Hydrogen Webinar #3
Hydrogen is not a Commodity Like Petroleum
Understanding the New Energy Paradigm

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Webinar Panelists

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Problem Statement

• It’s now clear that we need to completely stop burning fossil fuels in order to halt atmospheric warming caused by CO$_2$ and other Green House Gases

• Electricity from wind & solar is sufficient to supply all of the world’s energy needs *indefinitely*, however . . .
  − Power from wind & solar is intermittent requiring energy *storage*
  − The electric **grid is not available** in some prime areas of solar and wind production or areas of high energy use or across oceans
  − The transportation sector requires a **large quantity** of **portable** energy that can be **replenished fast**
  − Electricity **not suitable** for some industrial processes (steel, concrete & glass manufacturing)

*We Need a Form of Renewable Energy that is Portable and Storable*
The Change in Energy Paradigms

The Energy Triad – New Paradigm
• Solar & wind are the energy source
• Electricity is only a carrier but can be used directly
• Hydrogen and ammonia serve as both carriers and storage
• Each can be easily transformed to the other

Fossil fuels – Old Paradigm
• The source, carrier and storage of energy
# Energy Triad – Pros & Cons

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<th>Pro</th>
<th>Con</th>
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| **Electricity** | No conversion losses. Created and used in native form | • Needs transmission lines.  
• Energy generated must exactly match energy used, second-by-second |
| **Hydrogen H₂** | • Excellent fuel for transportation  
• Ready for use in Fuel Cell EV’s  
• Generated at point-of-use from electricity and water | • Transport by truck inefficient because it’s so voluminous  
• Transport by pipe requires special metals  
• Storage and transport require high compression |
| **Ammonia NH₃** | • 6 times as much hydrogen-per-volume as 5,000 PSI hydrogen gas (350 bar)  
• Worldwide distribution system in-place and experience with handling  
• Excellent alternative to electricity for transporting energy when transmission lines not available  
• Liquid at ambient temperature and 150 PSI  
• Can be used directly as a fuel in existing engines  
• Intrinsic odor makes leak detection readily apparent | • Additional conversion losses going back to hydrogen or electricity  
• Inhalation hazard at high concentrations |
Hardware to Transform Hydrogen and Ammonia

**Hydrogen-Electricity**

- **Electrolyzer**
  - Renewable Electricity
  - Water Vapor (Exhaust)
  - Oxygen (Exhaust)
  - Hydrogen

- **Fuel Cell**
  - Hydrogen
  - Oxygen (From Air)
  - Electricity

**Hydrogen Fuel Station**

**Electricity-Ammonia-Hydrogen**

- **Electrolyzer**
  - Renewable Electricity
  - Water Vapor (Exhaust)
  - Oxygen (Exhaust)
  - Hydrogen

- **Ammonia Reactor**
  - Hydrogen
  - Oxygen (Exhaust)
  - Nitrogen (From Air)

- **Ammonia “Cracker”**
  - Nitrogen (Exhaust)
  - Ammonia
  - Electricity

- **Ammonia Fuel Cell**
  - Nitrogen (Exhaust)
  - Water Vapor (Exhaust)
Modular carbon-free fuel production & use

29 October 2020

Joe Beach, President
“Green” ammonia fuel
- Air
- Water
- Clean electricity

CO₂-free heat & power
- Replace natural gas
- Provide hydrogen
- No CO₂
- Manageable NOx

Tech for ammonia production & use
Production: modular, flexible, renewable

- Ammonia Synthesis: Proprietary
- Ammonia Storage: Commercial
- Nitrogen Generation: Commercial
- Ammonia Liquefaction: Commercial
- Ammonia Storage: Commercial
- Hydrogen Generation: Commercial
- Circulation Pump: Commercial
- Ammonia Removal: Proprietary
- Air Compressor: Commercial
Mass produced modular: cheaper & faster

- Mass production reduces capex
- Fast, repeatable deployments
- Easy bidding process
- Quicker building & commissioning
- Add units to match market growth
Use: NH₃ cracking interest growing fast

NH₃ (ammonia) $\xrightarrow{\text{cracking}}$ N₂ (nitrogen) + H₂ (hydrogen)

Two primary interests:

Natural gas replacement  
Hydrogen delivery
Pure + cracked NH$_3$ burns like natural gas

- Only need to crack 30% of ammonia (saves energy)
- 70/30 mix replaces natural gas, but has no CO$_2$
- Allows use of turbines, engines, industrial burners
Green Ammonia: reducing the delivered cost of hydrogen for zero carbon transport, power and energy storage

Eneus Energy – Power to ammonia & hydrogen
Colorado Hydrogen Network, 29 October, 2020
Delivering green ammonia and reducing the cost of hydrogen for zero carbon transport, power and energy storage

Who are we?

