UCI University of California, Irvine

Energy of the Future
Women Leading the Charge in Energy Storage to Advance Renewable and EV Growth

March 26th, 2021

Iryna V. Zenyuk

NATIONAL FUEL CELL RESEARCH CENTER
UNIVERSITY OF CALIFORNIA•IRVINE

Associate Professor
Department of Chemical and Biomolecular Engineering
Department of Mechanical and Aerospace Engineering
Department of Materials Science and Engineering

University of California, Irvine

Home to the National Fuel Cell Research Center

36,000+ students

#1 Best College in the U.S. — MONEY

#9 Public University in the U.S. — U.S. News & World Report 2020

#1 Cool School in the U.S. for sustainability — Top 10 for 10 years — Sierra magazine

200,000+ Anteater alumni

Most applied to UC campus for California's aspiring freshmen for a second year in a row

82 majors — **75** minors

$133 million private donor support in 2018-19

$5 billion annual economic impact in Orange County

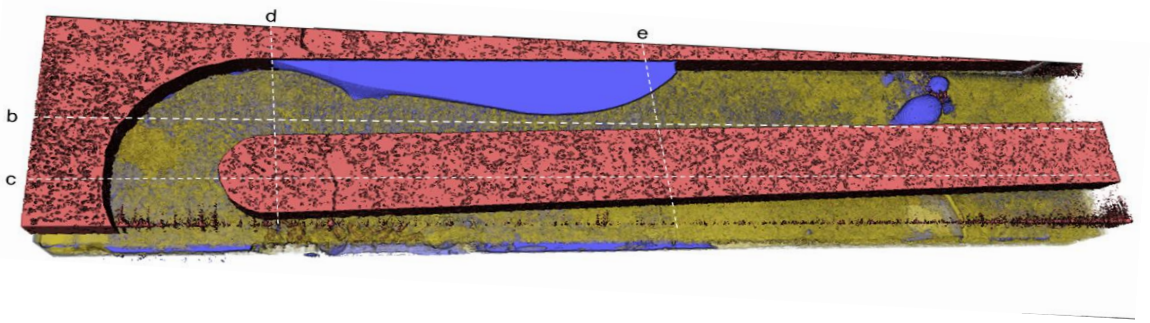
UCIRVINE

one of the 10 campuses of the University of California

… and, oh well, the mascot is – Peter, the…

UCI University of California, Irvine Zenyuk Group Introduction

- 7 Ph.D. students, 2 postdocs, 5 undergraduate
- 50 % fundamental and 50 % applied



Electrochemical characterization
Materials, set-up manufacturing
X-ray CT and other imaging
Multi-physics modeling

Fuel cells

Polymer electrolyte
Alkaline

U.S. DEPARTMENT OF ENERGY
NSF
BOSCH
Office of Naval Research ONR Science & Technology
IRD Fuel Cells A/S
SUMITOMO ELECTRIC

Fundamentals

Heat transfer
Mass transport
Porous media
Reaction kinetics
Electrokinetics at interfaces

