11th International Hydrail Conference

HYDROGEN FOR RAILWAY TRACTION: A PHD AT THE BIRMINGHAM CENTRE FOR RAILWAY RESEARCH AND EDUCATION

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• Interest in Railways and Energy
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Acknowledgment:
Thanks to Dr. David J. Closs, Dr. Yemisi Bolumole & Dr. John Macdonald for their insights and guidance.
Interest in Railways, Energy, and the Environment

• Interested in railways as long as I can remember

• Long interest in energy and electricity

• Early interest in nature and the environment

• First longer-term employment was as a banker (Bankkaufman) after advanced apprenticeship degree
Interest in Railways and Energy (1)

• Followed more business and management path with a Bachelor degree in Transport Management at Aston University
  – Link to railway interest with previous banking experience
  – Final year project in discontinuous electrification from a visual impact perspective

  – Research desire to find an alternative to continuous wayside electrification due to cost and visual impact

  – Two possible PhD research ideas:
    ➢ Advanced, lower-infrastructure requirement electrification
    ➢ Hydrogen as an energy carrier

  – PhD proposal for hydrogen idea developed with final year project advisor

• PhD at the Birmingham Centre for Railway Research and Education
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Traditional Propulsion Choices

- **Steam (start: early/mid 1800s)**
  - Start of ‘modern’ railway
  - Usually locomotives
  - Does not require continuous wayside power infrastructure
  - Often lower thermal efficiency than diesel
  - Relatively high maintenance expenses

- **Wayside Electric (start: late 1800s)**
  - First commercial use in trams
  - Eliminated exhaust emissions at the point-of-use
  - Multiple unit (railcar) trains possible
  - Best traction characteristics
  - High on-train conversion efficiency
  - High well-to-wheel efficiency possible
  - Requires continuous wayside power infrastructure
  - Several primary energy sources available (e.g., hydro, wind, coal, nuclear, etc.)
Traditional Propulsion Choices (2)

• Diesel (start: early/mid 1900s)
  – Globally, most common type of diesel drive system is diesel-electric
  – Effectively an electric system with on-board power plant
  – High efficiency possible (largely dependent on duty cycle)
  – Limited power due to diesel engine size and mass
  – Locomotive or multiple unit
  – Only one fuel choice
  – Emissions at the point-of-use
  – Does not require continuous wayside power infrastructure
Traditional Propulsion Choices (3): Wayside Electric Drawbacks

- Costly
  - continuous wayside power infrastructure necessary
  - approx. GBP 1 million per track kilometer
  - economy-of-scale necessary, i.e., high train density on infrastructure, for economic viability

- Visual impact
  - particularly a problem in historic urban areas
  - led to alternative developments, e.g., induction, linear motors, ground-level supply

- Potential for lower resilience
  - power cut can affect several trains and potentially the entire network (e.g. North East US power cut, Swiss railways transmission problems)

- Power infrastructure can be affected by weather, e.g.:
  - high winds (e.g., east coast main line, UK)
  - ice on conductor line (e.g., Germany main lines, US tram networks) – frequent ice breaker trains run, especially at non-service times (e.g., at night)
Traditional Propulsion Choices (4): Diesel Drawbacks

• Reliance on a single fuel source
  – Direct, strong impact on operating cost
    ➢ Led to exploration of alternatives, e.g. Natural Gas
  – Railway has little control over prices
  – Energy security can be a problem in some regions (e.g., Europe)

• Exhaust emissions
  – Combustion of diesel at the point-of-use
  – Contributes to greenhouse effect
  – Exhaust is carcinogenic
  – Exhaust contributes to SMOG
Recent Mainline Propulsion: Natural Gas

- Several developments of the technology
- Russia
  - Gas turbine, Liquefied Natural Gas (LNG)
  - Combustion engine, Compressed Natural Gas (CNG)
- North America
  - Combustion engine, CNG for switchers
  - Combustion engine, LNG for mainline
    - Florida East Coast Railway plans to run entire mainline fleet on Natural Gas by the end of the year
    - Several projects on Class I railroads
  - LNG usually requires a contribution of diesel (e.g., 80% NG, 20% diesel)
- Developments primarily driven by high diesel prices in the recent past
- Exhaust emissions at the point-of-use
  - After treatment required to meet exhaust emission legislation in several regions (e.g., US, EU)
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Hydrogen as an Energy Carrier for Transportation

• Hydrogen (H₂) is not a energy source
  – Does not occur in large quantities on it’s own on Earth
  – Has to be split from chemical compounds with energy input
  – Many different feedstocks available (hydrocarbons, e.g., coal, oil, natural gas) and splitting of water (electricity or heat) possible
  – Similar to electricity (has to be ‘created’ with energy input), hydrogen is an energy carrier
  – One of only two chemical energy carriers / fuels that does not contain carbon (the other is anhydrous ammonia, NH₃)

