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)
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
Electrochemical Reaction

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


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

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


Haul truck - Wikipedia

Komatsu 930E - Wikipedia