CENTRE D'INNOVATION CENTRE

Pathways to Decarbonizing the Rail Sector: A Canadian Perspective

Jim Lothrop, Director General
Innovation Centre

FRA – Emerging Decarbonization Technologies and Safety in Rail
Spring 2023

Transport Canada Transports Canada

Canada

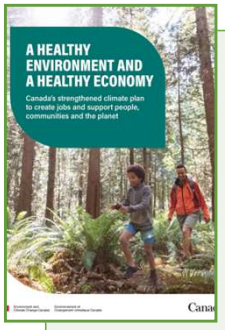
Emission Reduction Drivers for Canada

Paris Agreement (2015)

Canada's committed GHG reduction targets:

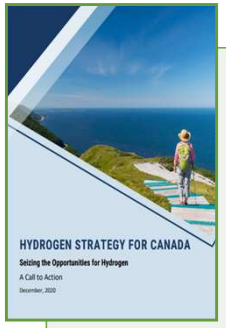
- 40-45% reduction by 2030, relative to 2005 levels
- Net-zero emissions by 2050

Government of Canada's Actions



Strengthened Climate Plan (2020)

- Federal Carbon Pricing
- Clean Fuel Regulations



Hydrogen Strategy for Canada (2020)

2030 Emissions Reduction Plan (2022)

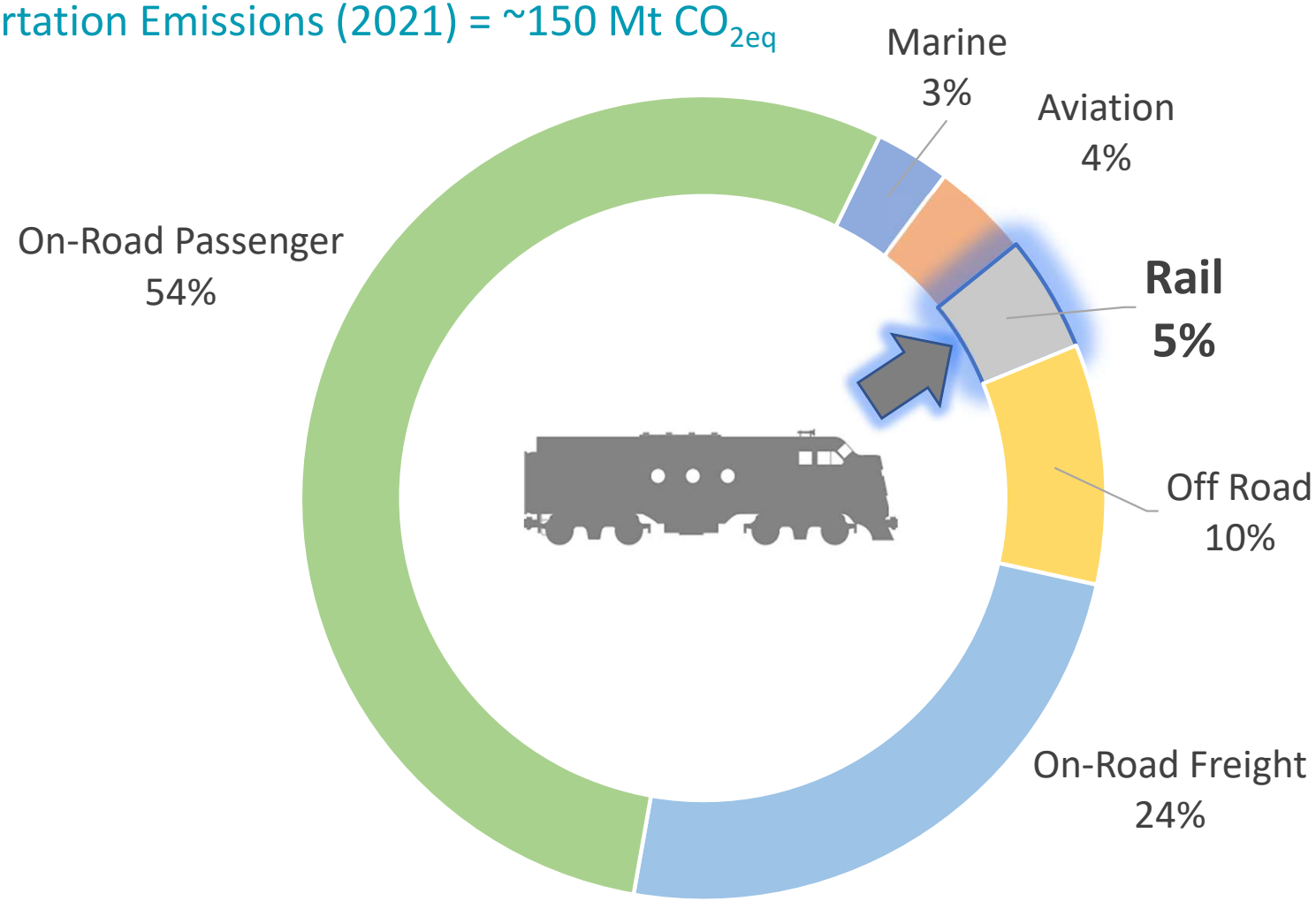
CANADIAN NET-ZERO EMISSIONS ACCOUNTABILITY ACT

