HYDROGEN FOR RAILWAY TRACTION

Andreas Hoffrichter
Research Associate
Birmingham Centre for Railway Research and Education
University of Birmingham, UK

Toronto: Ryerson University. 11th of June 2013
Outline

- Current railway traction
- Well-to-wheel analysis results
- Prototype locomotive Hydrogen Pioneer
- Performance modelling with computer simulation
Present Railway Traction

- The majority of railway traction vehicles employ electric motors.
- Energy to the traction motors is supplied either through wayside infrastructure (electric) or an on-board diesel-alternator set (diesel).
- At a global level, approximately 70% of railway energy for traction is supplied as diesel while 30% is provided by electricity. BUT varies significantly with region, e.g., 100% of railway network electrified in Switzerland, whereas 0% electrified in Canada (mainlines only).
- Railways are typically the largest single energy consumer in a country, e.g., for electricity in Germany and the UK, for diesel BNSF in the USA.
Problems Facing Diesel Traction

- Point-of-use emissions and overall Greenhouse Gas emissions
- Uncertainty about economical diesel supply

- Traditional solution: Electrification. BUT:
  - Large investment in infrastructure required
  - Visual impact of wayside infrastructure

- Alternative to Diesel traction required, other than electrification
Reasons for Hydrogen

- Abundant
- Non-toxic
- Not a greenhouse gas
- Various feedstocks
- Combustion product with oxygen is water
- Can reduce greenhouse gas emissions
- Does not require wayside infrastructure

For railways: Combines the advantages of diesel and electric traction and avoids most disadvantages: autonomous operation without emissions at the point-of-use while allowing a feedstock mix
Hydrogen Pioneer

- UK’s first hydrogen-powered train (locomotive)
- Developed, designed, constructed at the University of Birmingham, in the time frame four to five months
- Demonstrated at several occasions
- Narrow gauge hybrid locomotive
- 1.1 kW PEM fuel cell
- 4 Lead-acid batteries
- 4.4 kW continuous traction motor power
- Hydrogen storage either:
  - Metal hydride (approximately 500g of hydrogen)
  - 200 bar compressed gas (approximately 150g of hydrogen)
Hydrogen Pioneer (2)

- Locomotive used for performance evaluation, with various duty cycles

Some results:
- Measured fuel cell stack peak efficiency matches manufactures specifications at around 40% - 43%
- Fast response of the fuel cell stack to a change in load
- Hybrid system performed as designed
- Overall system design suitable for standard gauge traction vehicle
Hydrogen Pioneer (3)
Benchmark Performance Modelling

- Typical regional rail route in the UK Birmingham Moor Street to Stratford-upon-Avon and return (some commuter traffic)
- Currently operated with Diesel Multiple Units
- New diesel-electric vehicle chosen as a benchmark: Stadler GTW 2/6
- Hydrogen-only and hydrogen-hybrid vehicle designed and modelled to operate same schedule as the diesel benchmark
- Volume and mass implications of novel drive-train considered
Diesel-Electric Drive System

Diagram showing the components of a diesel-electric drive system, including the diesel fuel tank, diesel engine, power plant, DC-bus, traction package, and drive-train. The diagram also includes auxiliaries, DC-AC converters, and brake resistors.
Hydrogen-only Drive System
Hydrogen-Hybrid Drive System

Hydrogen Fuel Tank

Fuel Cell Stack

Energy Storage

Auxiliaries

DC - DC

DC - AC

Brake Resistors

DC - DC

DC - AC

M

Power-Plant

DC-BUS

Traction Package

Drive-Train
Some Modelling Results

- Hydrogen drive system can be installed in the vehicle with minimal impact on passenger space and vehicle mass.
- All three trains have a journey time of 94 min and a operating range of 16 hours. Refuelling on a daily basis as standard practice on many routes in the UK.
- Energy requirement reductions for the journey compared to diesel: 34% hydrogen-only, 55% hydrogen-hybrid (LHV).
- Well-to-wheel carbon reductions compared to diesel: 55% hydrogen-only, 72% hydrogen-hybrid, assuming that all the hydrogen is produced from natural gas (LHV).
Conclusion

- Hydrogen reduces the dependency on petroleum products
- Emission reduction possible
- Well-to-wheel efficiency similar to incumbent railway energy systems
- Prototype locomotive Hydrogen Pioneer demonstrated:
  - Construction with standard components possible
  - Hydrogen gas utilised in a fuel cell is suitable for railway traction
  - High power-plant efficiency
  - Quick response time of fuel cell stack
- Computer simulation showed similar performance to diesel traction, while reducing energy requirements and carbon emissions

» **Hydrogen is suitable for railway traction**
Acknowledgements for PhD support

- Engineering and Physical Science Research Council (EPSRC) for financial support
- Vehicle Projects for providing information, data, and support throughout the PhD period
- Rex Harris for the loan of a metal hydride tank
- Railway Challenge team for collaborative work leading to the Hydrogen Pioneer