• Some characteristics of hydrogen
  – Non-toxic
  – Not a greenhouse gas, and does not release any harmful emissions during combustion with oxygen
  – Highest energy density per mass
  – Low energy density per volume
  – Low radiant heat
  – Very common on Earth in compounds (e.g., water)
Hydrogen as an Energy Carrier for Transportation (2)

• Hydrogen storage
  – large quantities can be stored over long periods of time relatively easily compared to electricity
  – BUT difficult to store compared to liquid fuels (diesel, gasoline)
  – Compression, liquefaction, or hydride storage necessary to achieve acceptable range

• Can be used in a fuel cell
  – Only produces, electricity, heat, and water as exhaust
  – High chemical to electrical conversion efficiency

• High duty cycle efficiency for transport vehicles possible

• High well-to-wheel efficiency possible

• Low to near-zero carbon emissions possible (only embedded carbon in equipment manufacture)

• Several applications in the transport sector
  – Buses
  – Cars
  – Forklifts
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Doctoral Research at Birmingham Centre for Railway Research and Education (BCRRE)

• Approached Dr. Stuart Hillmansen and Prof. Clive Roberts at the BCRRE with my research proposal for hydrogen as an energy carrier for railway traction

• We discussed the research idea for approximately 2 hours
  – Stuart and Clive offered me a PhD position verbally at the end of the discussion
  – Funding was not secure at this stage but potential was identified

• A funded PhD position with a more broader research area (including electric car re-charging infrastructure) was offered to me from another university

• Decided to go with BCRRE due to great rail expertise

• Two funding proposal were submitted and the Engineering and Physical Science Research Council (EPSRC) application was successful
Doctoral Research at BCRRE (2)

- Supervisors
  - Dr. Stuart Hillmansen
  - Prof. Clive Roberts

- Well-to-Wheel Analysis
  - Diesel
  - Wayside Electric
  - Hydrogen

- Prototype Hydrail Locomotive
  - Part of a team
  - First practical hydrogen locomotive in the UK
  - Performance evaluation

- Single Train Simulation
  - Diesel
  - Hydrogen
  - Hydrogen-hybrid

- Overall
  - great experience
  - won prize for the best PhD in 2013 in the School of Electronic, Electrical and Computer Engineering

- Support
  - EPSRC funded
  - Assistance provided from Vehicle Projects Inc
Doctoral Research at BCRRE: Hydrogen Pioneer Locomotive

- Member of a team that developed, designed, and constructed a hydrogen-powered locomotive
- Was constructed for the IMechE railway challenge and for performance evaluation
- First practical hydrogen-powered locomotive in the UK
- Hydrogen-hybrid
  - 1.1 kW PEM Fuel Cell
  - Lead-acid batteries
  - 4.4 kW traction motors

Doctoral Research at BCRRE: Performance Evaluation of Hydrogen Pioneer

- Several test runs with different maximum speeds
- Hydrogen-hybrid concept feasible
- Locomotive has since been further developed

Doctoral Research at BCRRE:
Conceptual Design of a Hydrogen Regional Train

- All trains have a similar journey time
- Hydrogen-hybrid propulsion equipment and storage tanks can be accommodated without significant impact on passenger saloon
- 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)

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Recent and Ongoing Hydrail Research

• Single Train Simulator development at WMG (The University of Warwick)
  – Takes into account component efficiency maps
  – More accurate vehicle efficiency determination for maximum and duty cycle

• Part of a collaboration for a Future Railway feasibility study
  – Funded feasibility study
  – Team at WMG conducted simulation over various routes and several train configurations

• Collaboration with the University of California at Davis
  – Case study on the Capitol Corridor trains comparing several options including diesel benchmark
    – High-power locomotive-hauled bi-level coaches
      ➢ ~3280 kW (4400hp) diesel prime mover
      ➢ 290 kN max. tractive effort
      ➢ ~8300 l diesel fuel tank capacity
  – More detail provided by Raphael Isaac’s presentation at this conference

• Supervision of a MSc student that considered safety aspects of hydrail
Conclusion

• Long interest in railways, energy, and the environment
  – Hydrail combines these interests

• PhD research at BCRRE
  – Interesting and successful
  – Hydrogen is a feasible energy carrier for railway propulsion
  – Eliminates harmful emissions at the point-of-use
  – Can reduce overall WTW emissions

• Recent projects
  – Higher-power case study in California
  – Several hydrail projects going on, globally

• Future
  – Economic evaluation
  – Investigation of different service types (e.g., switchers, freight)