National net-zero GHG emission targets by 2050

Rail Emissions Context

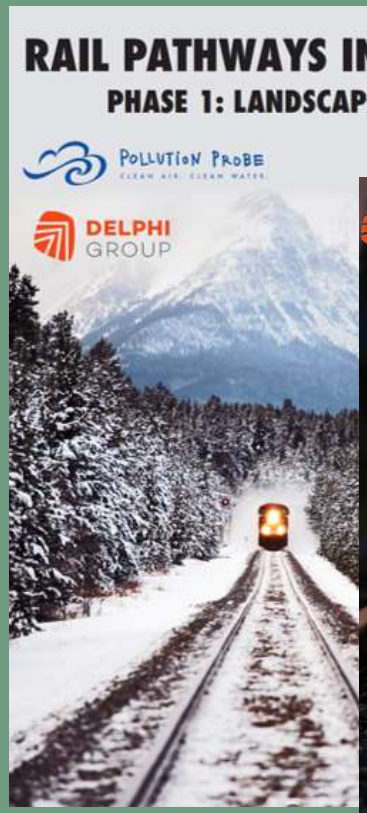
% Total of total Transport emissions

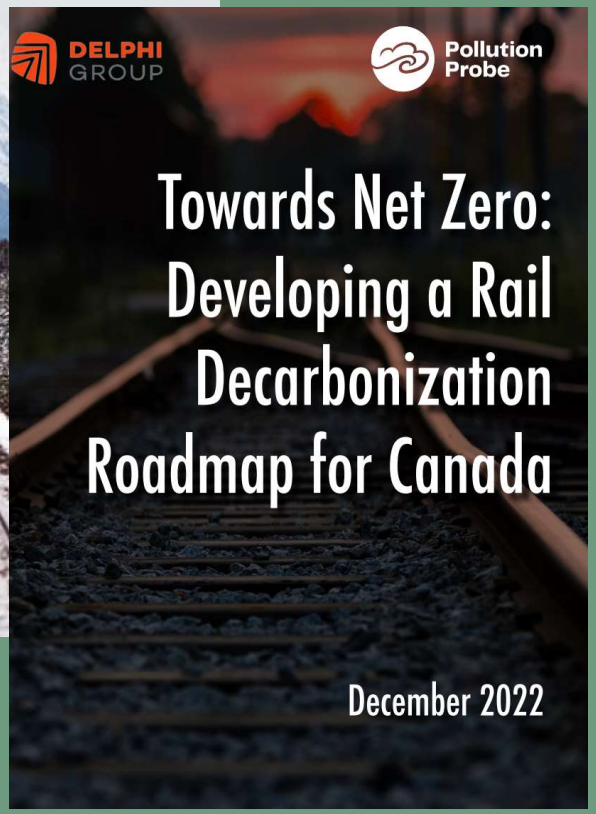
Transportation Emissions (2021) = ~150 Mt CO_{2eq}



Source: Canada's 2023 National Inventory Report (domestic emissions)

MOU 2018-2022: Collaborative Highlights





Rail Pathways Initiative

CHANGE energy 2 services

Assessing the potential for low carbon-intensity diesel use in railway operations in Canada:

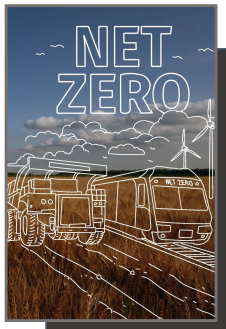
a research and stakeholder consultation project

Drop-in diesel alt feasibility

Locomotive Emissions Monitoring

Transport Canada's Rail Decarbonization Priorities for 2023-2024

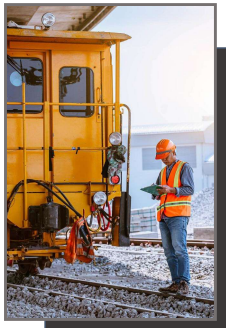
Renew Memorandum of Understanding (MOU) with the Railway Association of Canada (RAC).



Establish a decarbonization pathway to 2050 for Canada's rail sector

Develop options to **accelerate the renewal of Canada's locomotive fleet**.

Seek **international engagement** on new innovative solutions to reduce rail emissions.



Explore options to support **industry-led clean rail technology demonstrations**.

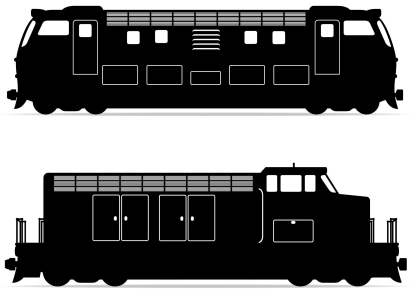
Decarbonization Activities in Canada

Target Setting

- CP and CN Science Based Targets Initiative
- VIA Rail Sustainability Plan

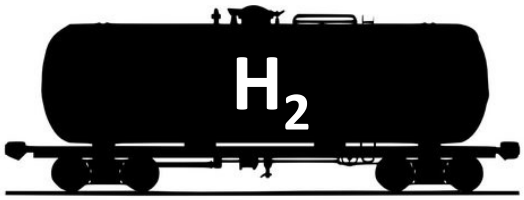
Fleet Renewal

- CP's Locomotive Modernization Program
- VIA Rail's Fleet Replacement Program

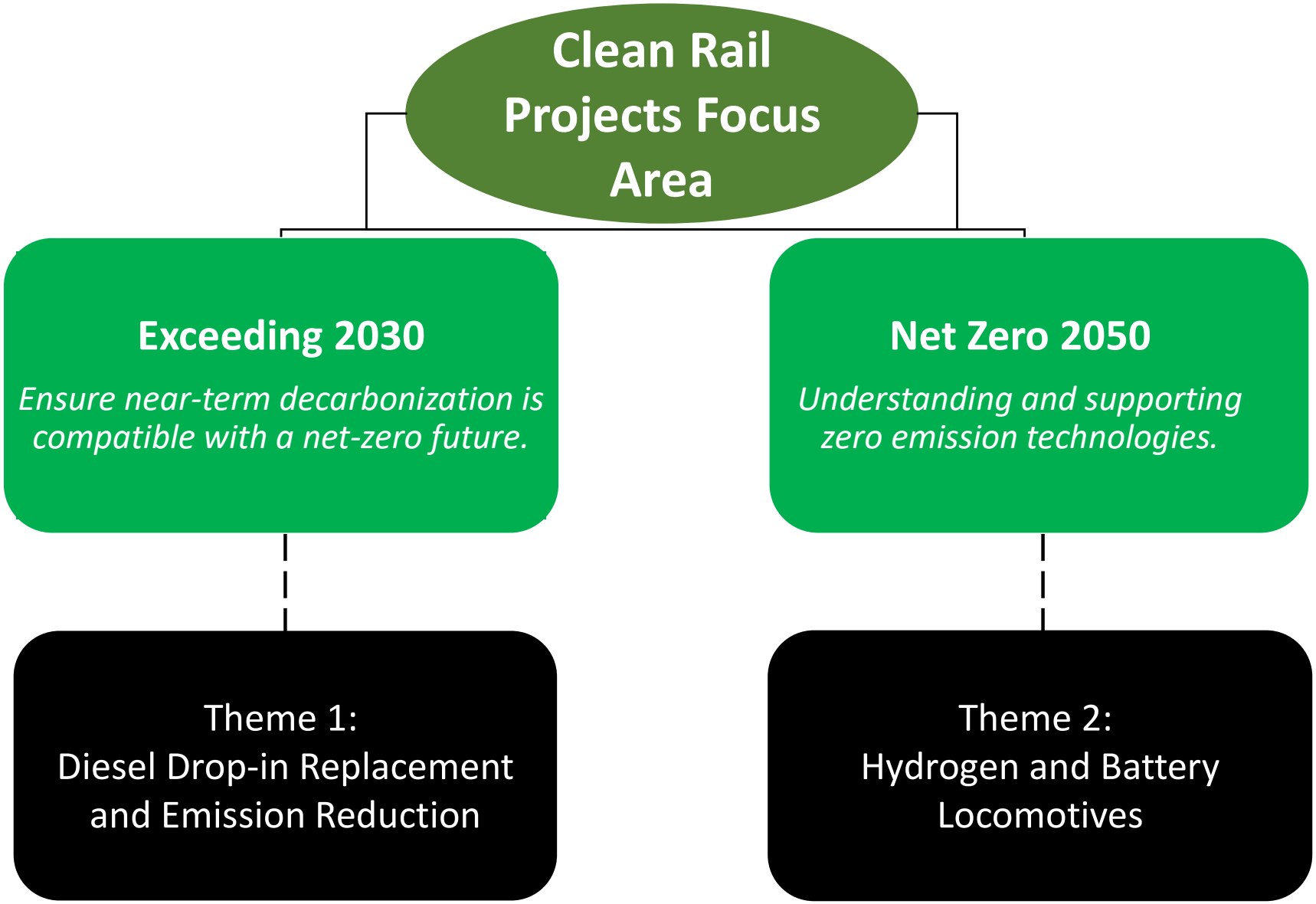


Zero-Emission Technologies Feasibility