Electrolyzers

Oxygen evolution on anode
Catalysts distribution
Cement

U.S. DEPARTMENT OF ENERGY
NSF

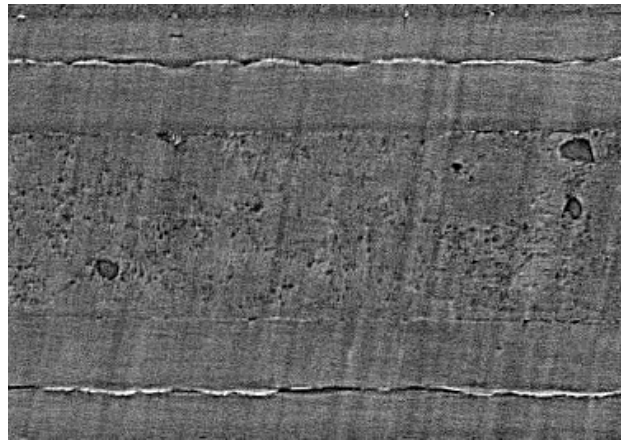
TOYOTA
ECS

NSF
CAREER

Batteries

Solid polymer electrolyte

arpa·e
CHANGING WHAT'S POSSIBLE
UNITED STATES AIR FORCE

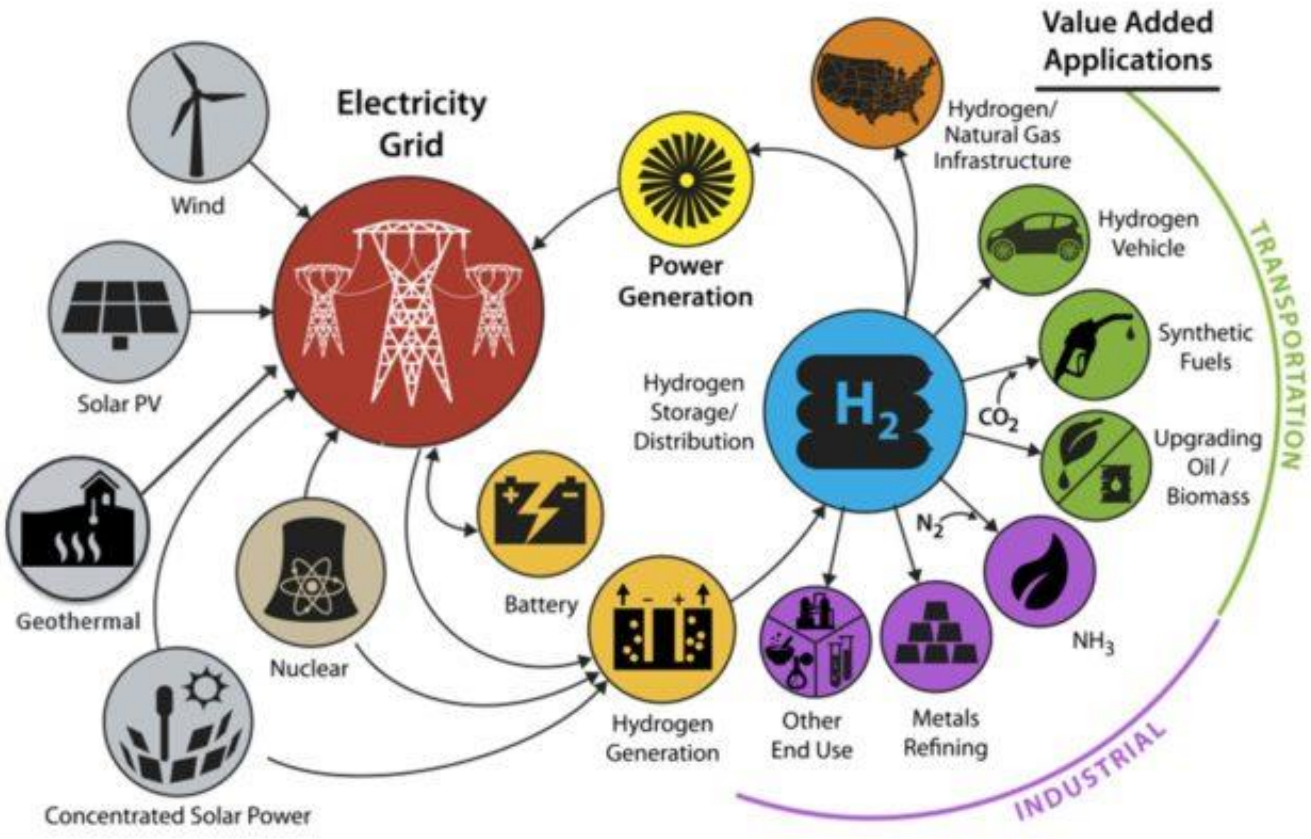


H_2 Economy: Definition

Definition of Hydrogen Society

(by Okazaki in 2016, plenary lecture at AIST)

A society where hydrogen is used as a secondary energy accounts for over 20 % of all energy consumption including the industrial applications, and hydrogen quantitatively and sufficiently contributes to energy security and carbon neutrality.



DOE website

H_2 Economy: Motivation

Hydrogen is a unique energy carrier with applications across sectors

Buildings:

- 47 % of US homes use natural gas space heating.
- Replacing or blending natural gas with low-carbon H_2 lower GHG emissions without need for new infrastructure

Transportation:

- Transportation 1/3 of CO_2 emissions in the US
- Fuel cell electric vehicles have larger on-board energy storage capacity compared to BEV; refuel quickly, zero-emissions,

Industrial processes:

