Feasibility Study into the Use of Hydrogen Fuel

2nd International Hydrogen Train and Hydrail Conference

June 7th 2006

Dr. Jeff Allan
Presentation Overview

• Background to Rail Safety and Standards Board
• Motivation for study and aims
• Technology status world-wide
• Parameters for study
• Findings
• Conclusions and next steps
RSSB

• Rail Safety and Standards Board is a not-for-profit company owned by major railway industry stakeholders.

• RSSB’s primary objective is to lead and facilitate the railway industry’s work to achieve continuous improvement in the health and safety performance of the railways in Great Britain.
UK Heavy Rail Railway Background

- Power requirements of the order of 1MW
- Heavy reliance on diesel compared to mainland Europe
- Electrification offers the opportunity of centralised energy production for Heavy Rail Transport
- Next key passenger fleet – 2015 onwards
Motivation for the study

• Environmental concern
• Security of supply of fuel
• Emerging technologies in other sectors
• Future cost of fuel
Stakeholders

- Key Stakeholders
  - the Railway Forum,
  - Rail Industry Association,
  - Department for Transport and
  - Rail Research UK

- Carried out by AEAT on behalf of RSSB
Feasibility Study into the Use of Hydrogen Fuel

Study Aims

• Determine current status of hydrogen fuel technology
• Evaluate business case for hydrogen fuel technology in a rail environment
• Provide information and guidance on how to progress the development of hydrogen fuel technology in a rail environment.
Feasibility Study into the Use of Hydrogen Fuel

Emerging Technologies

[Diagram of PEM Fuel Cell]
Emerging applications
Transport Modes

• Automotive lead with hydrogen internal combustion engines and hydrogen fuel cells

• Significant progress in Rail too
Mining Locomotive

- Retrofit of a battery locomotive
- 2x7.5 kW PEM FC
- Metal hydride Storage
- 4 tonnes
- Fuel Cell Propulsion Institute and US Department of Energy
Shunting Locomotive

- Retrofit of a diesel electric locomotive
- 1.2 MW PEM FC
- Metal hydride Storage
- 120 tonnes
- Fuel Cell Propulsion
Institute and US Department of Defense
Further Rail Projects

- East Japan Railway (New Energy) Train
  - Hybrid diesel/battery
- Vemb-Lemvig-Thyborøn line here in Denmark
  - 45 miles
  - Hydrogen innovation and research centre
Commercial development

- Reproduced from E4Tech report
Feasibility Study into the Use of Hydrogen Fuel

**H₂ production & distribution**
- Increasing de-carbonisation of H₂ production: renewables, fossil fuel with sequestration, new nuclear
- Widespread H₂ pipeline infrastructure: interconnection of local H₂ distribution grids; significant H₂ production from renewables, incl. biomass gasification
- Clusters of local H₂ distribution grids: H₂ produced from fossil fuels with C sequestration
- Local clusters of H₂ filling stations, H₂ transport by road, and local H₂ production at refuelling stations (reforming and electrolysis)
- H₂ produced by reforming natural gas and electrolysis

**2000**
- Fossil fuel-based economy

**2000**
- Public incentive and private effort: H₂ production
- Fuel cells vehicles and electricity generation
- Hydrogen production and use
- RTD, field test, niche fleets

**2010**
- Public incentive and private effort: H₂ production
- Fuel cells vehicles and electricity generation
- Hydrogen production and use
- RTD, field test, niche fleets
- First H₂ fleets (1st generation H₂ storage)
- Series production of FC vehicles for fleets (direct H₂ and on-board reforming) and other transport (boats): FC for auxiliary power units (incl. reformer)
- Stationary low-temperature fuel cell systems (PEM) (<300kW)
- Stationary high-temperature fuel cell systems (MCFC/SOFC) (<500kW)
- H₂ ICE developed; demonstration fleets of FC buses

**2020**
- Public reward and private benefits: H₂ production
- Fuel cells vehicles and electricity generation
- Hydrogen production and use
- Increasing market penetration
- FC and H₂ systems development and deployment
- 2nd generation on-board storage (long range)
- Low-cost high-temperature fuel cell systems:
  - FCs commercial in micro-applications
  - FC vehicles competitive for passenger cars
  - SOFC systems atmospheric and hybrid commercial (<10MW)

