Research into feasibility of hydrogen fuel in rail (T531)

**Background**

Increasing concern over environmental impact, security of supply and cost is causing the long-term use of hydrocarbon fuels for transport to come under greater scrutiny. Railways have had the option of electrification for more than 100 years, but the costs are high and have been justified historically only in intensively used areas and on strategic energy policy grounds.

The road transport industry is leading the research and development of alternative fuel sources, including hydrogen. Hydrogen has attractions as a transport fuel in that it has a low environmental impact at the point of use, a high-energy content and can be relatively easily transported. The European Union (EU) has made hydrogen a priority technology. European research and trial initiatives are well advanced resulting in prototype hydrogen fuel cell and hydrogen powered internal combustion engine (ICE) based road vehicles. The United Kingdom government has recently announced a funding package for demonstrations of hydrogen and fuel cell technologies, demonstrating its commitment to providing support for resolving the above problems, in particular for road transport.

The United Kingdom railway industry retains a relatively high reliance on diesel power compared with its major continental neighbours. It has initiated this work to investigate the current state of hydrogen fuel technology and its long-term possibilities for the UK railway, essentially as an alternative to further electrification, in pursuing reduced hydrocarbon dependence.

The project specification was developed with the help and support of the Railway Forum (RF), Rail Industry Association (RIA), Department for Transport (DfT) and Rail Research UK (RRUK).

**Objective**

The main aim of the study was to identify whether and when the United Kingdom rail industry should carry out further research and development into the application of hydrogen fuel, building on the progress being made in the road transport sector. A supplementary issue to be resolved was whether the work should be done in the UK alone, as part of a European strategy or in a worldwide context. The project tackled a number of issues broken down into three areas:

- Technology
- The business case
- Progressing development

**Method**

This study consisted of the following elements:

- Review of the current status of hydrogen technology.
- Consideration of ‘energy futures’ to provide an overview of the potential future role of hydrogen as an energy source. This also included a review of the possible barriers to increased uptake of hydrogen in future years.
- Investigation of railway application of hydrogen technology to date.
- Assessment of operational and safety implications associated with hydrogen when used as a transport fuel.
- Development of a business case for moving to hydrogen fuel in the rail sector including a comparison with further development of electrification in the United Kingdom.
- Identification of potential railway development applications.
- Assessment of costs of development and funding sources.
- Investigation into organisations active in this area.
• Assessment of risks for the railway industry in carrying out research in this area.

The study was conducted within a series of constraints against which the viability could be tested, effectively requiring the replacement system to have the same general capabilities as those afforded by diesel power today. For instance:

• Power output must be the same as current traction packages.
• Range must be equivalent to current packages so that refuelling intervals are not shortened.
• The volume, weight and capital cost of the traction package and its associated fuel tanks must be equivalent to current traction packages with their auxiliaries and fuel tanks.

Findings

• Hydrogen technology in general is still not fully developed.
• The main method of generating hydrogen currently is steam reforming of methane, which still generates CO$_2$, with an eventual switch to electrolytic generation, which will be dependent on the electricity generation mix for its environmental benefit.
• The two main technologies for utilising hydrogen are fuel cells and adapted ICEs. Hydrogen ICEs are further developed and cheaper than fuel cells but are about half as efficient. With the present method of producing hydrogen, ICEs have a worse impact on CO$_2$ emissions than current diesel technology, but fuel cells show a substantial improvement.
• Many fuel cell and hydrogen ICE demonstration projects have been developed for the automotive sector. To date only one fuel cell project has been demonstrated for the rail sector on a low speed mining locomotive. No hydrogen ICE rail vehicles have been developed to date.

• The fuel cell technology, which is most widely used in road transport traction applications, is the Proton Exchange Membrane (PEM) fuel cell. However Solid Oxide fuel cells are more developed for static power supply applications and have some advantages for specific (non-traction) railway applications.

A schematic of a PEM Fuel Cell (Reproduced from Fuel Cell World 2005)

• Hydrogen fuel cells are very unlikely to be used in mainstream rail applications until there has been an order of magnitude reduction in cost and improvement in the average operating lifetime.
• Commercially, hydrogen fuel technology is unlikely to become a mainstream part of the transport energy mix until at least 2020, and even then the first applications will be for road vehicles. Rail vehicles will not be ‘early adopters’ of these technologies.
The costs of hydrogen ICE and hydrogen fuel cell technology are likely to decrease between now and 2020, and at the same time the full range of performance criteria associated with these technologies are likely to improve significantly.

- The 2020 business case provides no immediate basis for further electrification of the network compared to continuing with diesel. However electrification does provide better CO₂ emissions than hydrogen or diesel because the greater efficiency of centralised energy production can be realised, and is established technology. Thus if a cost effective method of reducing carbon dioxide emissions is required for an intensive service, it would be better to pursue further track electrification than replace diesel trains with hydrogen fuel trains. It is also worth noting that electrification costs used in the model were based on a small sample taken at what may be a high point in United Kingdom railway unit costs. Current industry efficiency initiatives, if applied to electrification, would improve its case.

Next Steps

- A large-scale demonstration project in the United Kingdom, to trial the use of a fuel cell for rail traction power appears unjustified, but European projects with this objective should be strongly supported.
- There is a niche railway application where significant local air quality and environmental noise benefits at terminal stations could be achieved through the use of solid oxide fuel cell Auxiliary Power Units (APUs) on diesel locomotives and Diesel Multiple Units (DMUs). Fuel cell APUs would remove the need for engine idling at terminal stations as a means of providing train auxiliary power. It would be necessary and it is practical to convert diesel fuel to hydrogen on board the train.
- Current new rolling stock procurement (for delivery in five to ten years time) cannot benefit from hydrogen technology. However consideration should be given to specifying electric transmission as this is more likely to be
adaptable to alternative prime movers at mid-life upgrade.

- The fuel source for the next generation of 'go-anywhere' passenger trains, replacing 1980-1990 generation DMUs from 2015 onwards, should be very carefully considered when the time comes. Taking an optimistic view in extrapolating current development, it could be practical from the point of view of space, weight and cost to begin to apply hydrogen fuel cell technology to relatively light rail vehicles using current refuelling locations over this timeframe. However, the practicability of this will depend on the rate of development of a distribution network for road transport use.

The United Kingdom has a greater interest in finding a replacement for diesel-fuelled trains than the majority of the rest of Europe, which has an extensive electrification network. Having reviewed the outcome of the work with this in mind, and noting that this is a rapidly developing area of technology, key stakeholders have agreed the following specific actions:

- Monitor other transport sectors in particular road transport (which is most advanced) and marine (which shares power requirements with the heavy end of rail traction) – RSSB.
- Monitor the currently limited rail interest worldwide and support European rail sector developments – RRUK to initiate enquiries.
- Conduct a more detailed study of the long-term merits of main line electrification in the United Kingdom, using better data, benchmarked worldwide and better assessments of future sector costs – RSSB is working with DfT to deliver this (project T633).
- Understand how this initiative fits in with the national energy policy and more specifically the hydrogen economic policy (DfT and RF).
- Acquire appropriate knowledge and experience in hydrogen technology in the rail sector by pursuing the limited niche area described above. This would seek to resolve the niche problem and to gain experience should fuel costs increase to the point where the business case justifies replacement of diesel trains with hydrogen trains – RF to propose a plan outlining short and long-term actions for the industry.

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