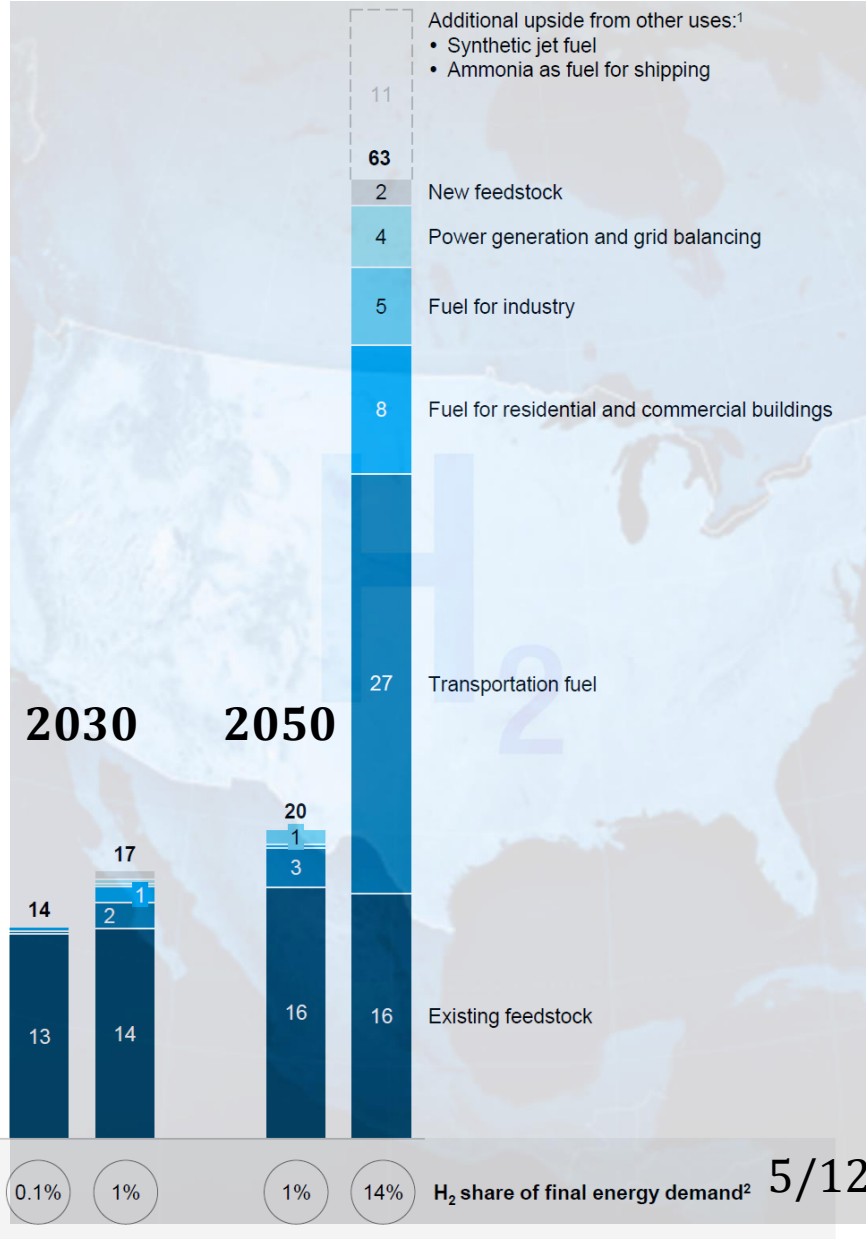
- Industry 20 % of carbon emissions in the US
- Hydrogen as feedstock for steelmaking, chemical production, refining, heating source to replace fossil fuels

Back-up power or off-grid power:

- Back-up power for data centers, hospitals, military bases; fast ramp-up and ramp-down capabilities

Power systems:

- Support deployment of variable renewables on the grid; electrolyzers can match variable and intermittent supply of wind and solar
- Hydrogen can be converted back to power via fuel cells



H_2 Characteristics

Lower heating value	33,33 kWh/kg
Higher heating value	39,41 kWh/kg
Density (gaseous)	0,09 kg/Nm³

- 99 % of US hydrogen is produced from fossil fuels, with 95 % from steam methane reforming
- 1 % is produced from electrolysis
- US produces more than 10 million metric tons (MMT) of hydrogen

