Expanding Electrification Journey to Hydrogen Economy

Minnesota Renewable Energy Roundtable

September 10, 2020





Advanced Technology Research

Commitment to improving our environment

6 CHALLENGES TOWARD 2050

| CHALLENGE 1 | CHALLENGE 2 | CHALLENGE 3 | CHALLENGE 4 | CHALLENGE 5 |
|--|---|---|--------------------|---|
| New vehicle Zero CO2 Emissions Challenge | Life Cycle Zero CO2 Emissions Challenge | Plant Zero CO ₂ Emissions Challenge Water Usage | | Challenge of Establishing a Recycling-based Society and System |
| | | | | |



CHALLENGE 6

Challenge of Establishing a Future Society in Harmony with Nature



Toyota electrification accelerating





- Early 2020 globally
- By 2025: **every** Toyota and Lexus model will have electrified powertrain option
- By 2030 2025: total electrified vehicle sales of > 5.5M units globally

Early 2020s: ten battery electric models

Commitment to Future Mobility and partnerships





SoftBank



Special needs mobility spectrum Should have been specific and spectrum Should be a sector of the spectrum Should be a spectrum Should be spectrum Should be







Future electrification at scale: portfolio of electric + H₂



Not competitors, but complements

Global electrification accelerating: ICE bans 2035/40

Only 2-3 product cycles away!

- Denmark
- France
- Britain



- Germany
- China



Mexico City





Why hydrogen? Versatile, zero-emission energy carrier





CLEAN power and/or heat

H₂ uses abound; key for difficult decarbonization cases

NREL's H2@Scale energy system conceptual



Resiliency benefits: redundancy and reliability

H₂ grid functions like an electric grid, but doesn't need to instantaneously balance energy generation and demand

Transformation in renewable energy: cheap, renewable hydrogen



Source: Arun Majumdar, DOE EERE Sunshot Report (Q1 2015), DOE EERE Wind Report (2015)



- Renewable electron prices dropping precipitously
- Cheapest electrons on planet
- Penetration increasing at fast rate

Renewable H₂ from electrolysis becoming more competitive nel[•]

CapEx: Electrolyzers from Nel - becoming competitive with SMR





* Including service, maintenance, and operation

** electricity

Source: Nel Hydrogen

Hydrogen as a storage of renewables



1 IEA data updated due to recent developments in building numerous 1MW hydrogen storage tanks

Source: IEA Energy Technology Roadmap Hydrogen and Fuel Cells, JRC Scientific and Policy Report (2013), California ISO

Hydrogen is most promising for long-term and carbon-free seasonal storage



12

100% renewable grid: enormous storage needed

Recent 1-year simulation of 100% renewable grid in California

Wind dominant case (37 GW solar capacity, 80 GW wind capacity)







Green Innovation: Fukuoka Renewable Hydrogen Town

300k homes in Japan with fuel cells by 2020



- Home fuel cells (90% efficiency)
- RH₂ production
- **Pipeline supply**
- H₂ stations (LDV and bus)
- H₂ highway
- FC vehicles / scooter
- FC forklift



Research: Hydrogen Energy Test and Research Center (Kyushu University)



Biogas: Fukuoka City Water Treatment Center (Deloitte)

Renewable energy as an export

- Australia piloting with RH2 and ammonia
- Norway, British Columbia, United Kingdom studying as well







Renewable hydrogen could fuel Australia's next export boom after CSIRO breakthrough

Australia's next big export industry could be its sunlight and wind, as gamechanging technology makes it easier to transport and deliver their energy as hydrogen.

First H₂ gas grid Netherlands study

Gasunie converts sustainable energy into H₂ with first 1 MW power-to-gas installation in Netherlands

Pilot project HyStock important step in scaling up power-to-gas technology.



Source: Netherlands Enterprise Agency, Topsector Energy TKI New Gas, Gasunie



Hydrogen Roadmap

- Achieve 2050 with electric and H₂
 - Versatile system role
 - Key to industry and heavy transit
- Integration
 - Renewables, CCS, biomass, infrastructure, grid storage
- Start now
 - Pilot demo, innovate, scale

Proposal to convert UK natural gas grid to H₂

UK's Northern Gas Networks and Cadent along with Norway's Equinor propose plan to achieve 100% carbon-free H₂ grid by 2100

Leverage steam methane reformation (SMR) with carbon capture storage (CCS)





H21 proposal

- 2028: North of England
 - Pilot to convert natural gas to H_2 grid
 - 3.7M homes & 400K businesses
- 2050: Scale up
 - Expand to 12M ____ additional homes in England
- 2100: 100% H₂ grid Full coverage of UK

Role of hydrogen in mobility? Got infrastructure?

Effective in long range, demanding duty cycles with minimum downtime (e.g., "shared" cars, transit buses, trucks, trains) Compared to batteries...

