

# Metal-water reactors for on-demand green hydrogen

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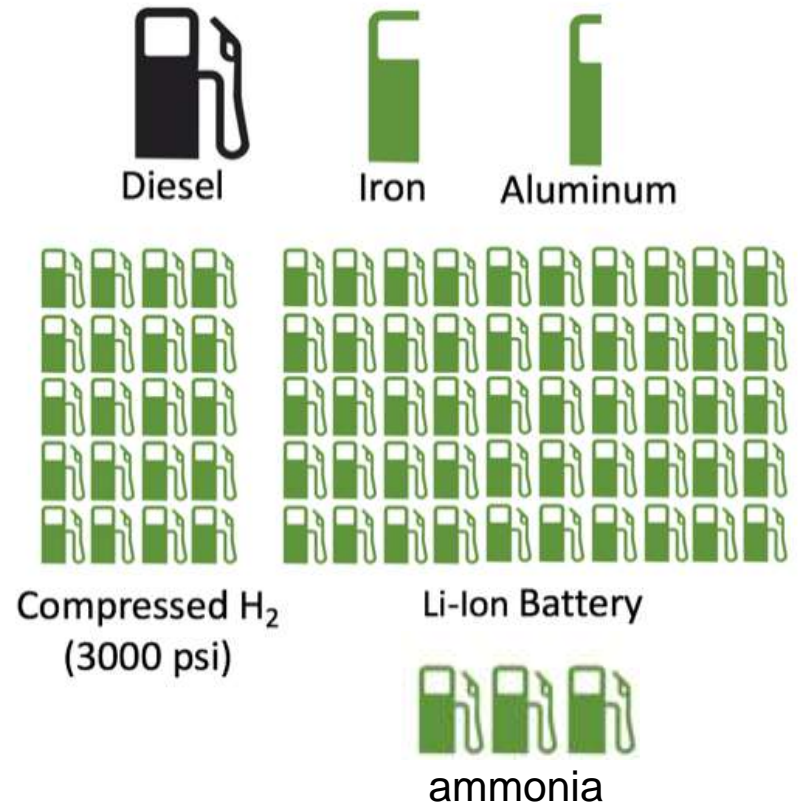
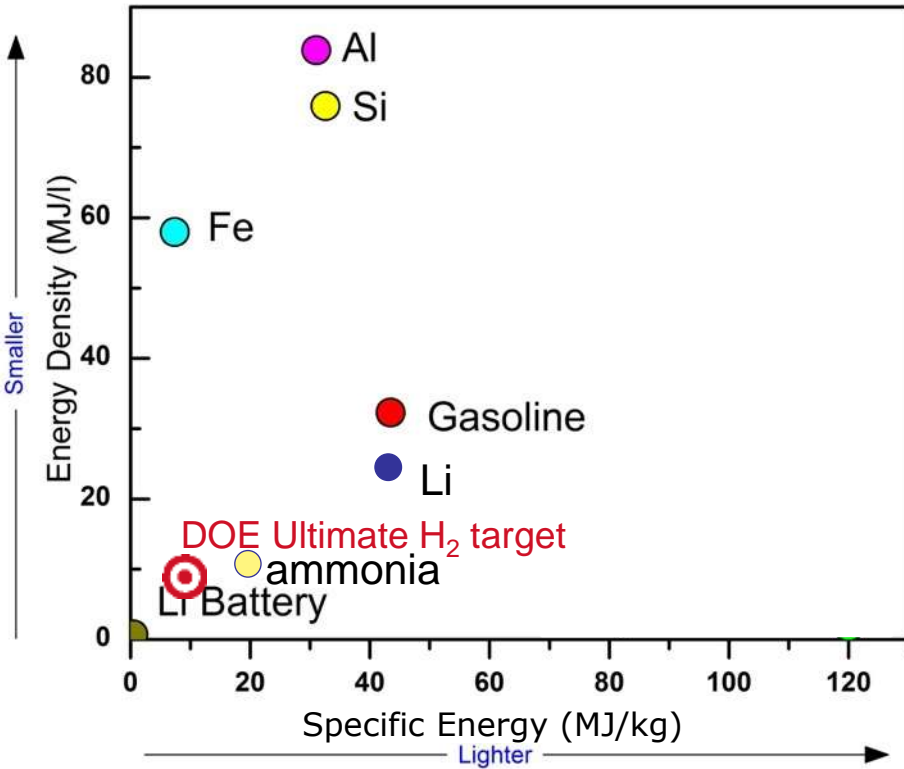
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**Director, Alternative Fuels Laboratory (afl)**

