Fuel Cell for Industrial Mining Trucks

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Introduction

What are mining trucks and their uses in industry?

- Also known as haul trucks
- These are off-highway, rigid dump trucks specifically engineered for use in high-production mining & heavy-duty construction environments
- Haul trucks are also used for transporting construction equipment between job sites

What is being used in mining trucks now?

- The Komatsu 930E is the best selling ultra class haul truck in the world (as of September 2016
- Komatsu has sold 1,900 units of 930E
- The 930E was the first haul truck to employ 2 AC electric traction motors & its powertrain was more efficient than a comparable DC powertrain
- The current model, the 930E-5 offer a payload capacity of up to 320 short tons (290 t)

Introduction (cont.)

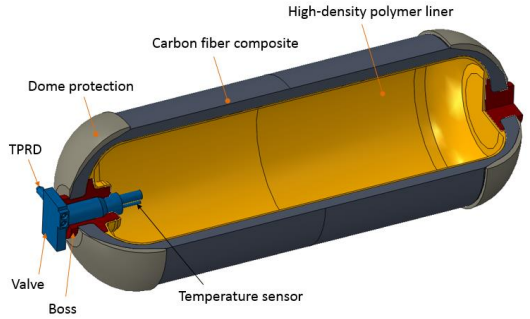
Purpose of fuel cell over conventional method?

- The industry standards are an electric/diesel powertrain which is cleaner than just diesel, however it can still be improved (HFCs have no emissions)
- On top of that, HFCs are more efficient than internal combustion engines (despite a much lower volumetric energy density) while still enjoying the benefits of EVs such as instantaneous acceleration

Fuel and Oxidizer

- Proton-Exchange Membrane Fuel Cell
  - Fuel: Hydrogen gas
    - Compressed gas stored in high pressure tank
  - Oxidizer: Oxygen gas (Air)
    - High availability from the air
    - No purchase cost
    - Possible air intake issues

- Safety Considerations
  - Hydrogen Gas:
    - Broad flammability range: 4-74% concentration in air
    - Low ignition energy: ~1/7 ignition energy of natural gas
  - Pressurized Hydrogen Storage Tank

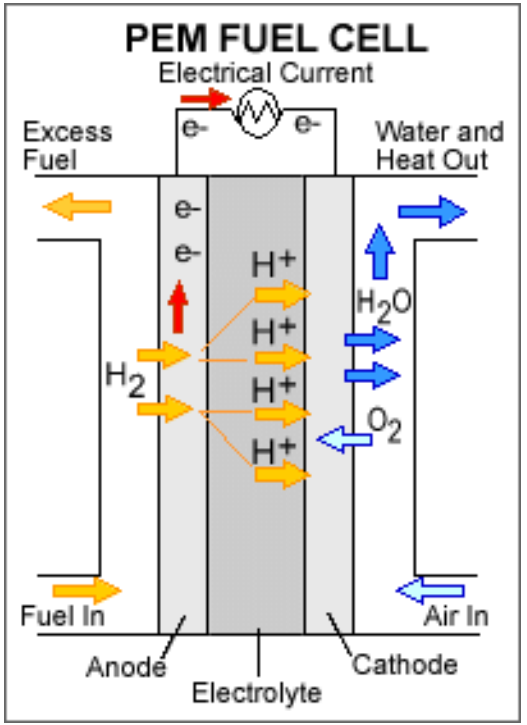


TPRD – Thermally Activated Pressure Relief Device

Credit: Process Modeling Group, Nuclear Engineering Division. Argonne National Laboratory (ANL)

Electrochemical Reaction

- Anode: $2H_2 \rightarrow 4H^+ + 4e^-$
- Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
- Overall: $2H_2 + O_2 \rightarrow 2H_2O$
- $E_0 = 1.23$ V



Fuel Cell Stores: Hydrogen Air/Oxygen MEAs

PEMFC Design

Diesel Electric Generator (current power source) specs: 3,100 HP, 3121 kW, 2000 gal Diesel capacity

Assuming average gen-set size of 70 m^3 for model, combined with around 8 m^3 of fuel

