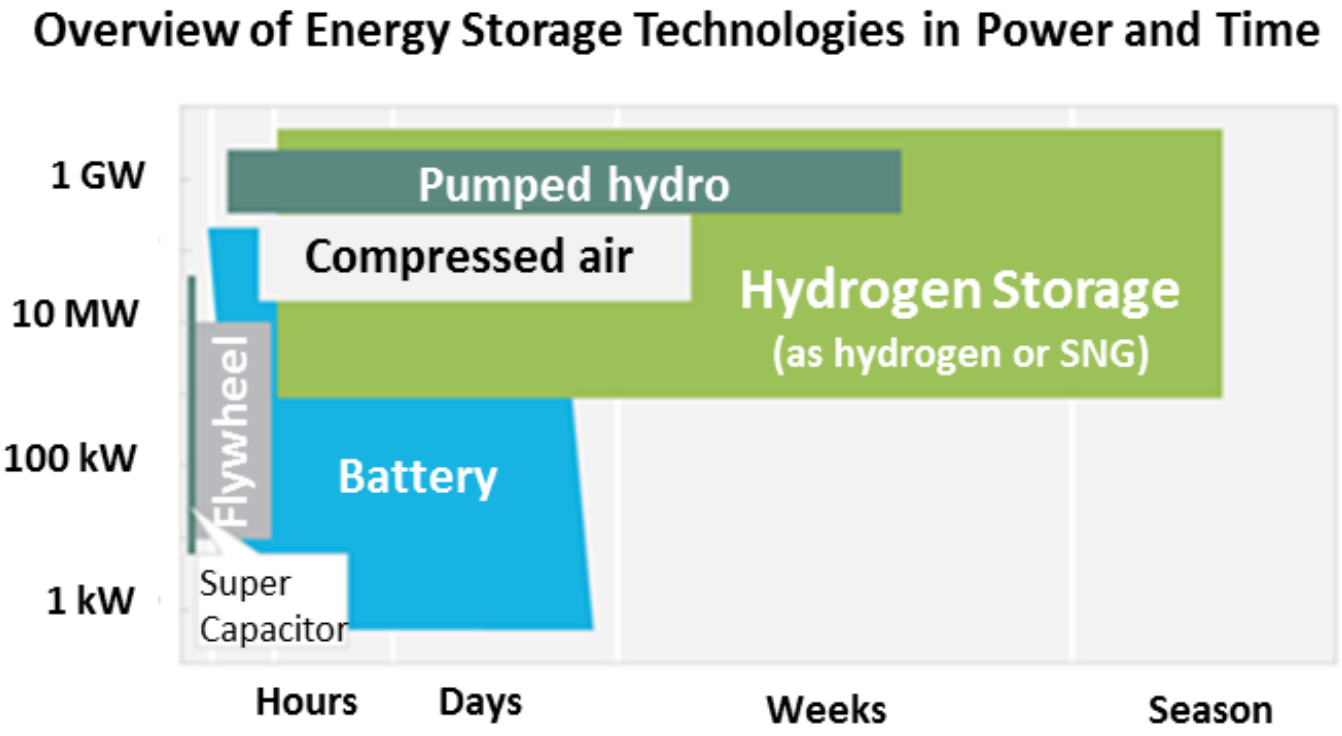