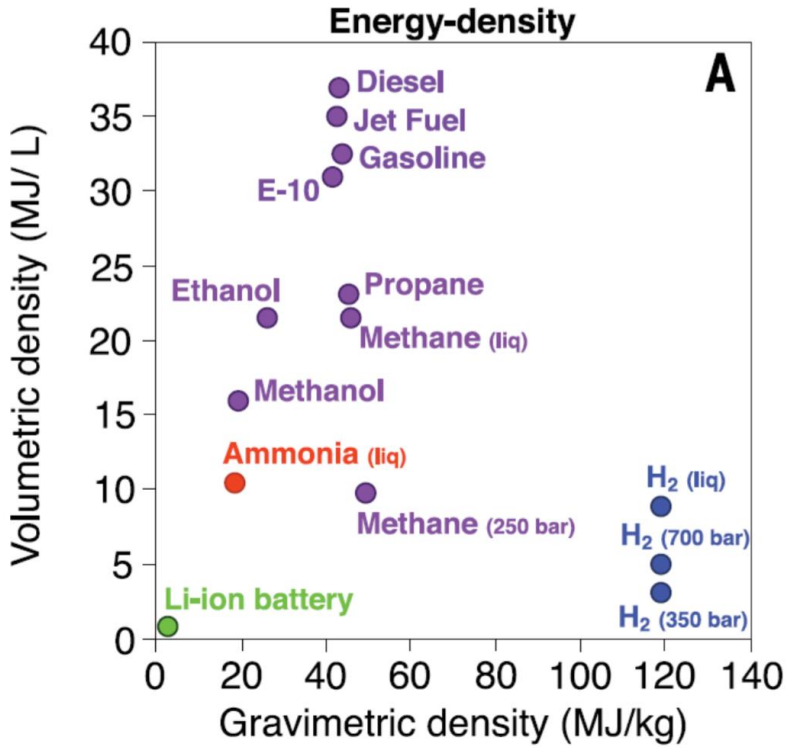
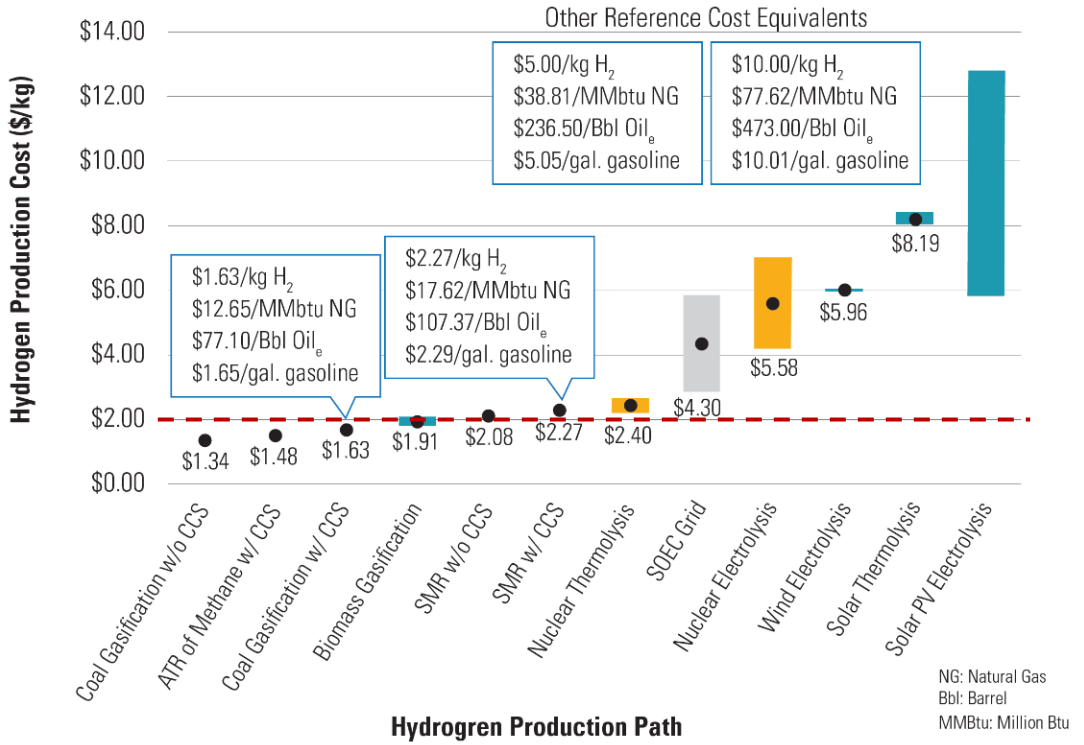


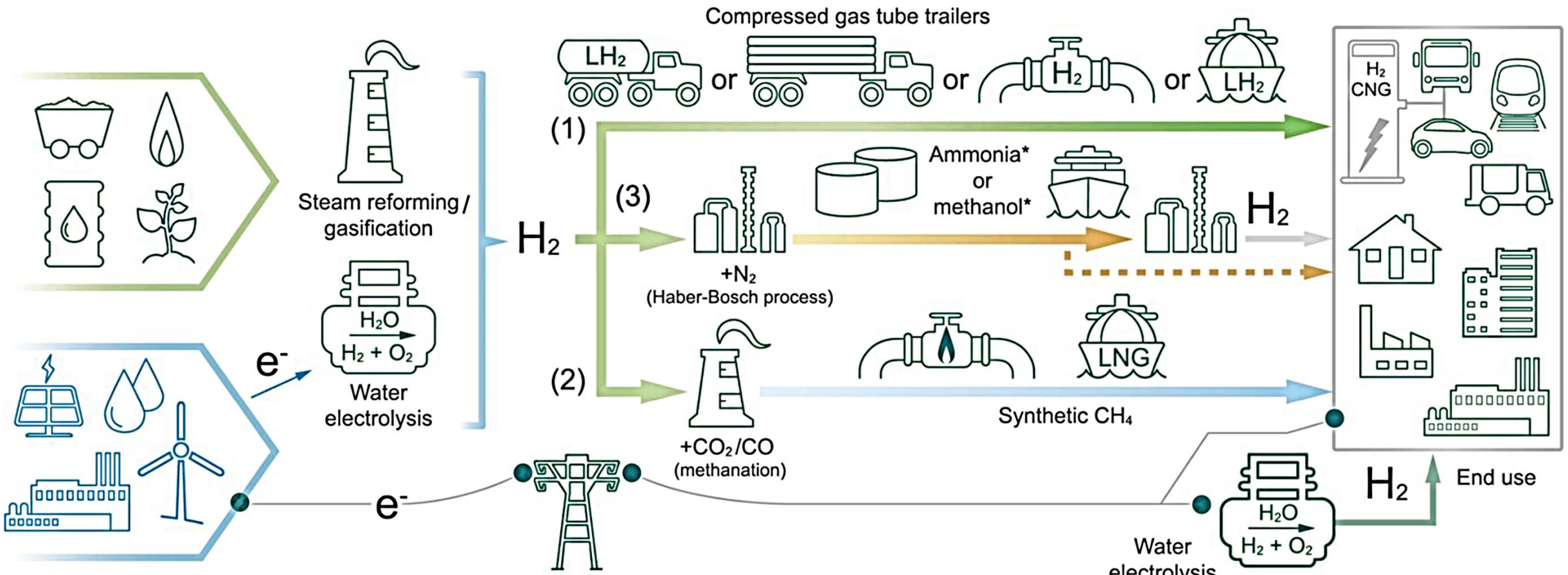
Figure 5. Current Hydrogen Production Cost Ranges and Averages by Technology and Equivalent Prices for Fossil Sources with CO_2 Capture and Storage