Total mass of system (estimated) = 29,000 kg

Fuel Cell used: EH-81 100kW - stack of 30 modules

Mass = 78 kg each, or 2,340 kg total

Volume = 0.03 m^3 each, or around 1 cubic meter total

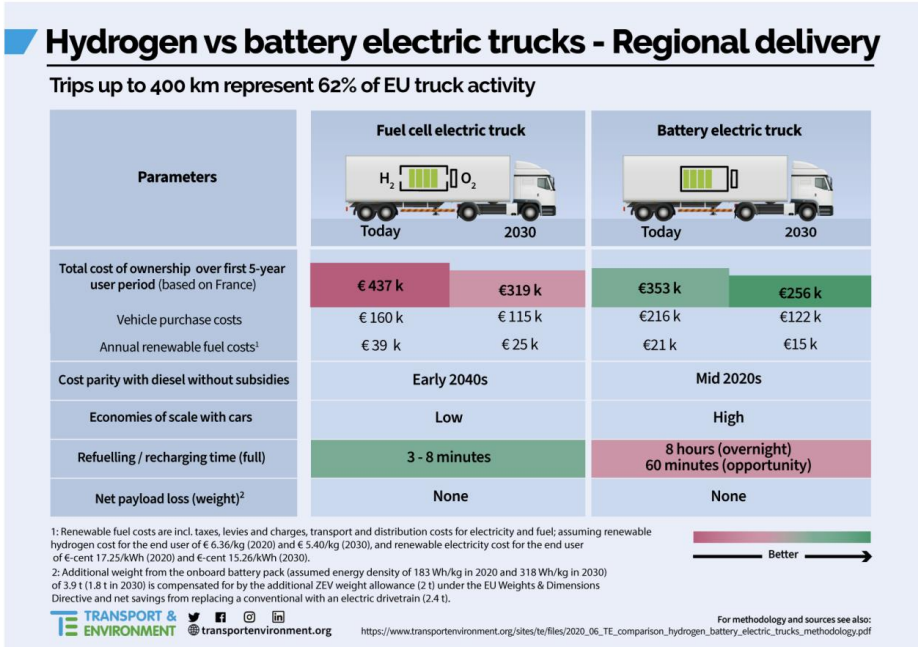
Volume of liquified H2 for 4 hr runtime = 9.6 m^3

Total mass of system = 3,000 kg

Assumptions: 66 MJ/kg useful energy, LHV = 120 MJ/kg, 55% efficiency of operation

Expected Benefits

- Smaller carbon footprint
- Decreased noise pollution
- Integrating hydraulic regeneration can save energy
- Long operating hours and fast refueling
- Hydrogen can be stored in a tank as opposed to a battery



Hydrogen vs battery electric trucks - Regional delivery

Trips up to 400 km represent 62% of EU truck activity

Parameters	Fuel cell electric truck		Battery electric truck	
	Today	2030	Today	2030
Total cost of ownership over first 5-year user period (based on France)	€ 437 k	€319 k	€353 k	€256 k
Vehicle purchase costs	€ 160 k	€ 115 k	€216 k	€122 k
Annual renewable fuel costs[1]	€ 39 k	€ 25 k	€21 k	€15 k
Cost parity with diesel without subsidies	Early 2040s		Mid 2020s	
Economies of scale with cars	Low		High	
Refuelling / recharging time (full)	3 - 8 minutes		8 hours (overnight) 60 minutes (opportunity)	
Net payload loss (weight)[2]	None		None	

1: Renewable fuel costs are incl. taxes, levies and charges, transport and distribution costs for electricity and fuel; assuming renewable hydrogen cost for the end user of € 6.36/kg (2020) and € 5.40/kg (2030), and renewable electricity cost for the end user of €-cent 17.25/kWh (2020) and €-cent 15.26/kWh (2030).

2: Additional weight from the onboard battery pack (assumed energy density of 183 Wh/kg in 2020 and 318 Wh/kg in 2030) of 3.9 t (1.8 t in 2030) is compensated for by the additional ZEV weight allowance (2 t) under the EU Weights & Dimensions Directive and net savings from replacing a conventional with an electric drivetrain (2.4 t).

Better

TRANSPORT & ENVIRONMENT transportenvironment.org

For methodology and sources see also: https://www.transportenvironment.org/sites/te/files/2020_06_TE_comparison_hydrogen_battery_electric_trucks_methodology.pdf

Disadvantages of the design

- Lack of fueling infrastructure
- Safety: pressurized gas could explode in a collision
- Price of Catalyst
- Maintenance intensive
- Management of pollutants

Cost Analysis

- Current price of using a diesel source is over half a million dollars
- Extrapolating data for the fuel cell design, it should cost around 200,000 more
  - Large quantity of fuel cells
  - Catalyst
- Need to account for Upkeep and Maintenance costs

Characteristic Features

PEMFC compared to: Battery

+ Higher volumetric and gravimetric energy density
+ Faster fueling
+ Potentially better temperature range (60°C → up to 200 °C)

- Safety / robustness concerns
- High fuel costs, lacking infrastructure

Characteristic Features

PEMFC compared to: Diesel generator (C175-16)

+ Higher volumetric and gravimetric energy density
+ No moving parts
+ Better efficiency (30% → 60%)
+ Potentially better temperature range (50°C → up to 200 °C)
+ Lower emissions (zero)
+ Cold starting

- Safety / robustness concerns
- High fuel costs, lacking infrastructure

Questions?

Thank you!

References

https://www.fuelcellstore.com/fuel-cell-components/membrane-electrode-assembly/hydrogen-air-oxygen-fuel-cell-mea

https://www.nasa.gov/pdf/513855main_ASK_41s_explosive.pdf

https://www.energy.gov/eere/fuelcells/physical-hydrogen-storage

https://www.cat.com/en_US/products/new/power-systems/electric-power/diesel-generator-sets/1000028916.html

https://www.cat.com/en_US/products/new/equipment/off-highway-trucks/mining-trucks/15970073.html

https://hyfindr.com/marketplace/components/fuel-cell-stacks/pem-stacks/fuel-cell-stack-eh-81-100-kw/

Haul truck - Wikipedia

Komatsu 930E - Wikipedia

https://techxplore.com/news/2022-01-fuel-cells-temperatures-200c.html