Northwest **Power** and **Conservation** Council

January 7, 2021

MEMORANDUM

TO: **Council Members**

FROM: **Steven Simmons**

SUBJECT: **Overview of Hydrogen**

BACKGROUND:

Presenter: Steven Simmons

Summary: This presentation is to cover a basic overview of hydrogen as an energy carrier. The term *hydrogen economy* refers to a broad energy transition to hydrogen that would touch on many facets of the economy, including dispatchable power, transportation, industry, and building heat. A piece meal build-out may also occur, where certain energy intensive applications that are not easily electrified are served by hydrogen, such as heavy-duty trucking, or high-temperature industrial processes.

Relevance: Staff has included alternative fuels – primarily renewable natural gas – in the power planning and forecasting work to date. Hydrogen as an energy carrier may be useful in the low-emission economy scenario work that will be done as part of the plan. This presentation is geared to provide a familiarity with basic terms and technologies of related to the production and use of hydrogen.

Workplan: A.4. Forecasting and Economic Analyses

851 S.W. Sixth Avenue, Suite 1100
Portland, Oregon 97204-1348
www.nwcouncil.org

Bill Edmonds
Executive Director

503-222-5161
800-452-5161
Fax: 503-820-2370

Overview of Hydrogen

Power Committee Meeting

January 12, 2021

Steven Simmons

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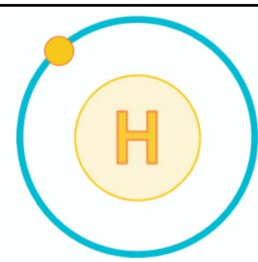
- Hitting net zero emission targets is going to take innovation
- Production of green hydrogen as an energy carrier requires consumption of renewable electricity - with a large-scale renewable buildout on the horizon there may be plenty of low-cost renewable electricity soon available
- Corporations that produce, store and use hydrogen have been raising serious capital recently – enough to kick-off large-scale projects



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- *Hydrogen Economy* – envisions a full transition to a new energy system with hydrogen at the center
- Large scale infrastructure is at least 10 years off – one key factor is how much existing infrastructure (gas pipelines, storage features, filling stations…) could be re-purposed for hydrogen
- A full green electrification of some current fossil fuel applications may be problematic or very expensive – use of an alternate clean fuel like hydrogen may provide a strategic tool

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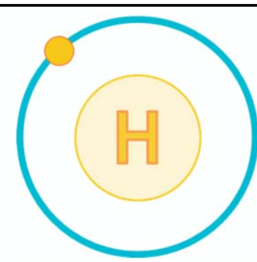
Today's Discussion



1. Properties
2. Current uses
3. Production
4. Dispatchable power
5. Storage, transport, applications
6. Vehicles

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1. Lightest and most abundant element in the universe
2. On Earth it tends to bond with other elements often forming hydrocarbons and water
3. At standard temperature and pressure is a nontoxic, colorless, odorless highly- combustible gas – and is a bit of an escape artist
4. Energy density on a per kg basis is very high – higher than petrol products. However energy density on a per volume basis is much lower than petrol. To transport, hydrogen requires compression or liquefaction
5. NASA has been using liquid hydrogen as rocket propellant since the 1950s, and developed hydrogen fuel cell technologies decades ago

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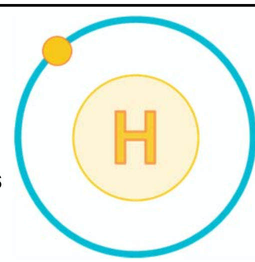
1. Hydrogen is currently used as a feedstock for many industrial applications – a big one is the synthesis of ammonia – NH_3 – which combines nitrogen with hydrogen. Also oil refining and plastics
2. Oil producers in Texas have established hydrogen systems for refining – including hydrogen production, storage in underground salt dome caverns, and dedicated hydrogen pipeline networks.
3. The hydrogen produced today in the US is fossil fuel (mostly natural gas) derived
4. Europe has been the leader to date in developing *green* hydrogen systems
   a. Companies are lining up *green* hydrogen producers from sun rich countries for import
   b. Experiments are underway to blend hydrogen into natural gas pipelines, as well as running pure hydrogen thru decommission gas pipelines
   c. The Netherlands may become a world market hub within 8 years



