
Presenter: Dr. Gord Lovegrove (CIVIL ENG), UBC STS Research Lab (P-I)
Co-authors: Hegazi Mohamed (PHD student, ELEC ENG)
Dr Loic Markley (ELEC ENG)

Appreciation to:
Transport Canada Clean Rail Program, research sponsor
NSERC Engage Program, research sponsor
Birmingham Railway Research Center, case study duty cycle data
Dr Peter Eggleton, Transport Canada report on H2 infrastructure needs
1. Problem Statement
2. Literature Review & Research Objectives
   • Continuous Electrification
   • Discontinuous Electrification
   • Hydrogen Propulsion
3. Methodology
4. Results
   1. Case Study: London to Newcastle
      • Fuel Cell / Battery Hybrid
5. Early report on UBC STS research with SRY FCB refit
Problem

Demand
• NA railway system continues to grow

Emissions
• System is outdated and diesel powered

Cost
• Complete electrification is an expensive solution
The Problem with Diesel

Noisy

Inefficient

Pollutant Emitting

$$
Solutions

Tank to Wheel Emissions

- Reduced Emissions
  - Genset Technology
  - Green Goats
- Zero Emissions
  - Electrification
    - Continuous
    - Discontinuous
  - Fuel Cell Technology
Outline

1. Problem Statement
2. Literature Review & Research Objectives
   • Continuous Electrification
   • Discontinuous Electrification
   • Hydrogen Propulsion
3. Methodology
4. Results
   1. Case Study: London to Newcastle
      • Fuel Cell / Battery Hybrid
5. Early results of NSERC Engage STS-SRY Refit Research
Continuous Electrification

Advantages:
• Access to a practically unlimited power supply
• Improved acceleration
• Safer: less risk of explosion in case of derailment
• Partial regenerative braking
• Zero tank-to-wheel emissions

Disadvantages:
• Very costly (4 – 5 million USD)/km
• EMI
• Conductor energy loss is significant
Electrified Intercity Passenger Rail in NA

<table>
<thead>
<tr>
<th></th>
<th>USA</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator</td>
<td>Amtrak</td>
<td>VIA Rail</td>
</tr>
<tr>
<td>Network</td>
<td>34,000 km</td>
<td>12,500 km</td>
</tr>
<tr>
<td>Electrification</td>
<td>2% - 3%</td>
<td>0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Electric</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>US DOE (2014)</td>
<td>53%</td>
<td>47%</td>
</tr>
</tbody>
</table>
Comparison with European Rail

Railroad Electrification Percentage

- Canada
- Greece
- Denmark
- Great Britain
- France
- Spain
- Norway
- Italy
- Netherlands
- Belgium
- Switzerland

Percentage: 0 20 40 60 80 100
Discontinuous Electrification

(Hirose, Hiroshi, Kouji Yoshida, and Kenichi Shibanuma)

Advantages:
• Reduced infrastructure cost
• Acceleration rates are unaffected
• Safety factor maintained
• Higher levels of regenerated energy
• Reduced stress on feeder substations
• Zero tank-to-wheel emissions

Disadvantages:
• Increased powertrain cost

Run by feeder line

Run by battery

Battery Charging Facility

Electrified Section  Non-electrified Section
Electrical Energy Storage (EES)

- Lithium-ion Battery
  - Energy Density: $500 - $1000 /kg
  - Power Density: $2500 - $5000 /kg
- Supercapacitor
Existing EES Technology in Railways
(Masamichi Ogasa)

- Never the prime-mover
- Primarily used to recover energy regenerated from braking
- Improves the quality of the power drawn from the utility supply
- Reportedly can help achieve energy savings of up to 30%
Hydrogen Fuel Cells

Figure 1: Basic diagram of a PEMFC.
Source: http://www.toyota.com/fuelcell/fcv.html
Hydrogen Propulsion Success Stories

- **1999-2002**: Fuel cell mining locomotive. By Vehicle Projects LLC
- **2003**: Successful test of a hydrogen powered motorized bogie. 
  Railway Technical Research Institute (RTRI), and East Japan Railway Company (JR East)
- **2005-2007**: Fuel cell-battery hybrid shunt locomotive
  By BNSF Railway Company, the US Army Corps of Engineers, and Vehicle Projects Inc
  For urban and military-base rail applications
- **2006**: Fully functioning hydrogen powered railcar
  By the Railway Technical Research Institute (RTRI) in Japan
- **2007**: A diesel-hybrid railcar transformed to operate on hydrogen
  By East Japan Railway Company (JR East)
Research Objectives

Technical Feasibility

Assess the ability of the proposed power sources to accommodate power demand dynamics in railway systems through simulation.

Attempt to find a correlation between the power source mix and key trip parameters

Compare the proposed solutions

Cost and Life Cycle Emissions Analysis
Outline

1. Problem Statement
2. Literature Review & Research Objectives
   • Continuous Electrification
   • Discontinuous Electrification
   • Hydrogen Propulsion
3. Methodology
4. Results
   1. Case Study: London to Newcastle
      • Fuel Cell / Battery Hybrid
Methodology

Vehicle Data:
- Inertial Mass
- Speed and Acceleration Limits
- Coefficient of Adhesion

Phase 1: Trajectory Planner / Equation of Motion Solver

Target Speed Profile

Phase 2: Powertrain Simulator

Infrastructure Data:
- Gradient and Curve Profile
- Speed Limit Profile
- Stations / Dwelling Time.
Phase 2: FCB Powertrain Simulation
1. Problem Statement
2. Literature Review & Research Objectives
   • Continuous Electrification
   • Discontinuous Electrification
   • Hydrogen Propulsion
3. Methodology
4. Results
   1. Case Study: London to Newcastle
      • Fuel Cell / Battery Hybrid
Case Study – Train Configuration

Volume Constraint

Mass Constraint

X 8

Unpowered Axle

Powered Axle
Case Study – Route
Fuel Cell-Battery (FCB) Model Configuration

- Fuel Cell
- Batteries
- Hydrogen Tanks
FCB Results: Sizing and Power Demand Profile
FCB Results: SOC and Hydrogen Consumption
FCB Results: SOC Sensitivity to Energy Mix

[Graph showing the relationship between hydrogen mass, battery mass, and SOC sensitivity with volume and mass constraints.]
Sizing Optimization

![Graph showing optimization of hydrogen mass and battery mass.](image)
Limitations

1. Safety and Regulations in place for FCB trains
2. Cost Benefit Analysis
3. Public Acceptance
Conclusions

1. Railway systems are very well suited to run onboard clean energy storage systems
2. Hydrogen fuel cells are capable of handling most dynamic load changes in railway systems
3. Fuel cell efficiency increases with a more steady duty cycle
4. Average fuel cell conversion efficiency is over 60%

5. Extra 4%-5% efficiency with lithium ion battery pack in a hybrid power train
5. Update on NSERC ENGAGE Program STS-SRY Refit

- Cooperative project between UBC and Southern Railway of British Columbia (SRY)
- Supported by the National Science and Engineering Research Council
1. NSERC Engage - Design a Green Goat switcher locomotive retrofit
   • Estimate costs, identify logistics, final design (2018)
2. NSERC CRD – Fund the retrofit (2019)
   • Hydrail experience in operation and maintenance
   • Troubleshoot & refine design & operations
NSERC ENGAGE Program

• Initial phase: defining the battery and fuel cell configuration to retrofit
• Results to date:
  • Logistics of data capture on in-service switchers
  • Duty cycle data capture underway
  • Looks promising
  • Stay tuned!
Thank you.