Professor, Mechanical Engineering, McGill University

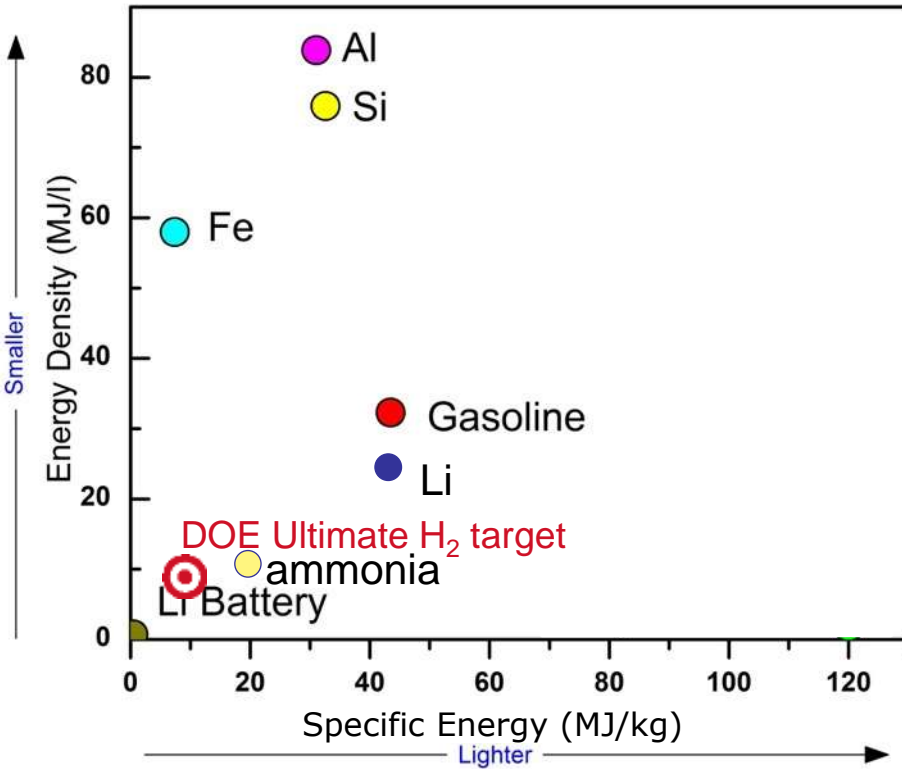
Clean hydrogen: virtual matchmaking between  
Canada, Switzerland and Wallonia

