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Power and Energy Technologies for a Future Low Carbon Military

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Ministry
of Defence

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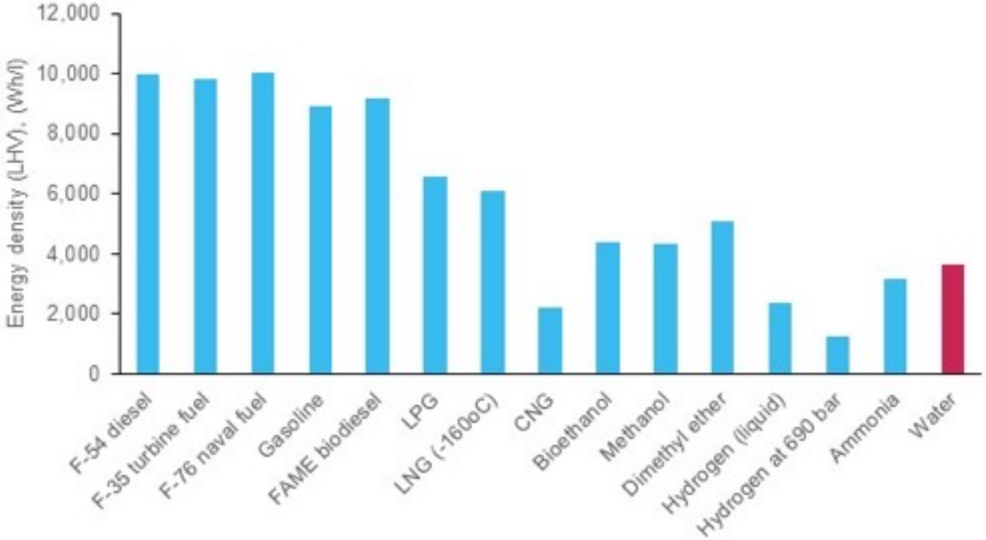
Fuels and Energy Carriers

- Liquid hydrocarbons underpin Defence capability for good reason
- No competing alternatives in terms of energy density
- Options include a sustainable like for like replacement fuel
- Also need to consider the efficiency of the power systems that use the fuels

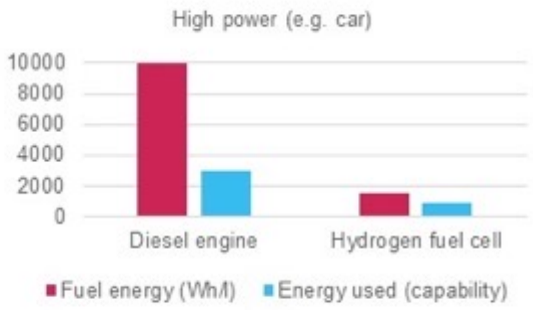


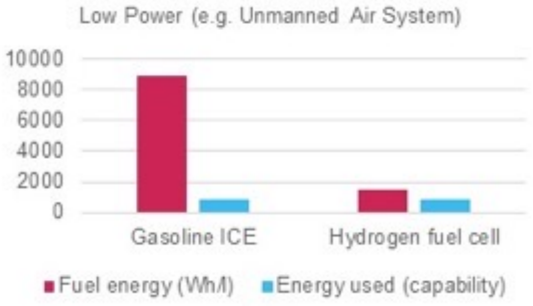
Energy density of Defence fuels and alternative energy carriers

Note: the value for water relates to the amount of hydrogen contained within it (assuming there is energy to extract this)

Energy Conversion Efficiency

- Capability depends on the energy content of the fuel and the efficiency of its conversion
- Engines, turbines etc.
  - Reasonable efficiency - coupled to current fuels they define current military capability
  - Efficiency decreases rapidly at the < kW scale due to scaling laws
- Fuel cells
  - Higher efficiency than engines and scale down well in terms of efficiency
- Hydrogen fuel cells
  - Despite efficiency hydrogen fuel cell systems provide lower capability than with current fuels and engines due to low energy density of hydrogen
  - However, the higher efficiency at low power levels can lead to a net gain in capability
    - Host or portable power and unmanned system applications
- Alternative fuel cells
  - Options that use high energy fuels, potentially Defence fuels





Fuels cells with high energy fuels

Direct Methanol Fuel Cells (DMFCs). Feeds methanol to the fuel cell directly

- Methanol: 4,995 Wh/l
- Efficiency: > 20%
- Power range: 25 – 500 W

Applications: Portable power, Auxiliary Power Units (APUs)

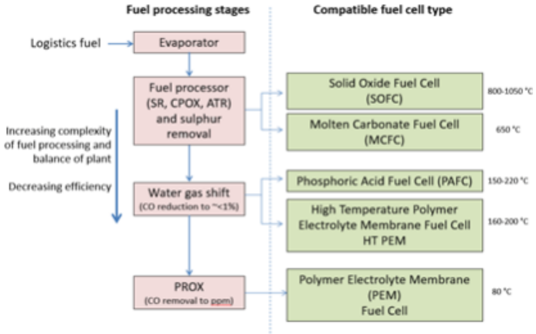
120 W DMFC

Fuel Cells Operating with Fuel Processors. Employ reactors to extract hydrogen from hydrogen containing fuels and feed this into the fuel cell