- H₂ stores far more energy than batteries at a fraction of the weight
- H₂-powered fleets place less burden on the electrical grid, while fueling faster



Source: Ballard, Mercury News (CA), FuelCellsWorks (China), Morning Call (China), Automotive News (Japan), NOW GmbH (Germany), Bloomberg (France)



| ments' H ₂ & FCEV goals | | | | | | | | | |
|------------------------------------|------|--------------------------------------|--|--|--|--|--|--|--|
| H ₂ stations, # | Year | FCEV volume, # | | | | | | | |
| 200 | 2025 | N/A | | | | | | | |
| 100 | 2020 | 10,000 | | | | | | | |
| 300 | 2025 | 50,000 | | | | | | | |
| 1,000 | 2030 | 2,000,000 | | | | | | | |
| 160 | 2020 | 40,000 | | | | | | | |
| 320 | 2025 | 200,000 | | | | | | | |
| 900 | 2030 | 800,000 | | | | | | | |
| 100 | 2020 | N/A | | | | | | | |
| 400 | 2025 | N/A | | | | | | | |
| 1,000 | 2030 | N/A | | | | | | | |
| 100 | 2023 | 5,000* | | | | | | | |
| 400-1,000 | 2028 | 52,000* *Fleet & heavy-duty focus | | | | | | | |

Station innovation: EV charging + H₂ + grid storage

EV charging,

light-duty (proprietary)

EV charging, light-duty



SSLA

H₂ refueling, light-duty and heavy-duty



3-in-1 station concept



Source: University of California-Davis, NREL, Electrify America



Scale potential: future RH₂ grid in Southern California

Hub and spoke local high-pressure pipelines develop (2030+)



Source: NREL, California Fuel Cell Partnership





Renewable hydrogen from biogas opportunity

Landfills, wastewater treatment, manure, institutional / industrial





Example: The Orange County Sanitation District (OCSD) in California commissioned a fuel cell power plant that efficiently converted biogas generated from the wastewater treatment process into electricity for use by OCSD. It also produced renewable hydrogen for an onsite fueling station operated by Air Products, to serve fuel cell vehicles in the region.



Hydrogen mobility: utilize electrification platform - Motor, battery, inverter are shared



Mobility: roles of BEV, PHEV, FCEV





Optimal use case

BEV \rightarrow **Small size**, short distance, low duty cycle (e.g., commuting in a city)

FCEV \rightarrow Large-size, long distance, high duty cycle (e.g., driving between cities, future diesel alternative)

Automotive executive survey results

First time fuel cell electric mobility ranks #1 trend among automotive executives



Platform strategies and standardization

Downsizing of internal combustion engi

Rationalization of production in Weste

FCEVs from multiple brands on the road today

Mercedes-Benz



Toyota



Honda



Hyundai



Toyota's FCEV production increasing to 30K after 2020



Source: Toyota

Increasing interest in fuel cell buses

Japan **Toyota FC Bus Introduction** To start from February 2017 for Tokyo, with a minimum 100 units by 2020 for Tokyo Olympics/Paralympics High-pressure hydrogen tank FC stack 10 tanks of MIRAI (700 bar) 2 units of MIRA Hydrogen Battery Motor 4 units of CROWN 2 units of Lexus RX The FC bus was developed using a unit of MIRAL Cruising range is approximately 200km

China

World's largest FC bus fleet: Zhangjiakou's

fleet of 74 FC buses made by Foton

Beijing 2022 Winter Olympics

Northern Europe

Cold weather: heat > mobility

Heating a transit bus in cold climates uses more energy than propelling it

Source: Toyota, California Fuel Cell Partnership, Xinhuanet, Mercedes-Benz

California

Sunline Transit



- New Flyer buses just over \$1million. below quote
- 900-kg hydrogen station
 - Fuel upwards of 26-30 buses
- On-site production
- Center of Excellence
 - Training
 - Facility

AC Transit



- 15 years
- Fuel cell longevity
 - 5 stacks exceed 25,000 hours

 - 12 of 13 stacks exceed 20,000
- 1 nearing 30,000 hours
- Reno trip
- 224 miles each
- way (2xs!)
- Rain and snow Steep grade
- 10.91 miles per gallon
- 2.8+ million miles of service
- Trained 270 mechanics
- 14,000+ hours of fuel cell bus mechanic training
- Dispensed 88,000+
 - kgs of H2 in 2017 More in 2018
 - already

Long Beach port corridor pollution: social equity

Diesel particulate matter in greater Los Angeles



ozone ambient air quality standards

- Heavy-Duty Diesel Trucks
- Off-Road Mobile Equipment
- RECLAIM
- Ocean Going Vessels
- Locomotives
- Cars/Light-Duty Trucks/SUVs Aircraft
- Manufacturing and Industrial
- Residential Fuel Combustion
- Heavy-Duty Gas Trucks
- Commercial Harbor Craft
- Service and Commercial
- Buses
- Medium-Duty Trucks
- Recreational Boats
- Other



Needed NOx emission reductions to achieve Federal 8-hour



Project Portal

Fully-functional, zero-emission, electric Class 8 truck, powered by fuel cell stacks from two Mirai sedans



Specifications Performance Class 8 truck chassis 670 horsepower • 2 Mirai fuel cell stacks 1,375 ft-lb torque 80,000 lbs GVWR 12 kWh of batteries • 700 bar H₂ storage 200+ miles of range **PACCAR KENWORTH**

Portal's H₂ fuel comes from a Tri-Generation system which produces renewable hydrogen, electricity, and heat from biogas using a high-temperature fuel cell





Source: Toyota Motor North America



New applications























Flying cars infrastructure: H₂ vs. EV?





























https://ssl.toyota.com/mirai/fcv.html





Energy Observer: powered by H₂ + solar





Hydrogen infrastructure and fuel cell electric vehicle references

| NREL | National Renewable Energy Laborate | www.nrel. | |
|-----------------------------------|--------------------------------------|------------|-------------|
| | | | |
| CALIFORNIA AIR RESOURCES BOARD | California Air Resources Board | ww2.arb.ca | |
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| NATIONAL FUEL CELL | National Fuel Cell Research Center - | www.nfcrc | |
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