# Metals are energy-dense, carbon-free, Power-to-X fuels



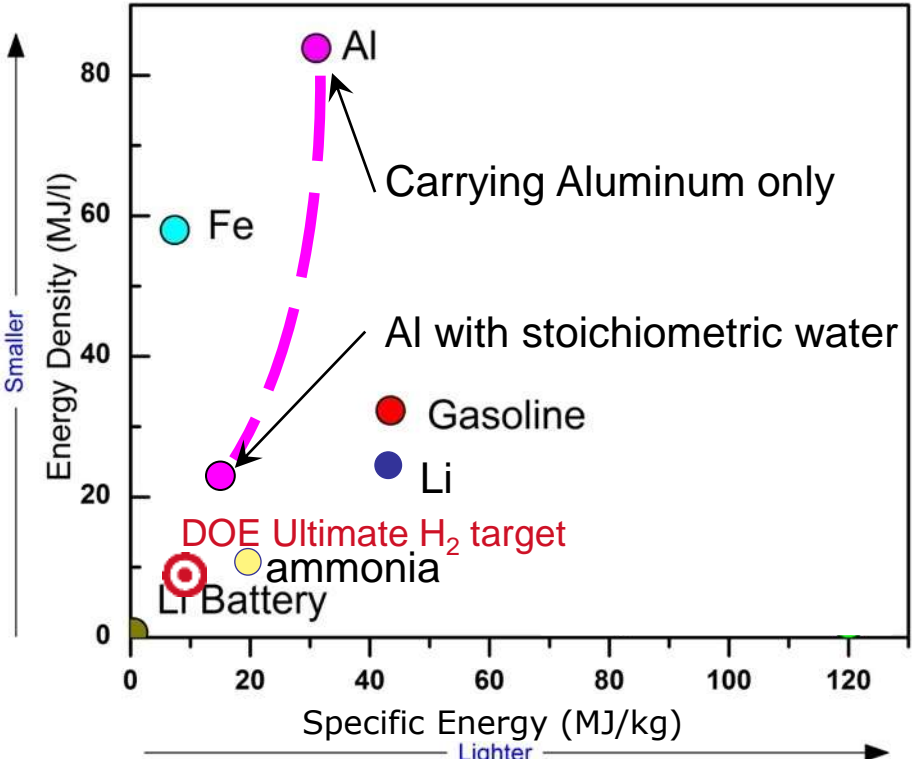
- Metal energy densities surpass fossil fuels

# Metal fuels can burn with air



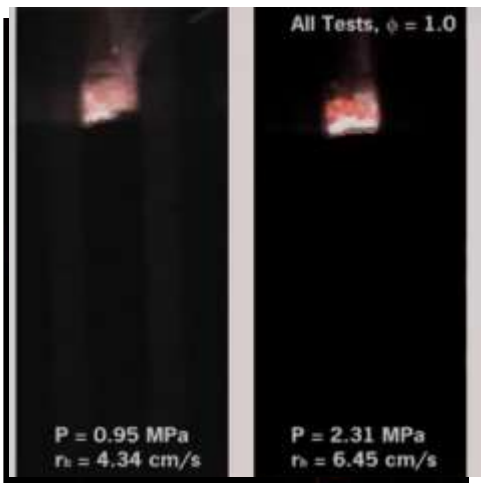
- Metal energy densities surpass fossil fuels
- Metal fuels burn in air producing heat

# Metal fuels can burn with water to produce hot hydrogen



- Metal energy densities surpass fossil fuels
- Metal fuels burn in air producing heat
- Metal fuels burn in water producing hot H<sub>2</sub>
- Heat (and H<sub>2</sub>) can be converted to power
- Combustion product is solid metal oxide
  - no CO<sub>2</sub>, CO, or UHC emissions

Aluminum-water propellant

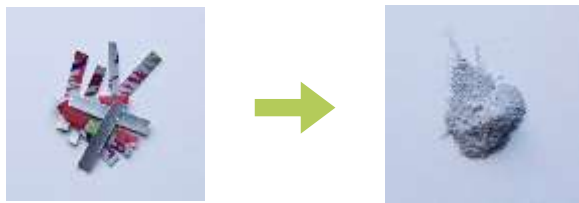
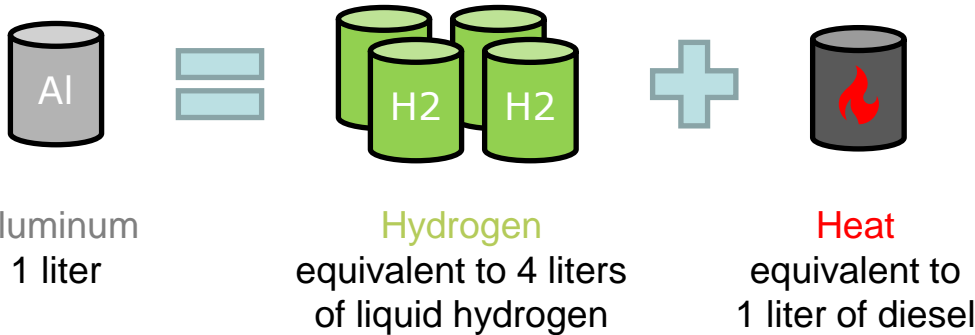


