Expanding Electrification
Journey to Hydrogen Economy
Minnesota Renewable Energy Roundtable
September 10, 2020
Commitment to improving our environment

Source: Toyota
Toyota electrification accelerating

- Early 2020s: **ten** battery electric models 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

Source: Toyota
Commitment to Future Mobility and partnerships
Special needs mobility spectrum

- Last Mile
- Environmental awareness
- Advanced wheel chairs
- Rehab training
- Assisted movement
- Personal assistance

User mobility spectrum:
- High
- Low
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
- Madrid
- Mexico City
Why hydrogen? Versatile, zero-emission energy carrier

- **ZERO** carbon footprint potential
- **HIGH** energy density
- **LONG** distance transport
- **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

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

Renewable H$_2$ from electrolysis becoming more competitive

**CapEx:** Electrolyzers from Nel - becoming competitive with SMR

**OpEx:** Renewable energy already enables fossil parity for hydrogen

* Including service, maintenance, and operation
** electricity

Source: Nel Hydrogen
Hydrogen as a storage of renewables

“You need other new technologies to convert cheap renewable energy into chemical fuel when the sun is shining or the wind is blowing. We won’t get there (through batteries), but one is hoping to get well below that through some innovative electrochemistry. If you make really cheap hydrogen from renewables and store it underground, then you have something very different.”

– Dr. Steven Chu, former US Energy Secretary

1 IEA data updated due to recent developments in building numerous 1MW hydrogen storage tanks
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)
- RH$_2$ production
- Pipeline supply
- H$_2$ stations (LDV and bus)
- H$_2$ highway
- FC vehicles / scooter
- FC forklift

Source: AltEnergyMag.com

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

THE RISE OF ELECTROFUELS
An alternative method for storing renewable energy.

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 game-changing technology makes it easier to transport and deliver their energy as hydrogen.

Source: Australian Broadcasting Commission, SolarPACES, Coast Protection Board of South Australia
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.

**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 H₂ grid
  – 3.7M homes & 400K businesses

• 2050: Scale up
  – Expand to 12M additional homes in England

• 2100: 100% H₂ grid
  – Full coverage of UK

Source: Ars Technica, Northern Gas Networks
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

Global governments’ H₂ & FCEV goals

<table>
<thead>
<tr>
<th>Region</th>
<th>H₂ stations, #</th>
<th>Year</th>
<th>FCEV volume, #</th>
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<td>400-1,000</td>
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*Fleet & heavy-duty focus
Station innovation: EV charging + H₂ + grid storage

EV charging, light-duty (proprietary)

On-site renewables
EV charging
Grid management
H₂ refueling, light-duty and heavy-duty

3-in-1 station concept

Source: University of California-Davis, NREL, Electrify America
Scale potential: future RH$_2$ grid in Southern California

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

Long-distance transport
- Pipeline?
- Liquid?
- Electricity?

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.

Source: NREL, Los Angeles Times, Fuel Cells Bulletin
Hydrogen mobility: utilize electrification platform
– Motor, battery, inverter are shared
Mobility: roles of BEV, PHEV, FCEV

Optimal use case

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

FCEV → 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

Fuel cell electrical mobility
- Connectivity & digitalization
- Market growth in emerging markets
- Hybrid electric mobility
- Battery electric mobility
- Creating value out of big data
- Mobility-as-a-service
- Autonomous & self-driving vehicles
- Platform strategies and standardization modules
- Downsizing of internal combustion engine (ICE)
- Rationalization of production in Western Europe

Source: KPMG Global Automotive Executive Survey 2018
FCEVs from multiple brands on the road today

Mercedes-Benz

Toyota

Over 6,000 in the US

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
  - 10 tanks of MIRAI (700 bar)
- FC stack
  - 2 units of MIRAI
- Motor
  - 2 units of Lexus RX
- Battery
  - 4 units of CROWN

The FC bus was developed using a unit of MIRAI. 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

**California**

- **Sunline Transit**
  - **New Flyer buses just over $1 million**
  - Below quote
  - **900-kg hydrogen station**
    - Fuel up to 26-30 buses
  - On-site production
  - Center of Excellence
    - Training
    - Facility

- **AC Transit**
  - **15 years**
  - Fuel cell longevity
    - 5,000 hours
    - 12,000-17,000 hours
    - 30,000 hours
  - **Renewable**
    - 324 miles each year
    - Rain and snow
    - Steep grade
  - **2.8+ million miles of service**
  - Trained 270 mechanics
    - 5,000+ hours of fuel cell bus mechanic training
  - Dispensed 88,000+ lbs of H2 in 2017
  - More in 2018 already

Source: Toyota, California Fuel Cell Partnership, Xinhuanet, Mercedes-Benz
Long Beach port corridor pollution: social equity

Diesel particulate matter in greater Los Angeles

Needed NOx emission reductions to achieve Federal 8-hour 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

Source: Los Angeles Times, South Coast Air Quality Management District Final 2016 Air Quality Management Plan
Project Portal

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

Specifications
- Class 8 truck chassis
- 2 Mirai fuel cell stacks
- 12 kWh of batteries
- 700 bar H₂ storage

Performance
- 670 horsepower
- 1,375 ft-lb torque
- 80,000 lbs GVWR
- 200+ miles of range

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?
Thank you

COMMITTED PARTNERS FOR ELECTRIFICATION INNOVATION
Energy Observer: powered by H$_2$ + solar
Hydrogen infrastructure and fuel cell electric vehicle references

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<td><a href="http://www.nrel.gov">www.nrel.gov</a></td>
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<td>California Air Resources Board</td>
<td>ww2.arb.ca.gov/</td>
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<td>National Fuel Cell Research Center - UCI</td>
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