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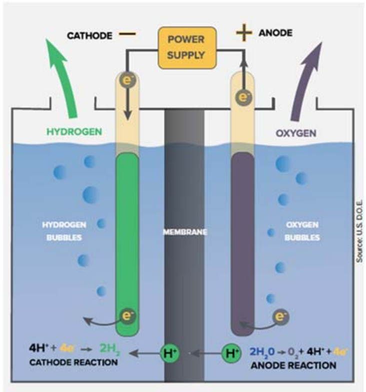

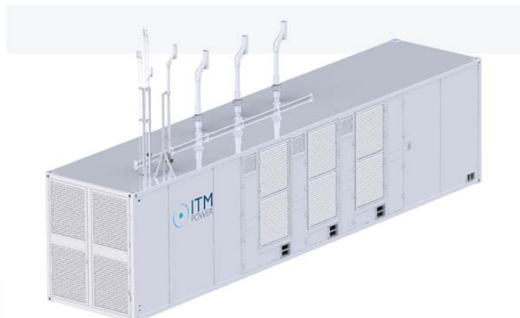

ITM PEM Electrolyzer

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The Colors of Hydrogen Production

Gray	Brown
INPUT Natural gas OUTPUT H_2 & CO_2 Steam methane reforming (SMR)	INPUT Coal gasification OUTPUT H_2 & CO_2
Blue	**Green**
INPUT Natural gas OUTPUT H_2 SMR with carbon capture & storage	INPUT Renewable Electricity OUTPUT H_2 & O_2 Electrolysis

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1. Virtually all of the hydrogen produced for industry today is *Gray* via steam methane reforming – natural gas (CH_4) reacting with high temperature steam. The process emits CO_2.

2. *Green* hydrogen is produced via Electrolysis - electricity is used to split water into hydrogen and oxygen

3. Electrolyzers can be scaled from small appliance sized to large-scale centralized systems, technologies include

   a. AE – alkaline electrolysis (most common now – 63 to 71% efficiency)
   b. PEM – proton (or polymer) exchange membrane (early market)
   c. Solid Oxide (in R&D)

4. Electricity consumption for electrolysis – 45 to 78 kWh per kg of hydrogen

5. Water consumption for electrolysis – 9 liters H_2O per kg hydrogen

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One way to think about hydrogen is in terms of how natural gas is stored, moved around and put to use today

From the point of production:

1. Pressurize the gas and store underground

2. Pressurize and move through pipelines

3. Liquify the gas and store above ground, and transport via trucks

4. Burn in Combustion Turbines (CT) to generate electricity for the grid

5. Use in fuel cell technologies to generate distributed electricity

6. Use as a feedstock for industrial processes

7. Burn as a fuel for high temperature industrial processes

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1. A hydrogen burning Combustion Turbine (CT) combined with storage could provide dispatchable generation for the grid and long-duration storage
2. Assuming the hydrogen is *green* – this would be relatively emission free power (depending on how the hydrogen was compressed or liquified)
3. Opportunity to purchase inexpensive curtailed solar and/or wind electricity, produce and store hydrogen gas, burn in a CT and sell back to the grid
4. Mitsubishi Power (MHPS) has a number of large-scale projects rolling to produce or use *green* hydrogen, store underground and burn in large CT power plants. Initially the projects would use a hydrogen-natural gas blend with a transition to 100% hydrogen over time
    - ACES/Delta Project in Utah
    - Orange County Power Station in Texas
    - Magnum Power Plant in the Netherlands

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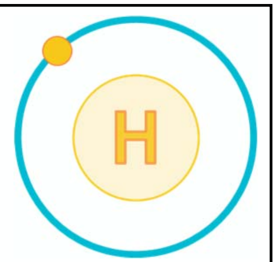
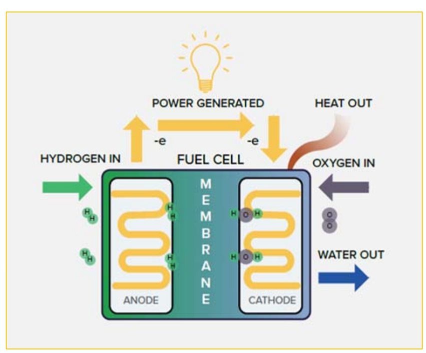
There are concerns over combusting hydrogen or hydrogen/natural gas blends in combustion turbines for electricity generation