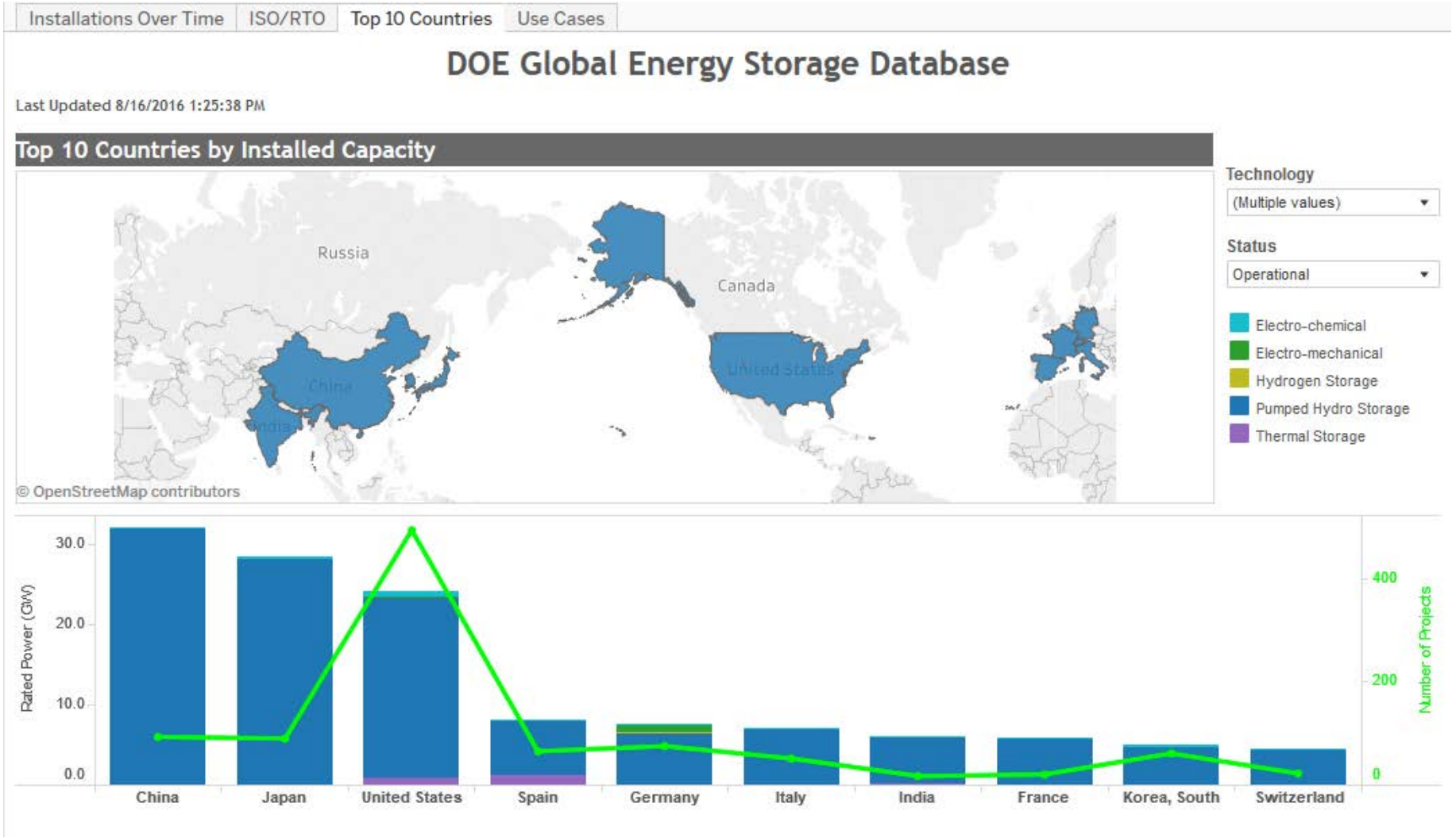