- CP's Hydrogen Locomotive Program
- CN's battery-electric locomotive
- Southern Railway of British Columbia's hydrogen-electric switcher locomotive
- VIA Rail and the Government of Canada's HFR Project



Clean Rail RD&D - Themes



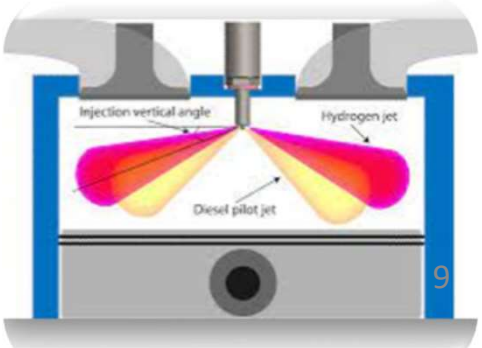
Theme #1: Drop-in Diesel Replacements and Emissions

GHG emissions –

Carbon Pricing and Clean Fuel Regulation

TC's RD&D focus

- Assessing operational performance of fuels
- Examining and controlling CAC emissions
- Hydrogen-diesel combustion feasibility

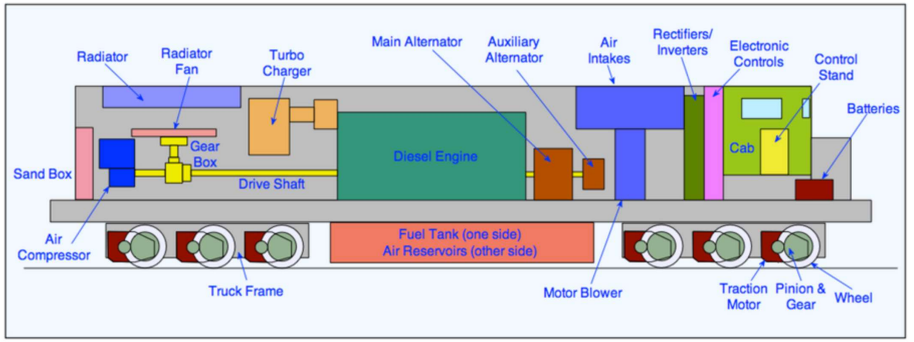


Theme #2: Hydrogen and Battery Locomotives

Technology Assessment

Risks and Hazards

Codes and Standards



Opportunities for Collaboration

Share research and have open conversations about the benefits, risks and challenges of new technologies

Align North American codes and standards to encourage interoperability & reliability

Share knowledge to inform safety oversight approaches for new technologies

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Thank you/Questions?