(1) Davis, S. J.; Lewis, N. S.; Shaner, M.; Aggarwal, S.; Arent, D.; Azevedo, I. L.; Benson, S. M.; Bradley, T.; Brouwer, J.; Chiang, Y.-M. Net-Zero Emissions Energy Systems. *Science (80-.).* **2018**, *360* (6396).

(2) Hydrogen Strategy, Enabling a Low-Carbon Economy, Office of Fossil Energy, United States Department of Energy, 2020

H_2 Supply Chain



*Alternative transport methods like ammonia and methanol will be assessed at IHS Markit fall 2019 workshops.
Source: IHS Markit

© 2019 IHS Markit/1736808

H2 Economy: 2020 Mainstream

Europe, US and Asia investment

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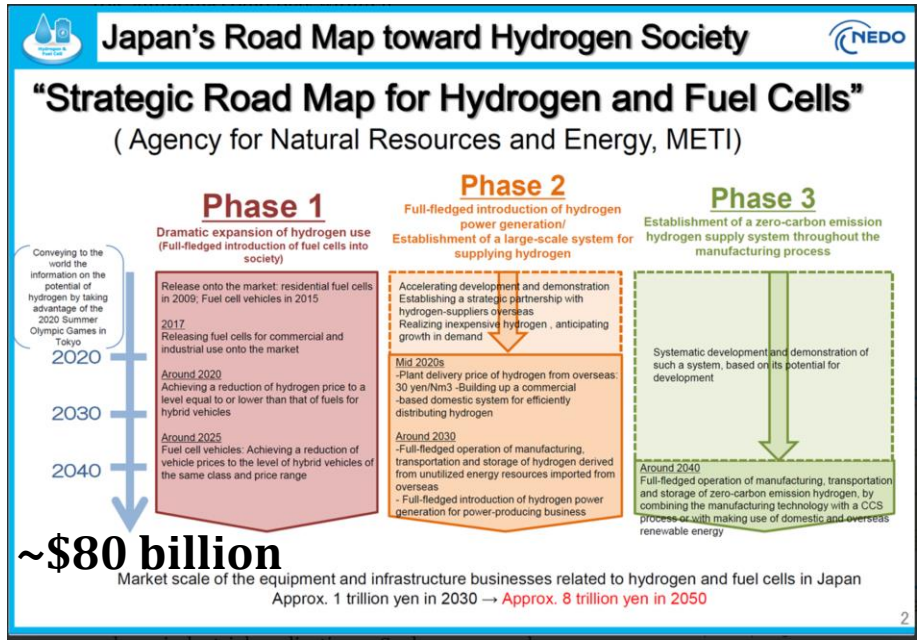
World's first national strategy: Japan



China: ~$34 billion (2017-2018)

Project	Fund (billion yuan)
H2 infrastructure	24.5
H2 town	67.2
HFCV	105.2
MEA	2.8
FC Stack & System	29.5