1. Combusting hydrogen generates high levels of NOx – pollutant formed from burning fuel at high temperatures – which may require a NOx control technology development
2. Concerns over extending the dependency on fossil natural gas as a blend



A **Hydrogen Fuel Cell** can produce electricity from hydrogen without combustion - avoiding NOx and natural gas

Hydrogen + oxygen producing electricity with heat and water output



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Storage

- Underground bulk storage – salt caverns, depleted oil wells
- Pressurize and store as a compressed gas
- Liquify and store and transport via truck
  - requires temps of -253 deg C
  - energy required around 12 kWh/kg
- Form ammonia (NH_3) liquify to store and transport

Transport

- Trucking liquified H_2 or NH_3
- Truck compressed gas tanks
- Build-out a dedicated hydrogen gas pipeline network
- Blend into existing long-haul and distribution natural gas pipelines
  - Huge cost differential between H_2 and CH_4 – may lose value of the *green* fuel
  - H_2 can react with steel pipe resulting in pipeline cracking issues

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Industrial

- Could directly replace fossil fuel as feedstock for oil refineries, chemical plants
- Could be used as a heating fuel where electrification may not be adequate for high temperature processes in steel, cement and other manufacturing

Transportation

- Run fuel cell light duty vehicles – more similar to the current vehicle transportation system. Long range cars, rapid re-fueling using filling stations along roadways
- Run long-haul trucking and bus lines using the similar system
- Heavy machinery
- Marine
- Aviation

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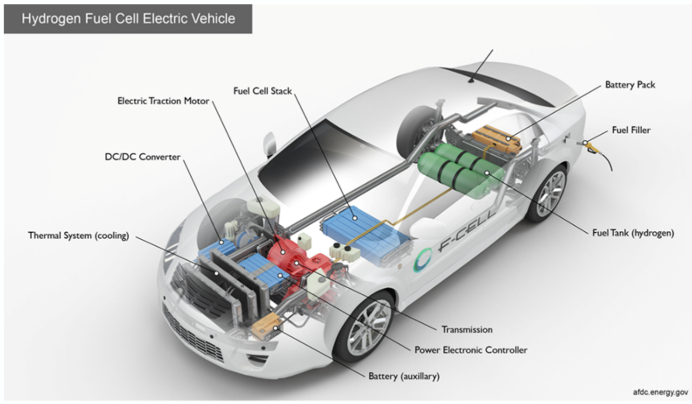

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Hydrogen Fuel Cell Vehicle - HFCV

- Electric vehicle – the electricity that runs the vehicle is produced from an on-board fuel cell – requires hydrogen and oxygen, releases water and heat with zero tailpipe emissions.
- Similar to the existing gasoline-based model – could have filling stations supplied by liquid hydrogen supply trucks all along the road system
- Can fill a tank in under 10 minutes, with a range of 250 to 400 miles
- There is a lack of hydrogen filling stations, and fuel is very expensive
- The fueling supply chain requires several steps – water source & electrolysis, high pressurization or liquification of the gas to transport, trucking to station. Each step requires energy expenditure.

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Light Duty Vehicles	**Toyota Mirai** HFCV	**Chevrolet Bolt** BEV	**Mazda 3** Gasoline
Range-miles	402	259	396
MPGe	67	120	30
Mileage	66.5 m/kg	3.5 m/kWh	30 m/gal
Fuel $ Rate	14 $/kg H_2	0.084 $/kWh	2.55 $/gal
$/mile	0.211	0.024	0.085
kWh/mile	0.677*	0.286	

* Electrolysis only

Heavy Duty Trucks – Class 8 – may be a good fit for hydrogen fuel cell vehicles. The fuel cell technology provides long haul range with a curb weight half of that of a battery electric truck – therefore could deliver a higher payload

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