ALICE rocket (aluminum-ice)

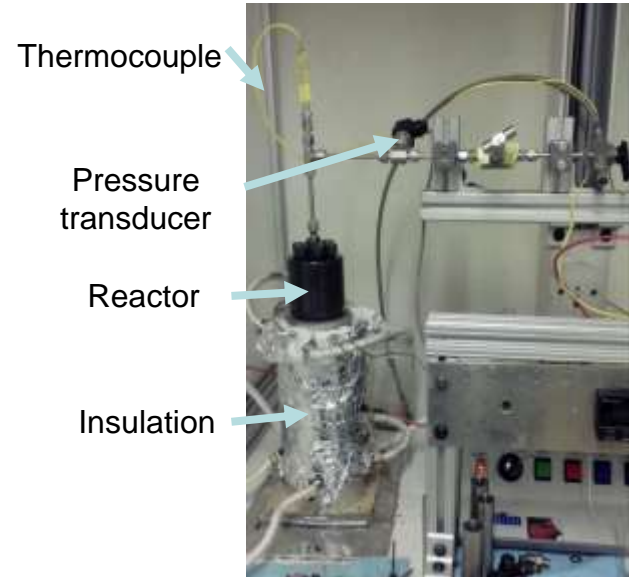


# Aluminum-water reactions enable on-demand hydrogen

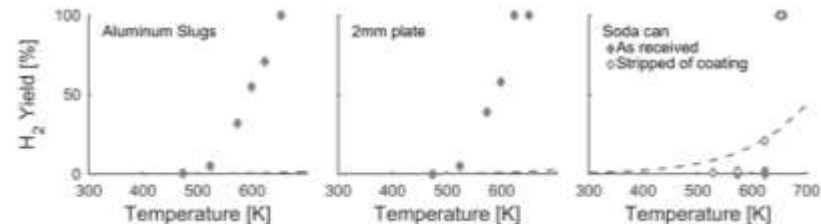
- Aluminum is very **energy dense**:
  - 2/3 the specific energy of diesel
  - Twice the energy density of diesel
- Aluminum reacts with water in our supercritical water reactor without a catalyst to produce **hydrogen** and **heat**