- Fuel examples: methanol/water, propane, natural gas, sulphur free diesel, ammonia
- Fuel cells examples: SOFC, MCFC, PAFCs, AFCs, HT PEMs and PEM

Applications: Portable power, APUs, Unmanned Air Systems (UAS) small (kW) to large (MW) Combined Heat and Power (CHP)

250 W SOFC operating on propane



Fuel processing technologies for different fuel cell types
SR – Steam Reforming, CPOX - Catalytic Partial Oxidation, ATR - Autothermal Reforming, PROX – Preferential Oxidation

Fuel processing of Defence fuels (e.g. F-34) is the ultimate goal but is technically challenging

A historic barrier has been the high sulphur content in fossil fuels which is a poison to fuel cells

Will future synthetic and biofuels remove this barrier?

If so, we need to avoid the inadvertent entry of additional catalyst poisons into future fuels (e.g. consideration to additive packs etc.).

Benefits

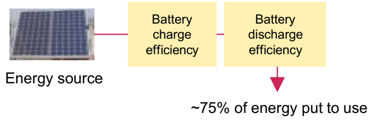
● Fuel savings ● Enhanced capability in the low power range ● Near silent operation

Challenges

● Robustness in the military environment ● Life and durability ● Long start up and shut down periods for high temperature systems ● Limited thermal cycles with high temperature systems ● TRL and current efficiency attained with (diesel and ammonia in particular) ● Cost

Energy Storage

- Batteries, capacitors, redox flow batteries, fuel production (e.g. hydrogen), pumped hydro, compressed air
- Uses:
  - As a power source
  - As an enabler to energy efficiency
    - Hybridisation for energy efficiency
    - Use in smart grids
    - Support capabilities
- As a power source (efficiency vs capability)
  - Batteries are favoured when energy source is limited



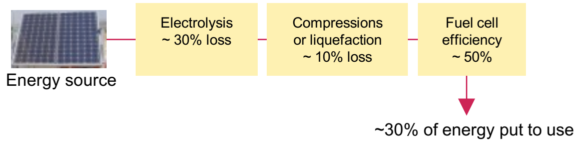
Energy source

Battery charge efficiency

Battery discharge efficiency

~75% of energy put to use

  - Fuel production (e.g. hydrogen) could enable more capable assets but needs an unrestricted source of energy due to low overall efficiency



Energy source

Electrolysis ~ 30% loss

Compressions or liquefaction ~ 10% loss

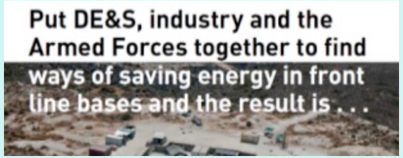
Fuel cell efficiency ~ 50%

~30% of energy put to use

- As an enabler to energy efficiency and sustainability

PowerFOB OCDs (Cyprus (Jul-11) and Kenya (Jun to Aug-12,)

Batteries used in combination with generators to address peak loads and optimise generator loading for peak efficiency. Some solar power included. Promising levels of fuel savings demonstrated



Put DE&S, industry and the Armed Forces together to find ways of saving energy in front line bases and the result is . . .

Lessons identified

- Technologies have upfront cost and logistic effort to deploy and accrue benefits over time
  - *Threshold payback time to justify deploying*
  - *BUT lifespan of base is not always known at time of deployment*
- Changeable nature of deployed bases does not always allow optimal planning in terms of energy technologies
  - *Need for adaptability and versatility in demand management systems and matching of power generation assets to demand*

Capping Comments

- Defence has adopted the highest energy fuels and these combined with current prime mover technology defines current military capability
- No alternative fuels compete against current capability
- Significant fuel savings could be possible through increased efficiency in conversion devices such as fuel cells but need to embrace similar fuels to provide maximum benefit
- Energy storage, demand management and renewable energy have been shown to provide fuel savings in previous Operation Concept Demonstrations
  - Need for adaptability and versatility in demand management systems and matching of power generation assets to demand

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Substitute Fuels

- Not all bio and synthetic fuels offer advantages in terms of reduction GHG emissions
- Factors include emissions associated with the processing route and also indirect emissions associated with feedstocks
  - Indirect Land Use Change when considering the use of dedicated fuel crops
  - Indirect (substitution) when using waste materials
- Greatest GHG benefits offered by Fischer Tropsch (FT) fuels using lignocellulosic feedstocks
  - More expensive and less developed (market wise) than other fuels (e.g. HEFA)

Well-to-wake GHG emissions for sustainable aviation fuels relative to petroleum jet fuel baseline (top – crop based, bottom – waste based)

LCA - Life Cycle Analysis, ICAO - International Civil Aviation Organisation, HEFA - Hydroprocessed Esters and Fatty Acids, ATJ - Alcohol to Jet, SIP - Synthesized Isolparaffin fuel, FT- Fischer Tropsch

Figures taken from: Fueling flight: Assessing the sustainability implications of alternative aviation fuels. Nikita Pavlenko, Stephanie Searle. International Council on Clean Transportation. Working Paper 2021-11. https://theicct.org/sites/default/files/publications/Alternative-aviation-fuel-sustainability-mar2021.pdf

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