Jim Lothrop P.eng
Director General, Innovation Centre
Transport Canada
Jim.lothrop@tc.gc.ca

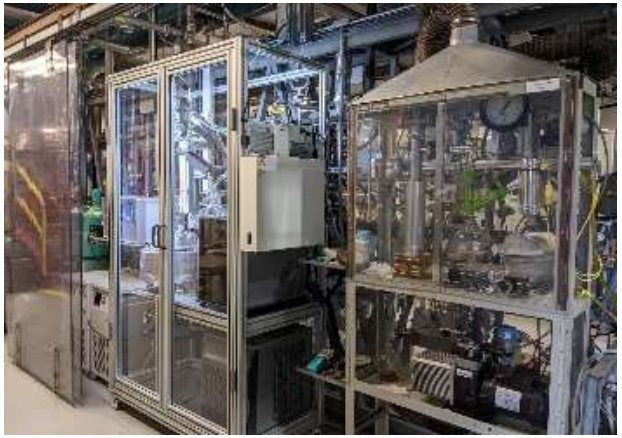
Matthew Krech
Chief, Rail and Aviation RD&D, Innovation Centre
Transport Canada
matthew.krech@tc.gc.ca

ANNEX A: Theme #1 – Diesel Drop-in Replacement and Emissions Reduction Projects

ANNEX A: Theme #1 Projects

No.	Project Title	Project Type
A1	Higher-Concentration-Blend Lignin-Derived Diesel Fuels for Rail Applications	**Transport Canada**
A2	Locomotive Emissions and Alternative Fuels Testing	
A3	Two-in-One Catalytic Converter for Simultaneous Removal of NOx and PM from Locomotives	
A4	EcoRail (Rail Vision)	
A5	Experimentation Fund – Hydrogen-Diesel Combustion System for Railway Locomotives – Testing Report	
A6	Southern Railway of British Columbia	**CTS-RD grant program**

A1. Higher-Concentration-Blend Lignin-Derived Diesel Fuels for Rail Applications



Project Description

Develop a diesel fuel derived from lignocellulosic material (lignin), sourced from waste biomass generated from Canada's forestry and agriculture industries, as a lower carbon intensity drop-in fuel.

Scope

- Develop an effective process for producing a lignin-derived drop-in replacement for diesel fuel) and verification of various blends.
- Advance the state of lignin-derived diesel production technology. Demonstrate that the oil product is a drop-in replacement for petroleum diesel by characterizing the highest L-diesel blends against CGSB 3.517 diesel fuel specifications, which are used for locomotives.
- **Collaborators: CanmetENERGY-Ottawa (CE-O)** is developing conversion technology and fuel blend, CRB Innovations (industrial partner) is developing the lignin product that is used as the feedstock.

Results

- ✓ Demonstrated that CE-O's catalytic hydrotreating process produces high quality oil products.
- ✓ The 100% L-diesel met 10 of 13 CGSB 3.517 specifications for Type A and B fuels.
- ✓ The 3 that were not met (electrical conductivity, lubricity, and cetane number) could be addressed using additives that are commonly used in ultra-low sulphur diesel
- ✓ Overall, the results indicate that there is no blending limit for L-diesel as a locomotive fuel.
- ✓ Supporting progression from TRL 6 to 7 of the lignin-diesel production process.
- ✓ See attached link for additional information (Lignin-Derived Drop-in Renewable Diesel Fuels for Rail Applications)

Next Steps

1. Explore opportunities to scale up production of L-diesel and carry out engine tests. Focus on engine wear-and-tear and emissions profile.
2. CE-O is setting up conversations with CRB Innovations to discuss scale-up
3. TC will look for rail partners that would be interested in becoming involved with engine testing.

A2. Locomotive Emissions and Alternative Fuels Testing

Project Description

- Enhance the quality of data used to estimate greenhouse gas (GHG) and criteria air contaminant (CAC) emissions from locomotives, such as spatial accounting of fuel consumption, temporal and spatial information of renewable content in fuel consumed, information about CAC emissions profile gathered from physical testing, etc.
- Seek out emission testing opportunities to contribute to CAC and black carbon emission knowledge, by working a partner to improve the collection and dissemination of fuel consumption information and GHG emission accounting.