Image: Hydrogen Council

One hydrogen cavern could provide **~ 100 GWh energy storage**

Hydrogen can be used to monetize surplus electricity from the grid, or remote, off-grid energy feedstock (e.g. solar, wind) for days to months.

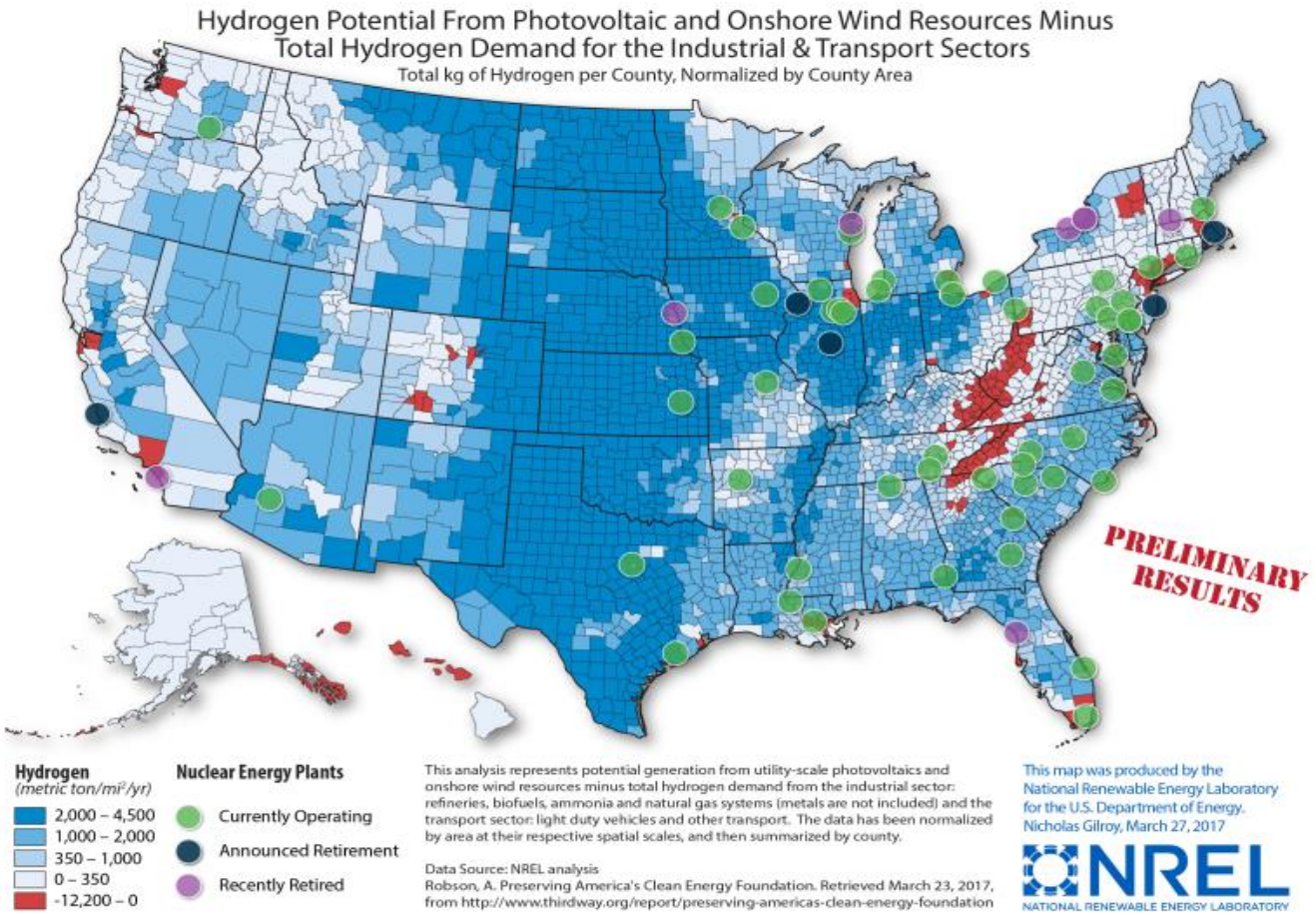
DOE Global Energy Storage Database



China and the U.S. in the lead: # GW and # of projects

Source: DOE Office of Electricity and Reliability

H2@Scale: Nationwide Resource Assessment



Lab PIs: Mark Ruth, Bryan Pivovar, Richard Boardman, et al

Labs assess resource availability. Most regions have sufficient resources.