**2030**
- Public reward and private benefits: H₂ production
- Fuel cells vehicles and electricity generation
- Hydrogen production and use
- Increasing market penetration
- H₂ prime fuel choice for FC vehicles
- Significant growth in distributed power generation with substantial penetration of FCs
- 2nd generation on-board storage (long range)
- Low-cost high-temperature fuel cell systems:
  - FCs commercial in micro-applications
  - FC vehicles competitive for passenger cars
  - SOFC systems atmospheric and hybrid commercial (<10MW)

**2040**
- Public reward and private benefits: H₂ production
- Fuel cells vehicles and electricity generation
- Hydrogen production and use
- Increasing market penetration
- H₂ prime fuel choice for FC vehicles
- Significant growth in distributed power generation with substantial penetration of FCs
- 2nd generation on-board storage (long range)
- Low-cost high-temperature fuel cell systems:
  - FCs commercial in micro-applications
  - FC vehicles competitive for passenger cars
  - SOFC systems atmospheric and hybrid commercial (<10MW)

**2050**
- Hydrogen-oriented economy
- Full-scale commercialisation of FC mobile applications
- FC stations: applications
- Fuel cells become dominant technology in transport, in distributed power generation, and in micro-applications
Projected fuel cell costs

Mass-market automotive PEMFC cost, $/kW

US DOE Figures

Feasibility Study into the Use of Hydrogen Fuel
Parameters for study

- 3 representative traction units chosen
  - Class 66 freight, class 220 high speed passenger, class 170 commuter
- Range as for diesel
- 2010 selected for technology assessment
- 2020 selected for business case assessment
Findings – Internal Combustion Engine Advantages

• Less expensive to manufacture than fuel cell powertrains (although hydrogen ICEs are approximately 15% more expensive than a conventional petrol engine).
• Can run on pure hydrogen or a blend of hydrogen and compressed natural gas
• Approximately 25% more efficient than petrol engines, and slightly more efficient than diesel engines
• Emit much lower levels of NOx (oxides of nitrogen) emissions than conventional petrol and diesel engines
• Particulate emissions close to zero
Findings – Internal Combustion Engine Disadvantages

- Compared to hydrogen fuel cell powertrains, hydrogen ICEs require a larger quantity of fuel to travel a given distance.
- There is a corresponding additional cost associated with the need for more fuel.
- The higher fuel consumption means that hydrogen ICE vehicles need more fuel storage capacity than hydrogen fuel cell vehicles (again leading to increased costs).
- Net “well-to-wheel” CO2 emissions from hydrogen ICEs have been shown to be greater than well-to-wheel CO2 emissions from petrol and diesel engines.
Fuel Cell Case Study - Class 170

MTU 6H 1800 R80 DMU railcar engine

- 315 kW power output
- 1480mm x 1415mm x 715mm (1.5 m³)
- 1,000 kg
- 0.315 kW/kg
- 210 kW/m³

Scaling up the current best fuel cell technology, an equivalent fuel cell powertrain would weigh 3,675 kg and would have a volume of 8.8 m³
Findings – space and weight

• Drive train 8.8m$^3$
• Consideration of fuel storage
  – Metal Hydride 1m$^3$
  – Ammonia 2m$^3$
  – Liquid 2m$^3$
  – 700 Bar Compressed Gas 4m$^3$
  – 350 Bar Compressed Gas 9m$^3$
• Approx 3% increase in weight over diesel
# Feasibility Study into the Use of Hydrogen Fuel

## Findings cost/vkm in 2020

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<th>Technology</th>
<th>Env Costs</th>
<th>Fuel low</th>
<th>Fuel high</th>
<th>Capital costs</th>
<th>Net low costs</th>
<th>Net high</th>
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<td>Electric on existing infrastructure</td>
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Summary of Findings

• By 2010, weight of fuel cell and fuel, space considerations acceptable
• By 2020 Cost of fuel cell application acceptable?
• Key remaining issue - lifetime
Next Steps for GB

• Possible medium cost development route is with an APU for a diesel locomotive using an SOFC fuel cell and an on-board reformer – quality of air improvements and experience gained

• Electrification Study

• Review progress worldwide especially here in Denmark
Conclusions

• Internal Combustion Engine not considered suitable
• Business case for heavy rail fuel cell by 2020?
• More detailed examination of electrification needed
• Possible niche application of auxiliary power supply for diesel locomotives as a research project
• Continue to investigate rail and other transport work elsewhere
A Final Thought

- Power levels for heavy rail exceed most road transport applications
- Closest mode of transport with similar demands - Ships
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First fuel cell submarine in the Italian Navy,
Thank you

Details of current RSSB R&D and published work can be found at www.rssb.co.uk