Eneus Energy integrates existing, proven industrial technologies to produce ‘green’ ammonia (N.H.) using only water, air and renewable energy. This reduces the carbon footprint of green ammonia (and its constituent gases) to zero.
Traditional vs Green Ammonia

**Natural Gas**
- Ammonia Plant (stage 1)
  - Hydrogen ($H_2$)
  - Nitrogen ($N_2$)
- Ammonia Plant (Haber-Bosch process)
  - Ammonia ($NH_3$)

- $CO_2$ (1% of global GHG emissions)

- Risk of carbon tax

**Water**
- Electrolyser
  - Hydrogen ($H_2$)
- Air Separation Unit
  - Nitrogen ($N_2$)
- Ammonia Plant (Haber-Bosch process)
  - Green Ammonia ($NH_3$)

- Green Electricity

- Volatile price

- Stable long-term PPAs

- Zero GHG emissions

- Transport & Cracker
  - Green Hydrogen ($H_2$)

- To Market

- Green Electricity

- Risk of carbon tax

- 1% of global GHG emissions
Density, Economics

Hydrogen Density per m$^3$

- Hydrogen Gas (350 bar)
- Hydrogen Gas (700 bar)
- Liquid Hydrogen
- Liquid Organic HydroCarbon
- Liquid Ammonia
Energy storage capacity: a question of scale?

World’s largest battery
Hornsdale Power Reserve
129 MWh
0.1329 GWh
1

World’s largest liquid hydrogen storage vessel, Cape Canaveral
270 tonnes at -253 °C
8,999 MWh
9 GWh
x70

Large liquid ammonia store
60,000 tonnes at -33 °C
312,000 MWh
312 GWh
x2418

Embodied Energy Storage Capacities
Storage and Transportation of NH₃

Anhydrous ammonia is the 4th largest traded commodity globally. Fossil based ammonia is predominantly produced by stripping hydrogen from natural gas by steam methane reforming (SMR). The global ammonia sector has a robust storage and transportation infrastructure (truck, rail, pipeline, barges and ships), and an established HSE regime. Ammonia is shipped globally using Liquified Petroleum Gas (LPG) carriers.
International Shipping: Targets & Options

Shipping is one of the largest greenhouse gas (GHG) emitting sectors of the global economy, responsible for around 1 Gt of CO2eq every year. If shipping were a country, it would be the 6th biggest emitter.

The annual global sales of shipping fuel (bunker fuel) is currently around 300 million tonnes, and the global bunker fuel market was valued at $137.21 billion in 2017 and is expected to reach $273.05 billion by 2025.

To address this GHG emissions, the International Maritime Organisation (IMO) has accepted a legally binding target to reduce overall carbon intensity of the cargo transported per kilometer by at least 40% by 2030, and 70% by 2050 with a reduction in the total annual GHG emissions by at least 50% by 2050 (compared to 2008).

Within their decarbonization strategy6 the IMO concludes that battery-powered ships offer the most efficient and immediate solution to reducing shipping’s GHG emissions for shorter distances. For longer journeys, liquid hydrogen and liquid ammonia made with zero-emission electricity will be needed.

**Options - Electrofuels**

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<th>Carbon free (non-hydrocarbon)</th>
<th>Carbon containing (hydrocarbon)</th>
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<tr>
<td>Liquid hydrogen</td>
<td>Synthetic (electro) methane</td>
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<tr>
<td>Liquid ammonia</td>
<td>Synthetic (electro) diesel</td>
</tr>
<tr>
<td>Batteries (RES)</td>
<td>Batteries (grid)</td>
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