Source: CAIP

1 yuan(元) = 15 JP¥ = 15 円

230 Billion Yuan ≈ 31 Billion US$ ≈ 3.5 Trillion JP¥ = 3.5 兆円 !!!

Prof. Mao, Zongqiang, Tokyo Tech, 4th Open Hydrogen Symposium, January 31, 2019

EUROPEAN COMMISSION

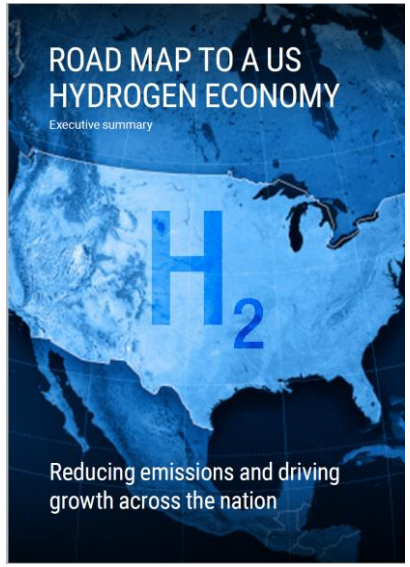
Brussels, 8.7.2020
COM(2020) 301 final

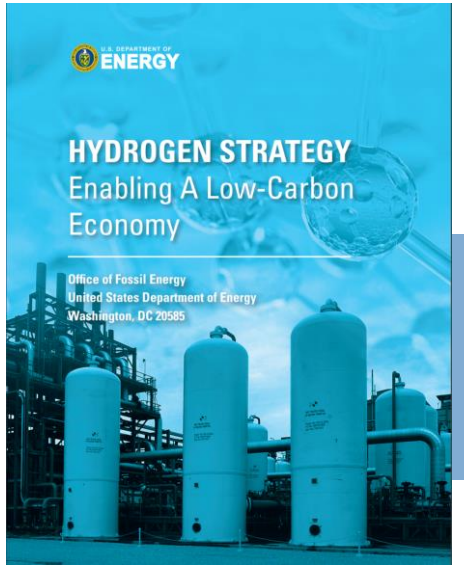
$30+Billion/7 years

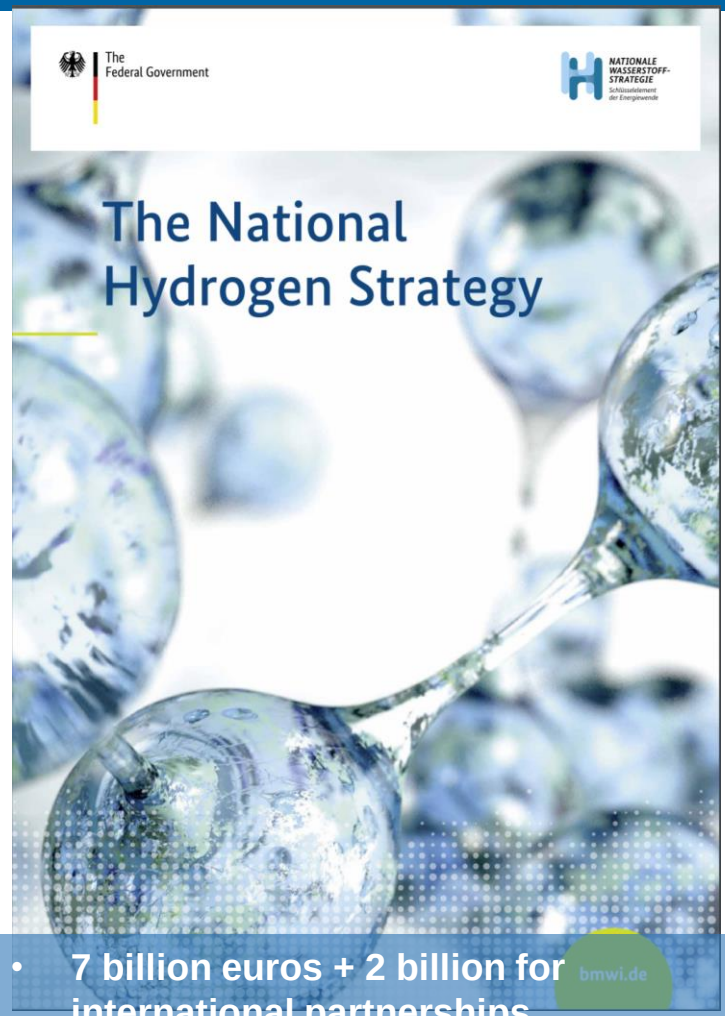
COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

A hydrogen strategy for a climate-neutral Europe

- Now to 2024 installation of at least 6 GW of clean hydrogen electrolyzers in the EU
- Production of up to one million tonnes of renewable hydrogen.







- 7 billion euros + 2 billion for international partnerships
- 7 % of total budget for economic recovery after COVID-19
- 5 GW (2030), 10 GW (2040)