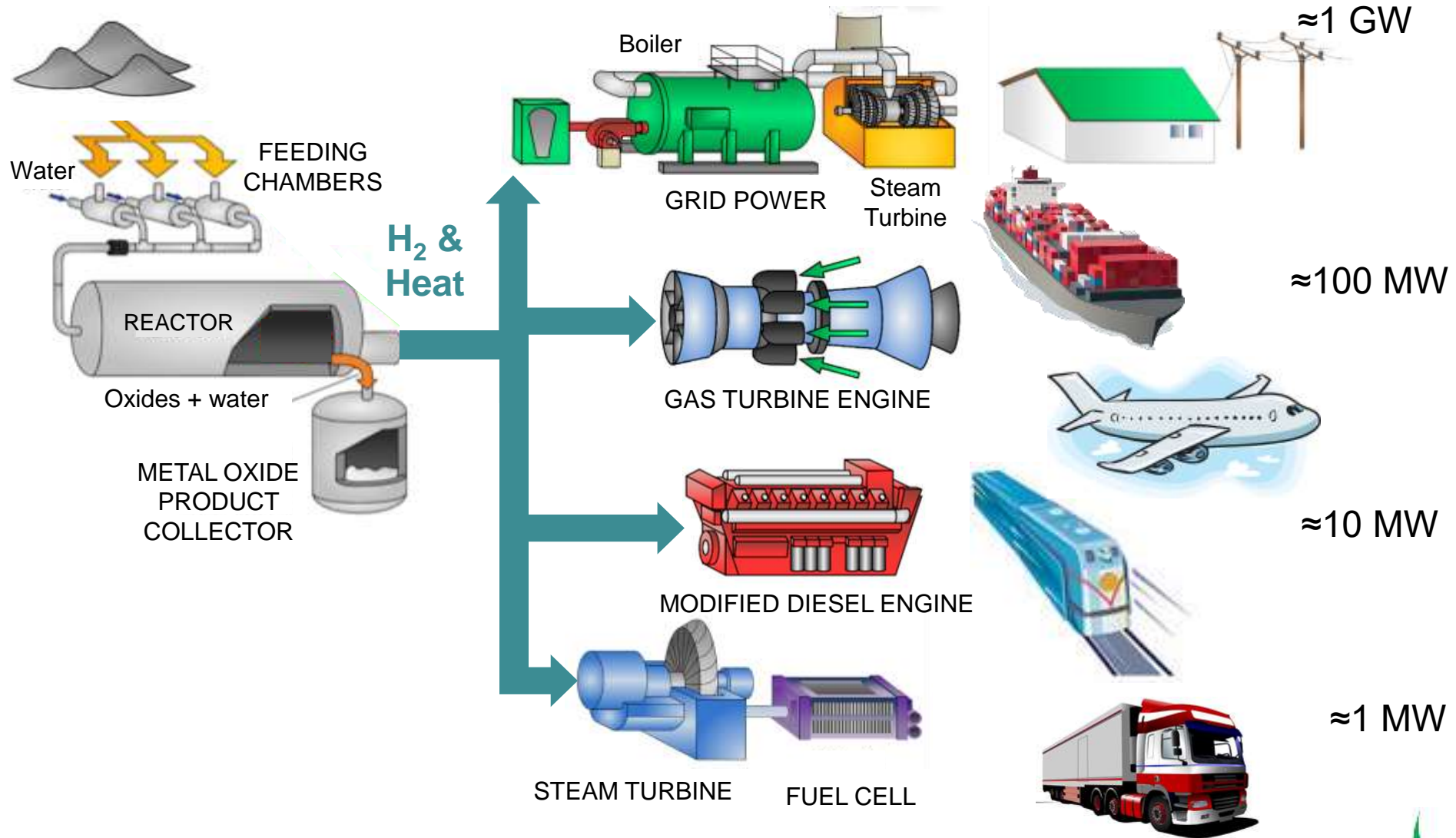
Also works with aluminum alloys, scrap aluminum, tap water, and seawater with no change in reaction yield!