Objectives:

- Determine how emissions, particularly CAC emissions, vary across locomotives with different 'generations' of design
    1. Determine how changing renewable fuel content in diesel affects CAC emissions profile
    2. Determine relationship between black carbon emissions and PM emissions

- Contract the development of locomotive testing plans, execution of specific movement test runs/routes, and stationary and in-service emission testing on an as needed basis.

- **Collaborators**: Environment and Climate Change Canada (ECCC), Heath Canada, Natural Resources Canada (NRCan), University of British Columbia (UBC), railway partners

Results

✓ Defined areas of emission inventory accounting and emissions factors to improve.

Next Steps

1. Evaluate potential linkages with the renewal of the Railway Association of Canada – Transport Canada Memorandum of Understanding for Reducing Locomotive Emissions
2. Work to better define emission testing needs of government and industry
3. Conversations with railway companies to find interest in alternative fuel procurement and testing.

A3. Two-in-One Catalytic Converter for Simultaneous Removal of NOx and PM from Locomotives

Project Description

- Current locomotive designs employ exhaust gas recirculation to control NOx and diesel particulate filters to control PM at Tier IV locomotive emission standard levels. This configuration reduces engine output power.
- This project is an attempt to develop a technology that could reduce NOx and PM at lower-cost and with better engine power performance with a target of developing technology that can be retrofitted onto older locomotives.

Scope

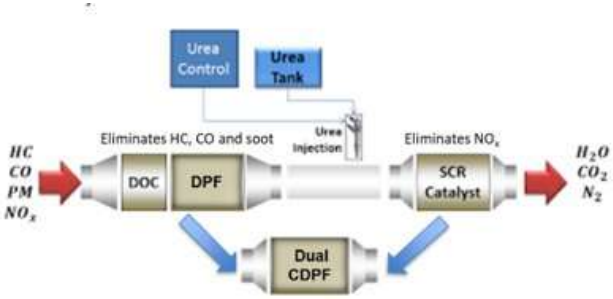
- NOx and PM emissions only. These are the main diesel emissions addressed by exhaust aftertreatment.
- **Objective:** Develop, and validate, a prototype catalytic converter that would control emissions of NOx and PM from a Tier 0 locomotive without a penalty to engine power.
- **Collaborators:** CanmetENERGY-Ottawa (CE-O) will develop and assemble the prototype catalytic converter. CanmetMINING-Ottawa is supporting by providing diesel mining engines for demonstration testing.

Results

- ✓ In-lab verification that the catalyst works as intended
- ✓ Results from the test engine indicate that the prototype catalyst is effective at removing particulate emissions, over 88%. However, the selective catalytic reduction portion did not perform as envisioned, only achieving an average reduction of NOx emissions of 15%. This is far below the capabilities of conventional commercial SCR systems.
- ✓ Despite the poor NOx performance, NO2 reduction was good, over 84% reduction.
- ✓ The TRL for the two-in-one catalytic converter remains at 3.
- ✓ Report is available on the open government site GEOSCAN (2-in-1 Catalytic Converter Evaluation)

Thoughts for future work

Additional research into the SCR catalyst is required. Problems identified included blockage by DPM that was not fully purged, thermal instability within the catalyst, and deactivation of the reactants. Testing with different coatings, DPM management systems, and ratio of soot oxidation and SCR catalyst could be pursued.