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The US News on Hydrogen

Featuring UC Irvine H_2 initiatives

The New York Times

November 11, 2020

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NFCRC: H_2 Hub of SoCal

In the heart of the UC Irvine campus

Jack Brower, Director NFCRC

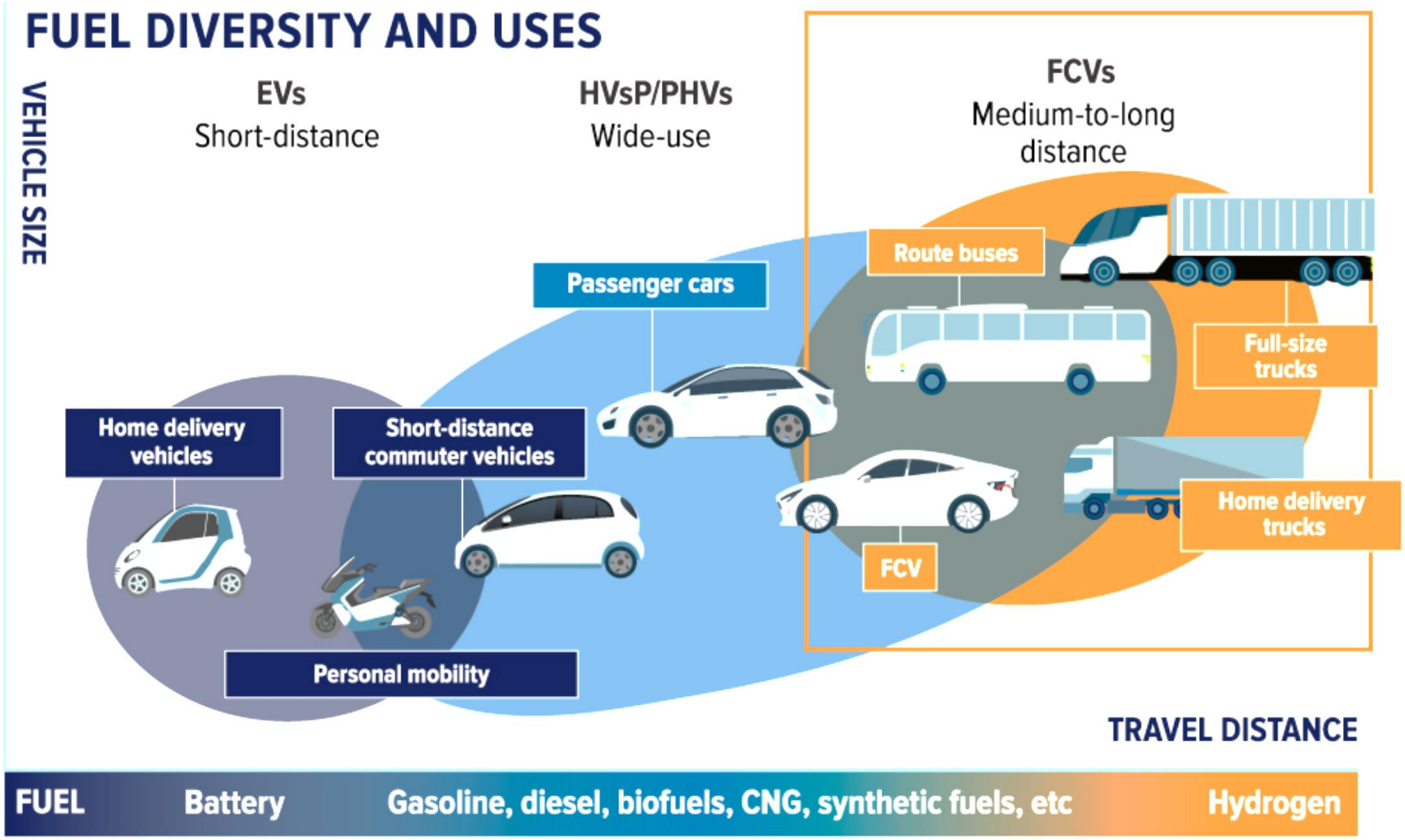
Iryna Zenyuk, Associate Director

Mission: To Facilitate and to Accelerate the Development and Deployment of Advanced Power and Energy Systems