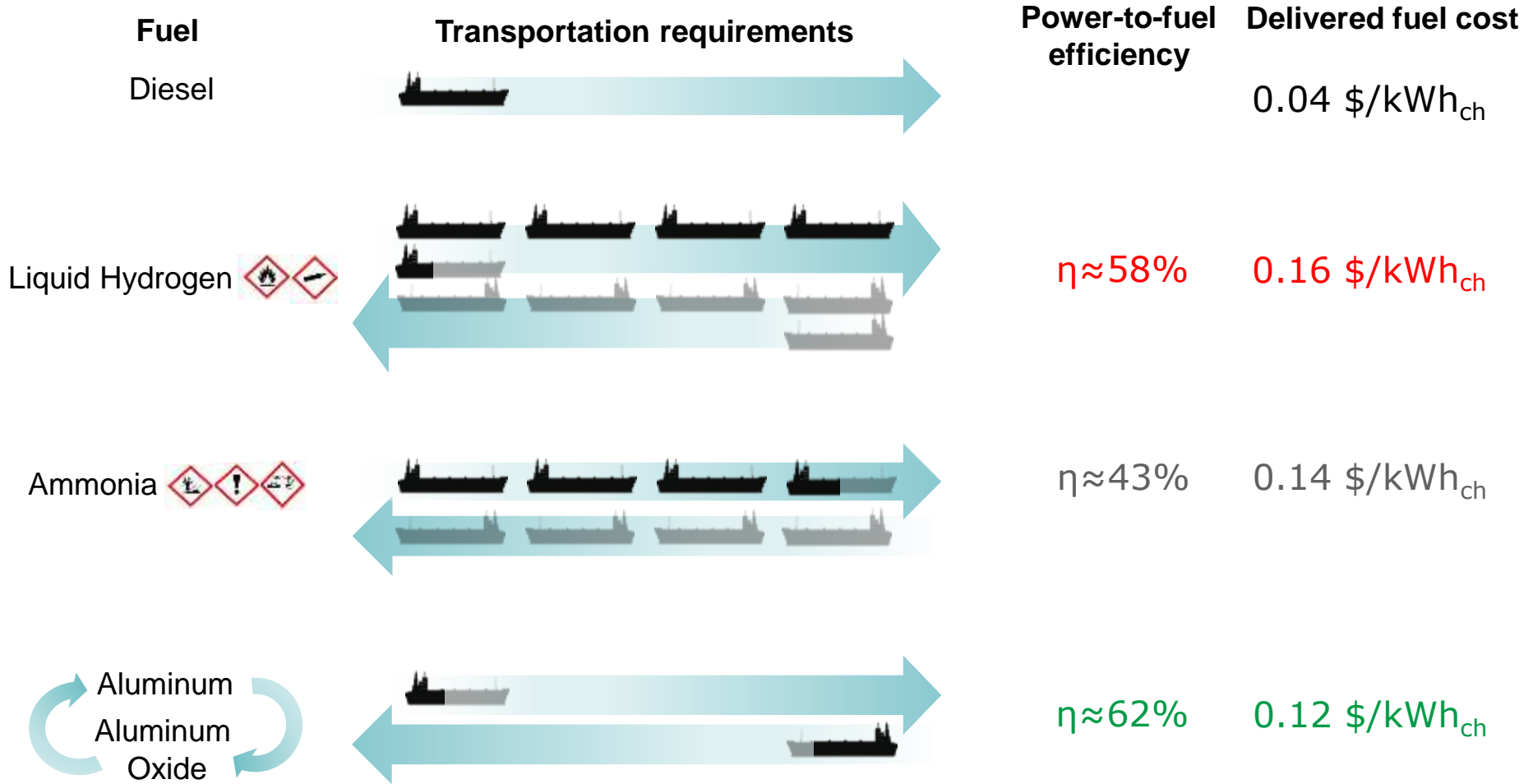
Supercritical aluminum-water reactor at McGill University



# Metal-water reactors produce hydrogen for many uses



# Metal fuels are the cheapest Power-to-X option



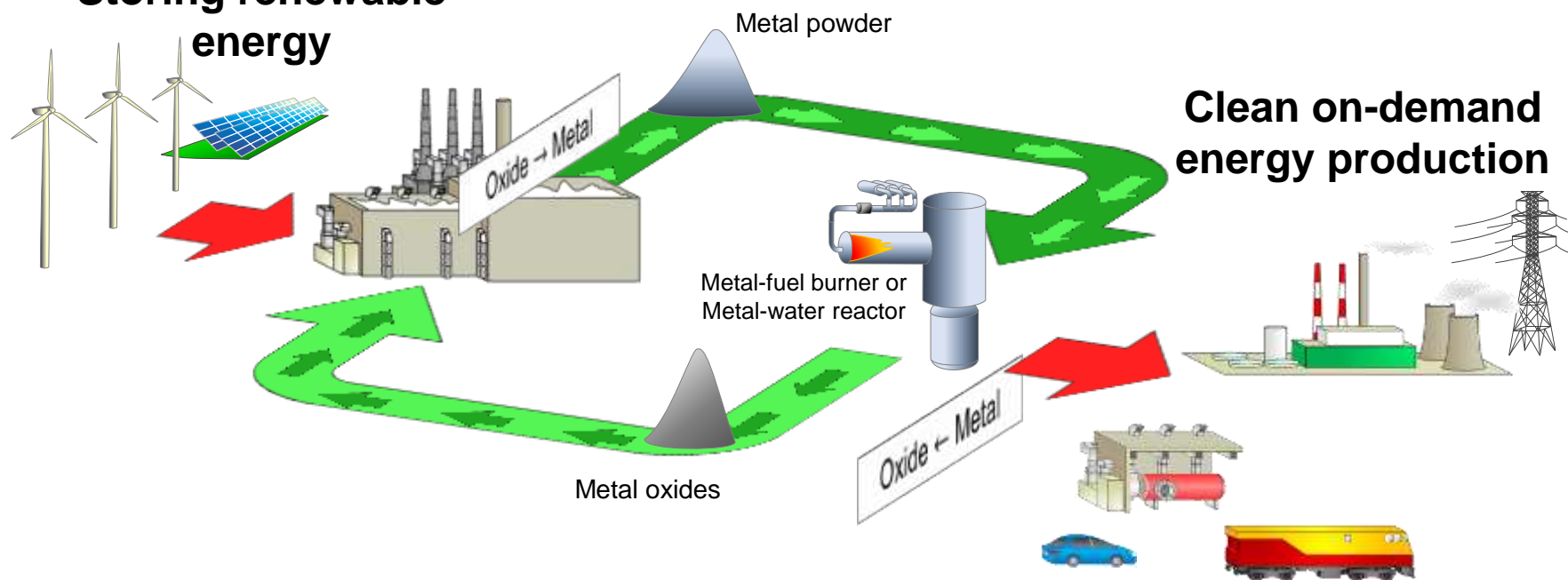
Costs based on shipping fuels  
2400km and 0.026\$/kWh<sub>el</sub>