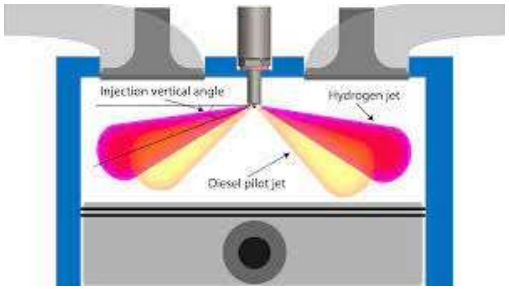


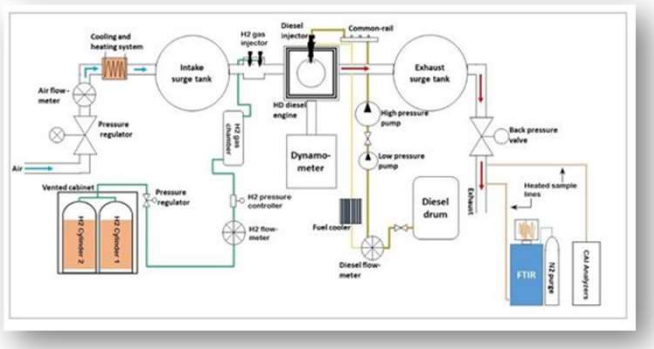
A4. Experimentation Fund – Hydrogen-Diesel Combustion System for Railway Locomotives – Testing Report

Project Description

The Government of Canada and NRC are investigating hydrogen-diesel combustion's feasibility for reducing emissions from locomotives in the context of Canada's 2030 and 2050 GHG emissions goals. The final draft of the report will be provided later in 2023.

- Dual-fuel combustion involves replacing a portion of diesel fuel with hydrogen. As a carbon-free energy carrier, it is hypothesized that partial hydrogen use could notably reduce GHG and PM emissions, while maintaining diesel-like efficiency.
- Currently, industry has done some work on the feasibility and business case for hydrogen/diesel combustion in trucks, but not for rail. If this technology is feasible, it could open alternate paths to reducing emissions in rail.
- **Objective:** Experimentally test and investigate the combustion and emissions performance of a heavy-duty hydrogen/diesel dual fuel combustion engine under locomotive operating conditions, and evaluate whether it is feasible for locomotive applications





Results

- ✓ A literature review and testing report were produced which evaluated the current use of hydrogen-diesel co-combustion in rail and other modes.
- ✓ It was found that the overall technological readiness level was on the low end (TRL 2-3), as research from industry and academia is limited to lab testing.
- ✓ GHG emissions benefits were highest (up to 50% reduction) when maximum hydrogen energy fraction was used (50%), but this was counterbalanced by an increase in NOx emissions. The GHG emissions benefits are dependent on the carbon-intensity of the hydrogen that is produced.
- ✓ The high combustion temperature of hydrogen makes it difficult to use in a diesel engine at high loads; the pressure imposed on the cylinders can quickly exceed the material limits of the engine.
- ✓ Enabling the use of a high hydrogen ratio would require significant engine modification.
- ✓ Many parameters must be balanced when determining optimum injection timings. Advancing injection timing led to a reduction in PM and CO emissions, but also further increased NOx emissions. On the contrary, retarding injection timing reduced peak pressure rise rate, which may allow for higher hydrogen content (thus reducing GHG emissions).

Next Steps:

- The testing and literature review portions of the project are complete. The final task is to develop the final report, which combines conclusions gathered from the testing report and literature review into a final, published paper. This is expected to be completed by June 30, 2023, and will be posted to Transport Canada's report database.

A5. EcoRail (Rail Vision)

Project Description

Implement EcoRail, an AI technology software that supports the collection, management and interpretation of fuel consumption data in order to reduce GHG and CAC emissions related to passenger train operation, into VIA Rail Canada's framework and provide training, technical support, oversight services, and consultation. This involved configuring the data pipeline of EcoRail with VIA Rail's event recorder data, configuring its models for the new rail environment (map of routes, locomotives, topography, etc.), and configuring EcoRail's output to match VIA Rail's viewing/permission preferences.

Scope

- Prove and validate the usefulness of EcoRail's fuel efficiency and performance insights for use on other passenger operations, as well as the rail infrastructure of the high frequency Quebec City – Windsor rail corridor. The follow activities were undertaken:
    - Data collection from existing equipment and automation of the data transfer process
    - Configured models to VIA's environment (map of routes, locomotives, topography, etc.)
    - Conducted testing in VIA's simulator though a baseline run without instruction being compared with runs along the same sections of track while receiving driving behaviour recommendations from the EcoRail app
    - Modified algorithms to reduce time delay while increasing savings
- Through implementation of EcoRail, assist VIA Rail to better track its performance, reduce its environmental impact and prepare the ground to enhance training in the future.