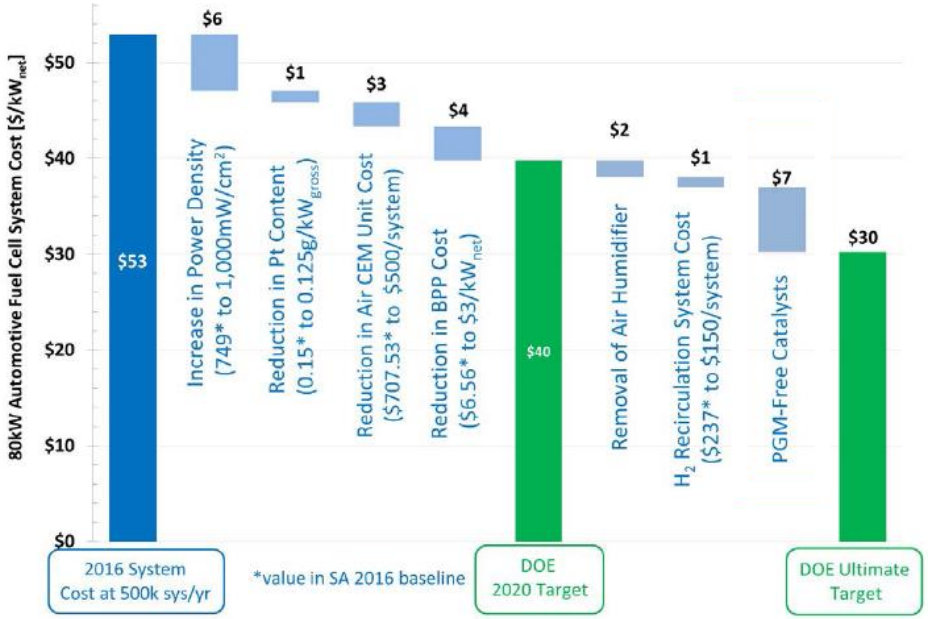
Transforming Transportation

Fuel cell electric vehicles and targets

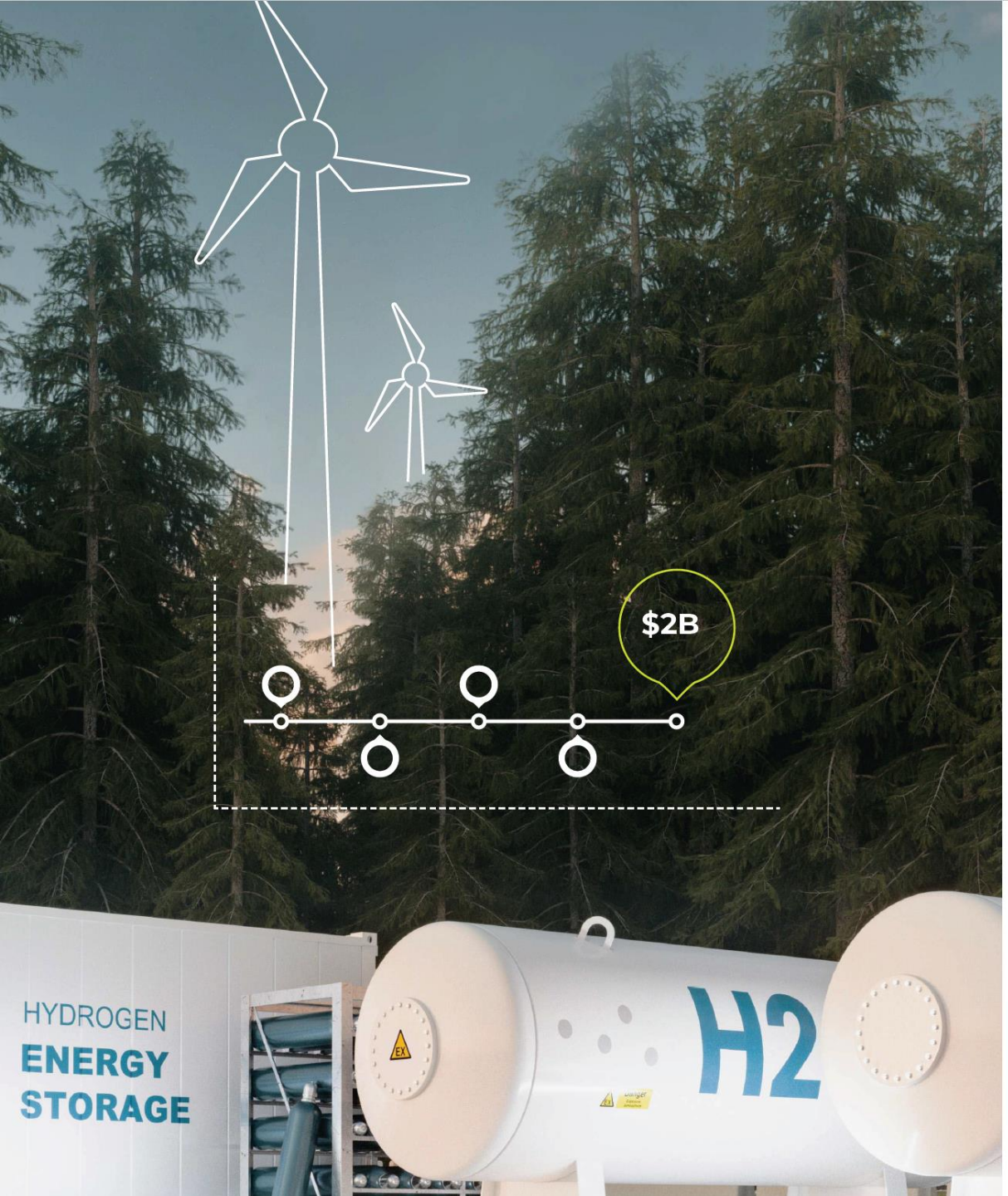
- Refuels in minutes
- ~360 miles in driving range
- > $6g_{PGM}$/vehicle



- Vehicles integration problems resolved (packaging, safety and cold start)
- System costs are still high compared to internal combustion engine
- Pt metal cost will not benefit from economy of scale – need to reduce Pt loading



Source: 2017 Annual Merit Review and Peer Evaluation Meeting



SoCalGas Will Accelerate

TO CLEANER FUELS

SoCalGas will accelerate the shift to cleaner fuels, complementing wind and solar energy, and add clean fuels, such as hydrogen, to the energy mix. Over the next five years, we plan to invest more than $2 billion to modernize our infrastructure to decarbonize, diversify, and digitalize our business.

Specifically, we will concentrate on three key areas:

1. Leveraging our gas infrastructure to provide the energy ecosystem with flexibility, storage, reliability and resiliency.
2. Investing in innovative technologies to create a portfolio of decarbonization solutions for an evolving energy transition.
3. Advancing through collaboration to engage, inspire, and empower partners on local, state, and global climate goals.