# Metals are efficient, cheap and safe sustainable fuels

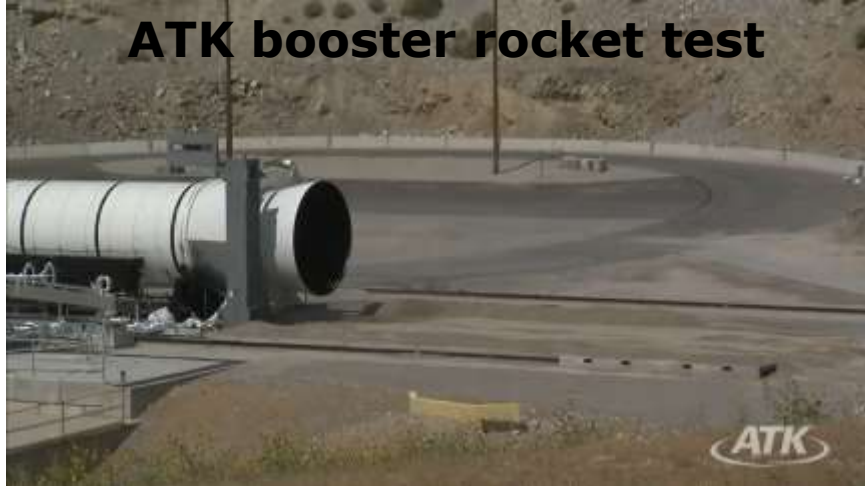
## Storing renewable energy



- Metals promising clean recyclable fuels and sustainable energy commodities
  - Solid combustion products simplify collection and recycling to close the loop
  - Recycling can be done with zero carbon emissions through metal electrolysis
- Metal fuels can be directly burned with air to produce heat (Dry Cycle)
  - External-combustion engines enable high energy and power densities
- Active metal fuels react with water producing hydrogen in situ (Wet Cycle)
  - Hot hydrogen, diluted in steam, an ideal fuel for gas-turbine or diesel engines



# Metal fuels: cleantech powered by rocket science



<http://y2u.be/hoUqx-nA99M>



- European Space Agency video about metal fuels:
  - [https://www.esa.int/ESA\\_Multimedia/Videos/2021/01/Metal\\_Fuels\\_We\\_research.You\\_benefit](https://www.esa.int/ESA_Multimedia/Videos/2021/01/Metal_Fuels_We_research.You_benefit)
- McGill video and article on metal fuels:
  - [https://www.youtube.com/watch?v=tNITNdFN3-0&feature=emb\\_logo](https://www.youtube.com/watch?v=tNITNdFN3-0&feature=emb_logo)
  - <https://reporter.mcgill.ca/could-metal-particles-be-a-clean-fuel-of-the-future/>
- Review paper on metals as recyclable fuels:
  - Recyclable metal fuels for clean and compact zero-carbon power by J.M Bergthorson (2018) *Progress in Energy & Combustion Science* (open access)
  - <https://www.sciencedirect.com/science/article/pii/S0360128518300327>
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