Red: Only regions where projected industrial & transportation demand exceeds supply.

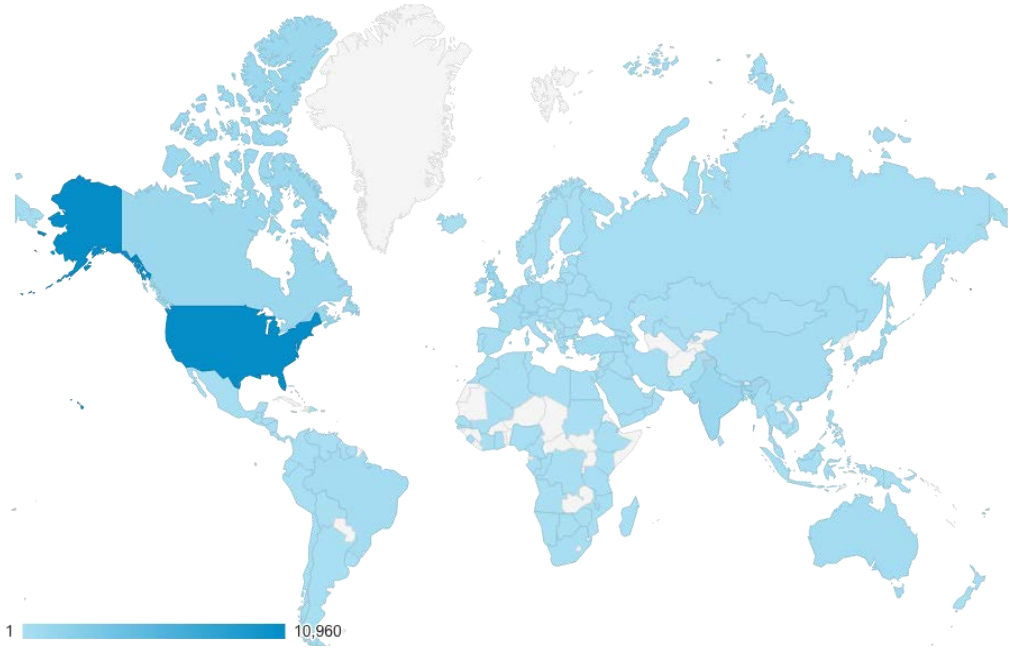
Safety Resources and Models Available

H2Tools.org disseminates information on hydrogen safety

A Global Resource

More than 150,000 visits since 2015 - 50% are international

Portions translated to Japanese, other languages underway



Hydrogen Risk Assessment Models (HyRAM) for risk analysis under various scenarios. Can be applied to develop:

- Conduct **Quantitative Risk Assessment (QRA)** to guide code requirements
- Assess **Liquid Hydrogen Separation Distances**

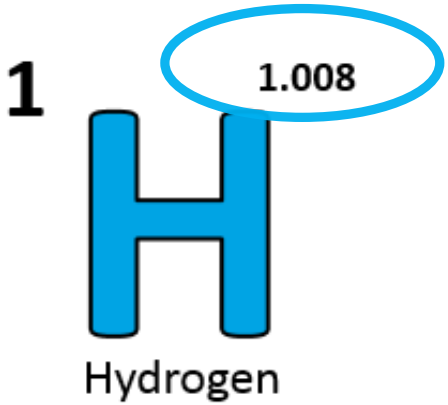
HyRAM
HYDROGEN RISK ASSESSMENT MODELS

Increasing Awareness

Celebrate Hydrogen & Fuel Cell Day

October 8 or 10/8

(Held on its very own atomic- weight-day)



Learn more:

energy.gov/eere/fuelcells

Save the Date

June 12-15, 2018

Annual Merit Review

Washington, DC

INCREASE YOUR H_2IQ

Download slide deck for free at at:

energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource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Thank You

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