Results

- ✓ The testing results of the final trials, following application improvements and incorporation of feedback on priorities, in Via Rail's simulator demonstrated savings of **15%** of Via Rail's diesel usage, with only 2 min of travel time, added over nearly 4.5 hours of travel (less than 1%).
- ✓ This produced a projecting annual savings, based on VIA's pre-pandemic schedule, of up to **1.55 million liters of diesel**, over **4 million tons of CO2** annually for the Toronto-Ottawa corridor, representing only a quarter of operations.

Next Steps

- Explore interest in additional collaboration with VIA
- 50 consecutive hours of testing, without issues, in the VIA simulator is required prior to in-cab testing
- Increase reliability by testing the application in-cab across all regions, even those without cellular coverage

CTS-RD Projects – Theme #1

Clean Transportation System – Research and Development Program (CTS-RD)

The CTS-RD program provides grant funding to advance scientific knowledge, and the development of technologies, that reduce greenhouse gas (GHG), and/or criteria air contaminants (CAC) emissions from the aviation, marine, and rail modes of transportation. The following project received grant funding in 2021:

A6. Southern Railway of British Columbia (SRY) Limited:
SRY has launched a pilot project to transition one diesel locomotive engine to 100% biodiesel-power (B100). The test locomotive is being used in SRY's day-to-day freight rail operations in Southern British Columbia. The project will validate train performance and emission reductions. This is the first rail B100 pilot test in Canada.

ANNEX B: Theme #2 – Hydrogen and Battery Locomotives Projects

ANNEX B: Theme #2 Projects

No.	Project Title	Project Type
B1	Hydrail Switcher Locomotive Project	**Transport Canada**
B2	Hydrail Railway Transition in Canada: Technological, Operational, Economical, and Societal (TOES) Barriers and Opportunities	
B3	Hydrogen-Powered Locomotives: Assessment of Risks, Mitigation Strategies, and Analysis of Applicable Standards	
B4	Hydrogen and Battery-Powered Locomotives: Detailed assessment of Risks and Mitigation Strategies (Phase II)	
B5	Ballard Power Systems	**CTS-RD grant program**
B6	Canadian Nuclear Laboratories	
B7	CSA Group	
B8	University of British Columbia	

B1. Hydrail Switcher Locomotive Project (2019-2020)

Project Description

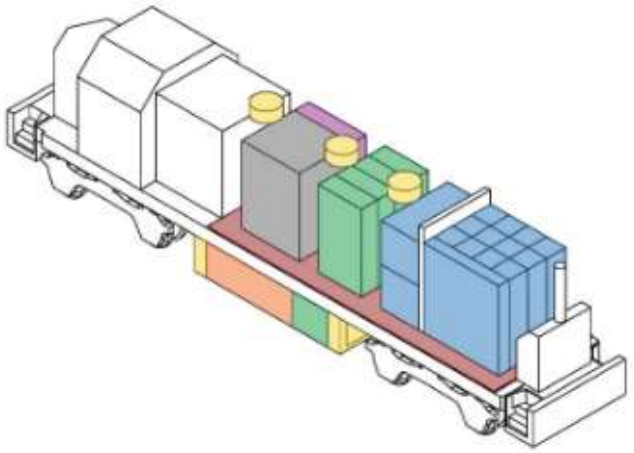
- Explore the design and deployment requirements for a hydrogen fuel cell switcher locomotive operating within a trainyard with supporting fuel infrastructure.
- For this project, the conceptual hydrogen switcher locomotive would be retrofitted from an existing diesel locomotive.
- The study serves as a thought-experiment to provide a preliminary assessment of the readiness of the needed technologies, costs to build and operate, and high-level perspective of how the conceptual design would fit in Canada's regulatory regime.

Results

This report helped to inform the Government of Canada's assessment of the technological readiness of hydrogen locomotives and fueled the development of many hydrogen-related clean rail projects from 2020-onwards. In summary, the report:

- ✓ Determined that the technology is ready for use in rail, but that it has not been verified when integrated as a full locomotive package.
- ✓ Hydrogen fuel cells could match or exceed the performance of diesel engines
- ✓ Found that there would be meaningful GHG and CAC emission reductions, but GHG emission reductions would be dependent on the carbon intensity of the hydrogen that is used.
- ✓ Determined that a major area of uncertainty in the cost of converting a locomotive from diesel to hydrogen fuel cell is the power control system. Such a system has not been developed and the R&D needed to create it could increase the costs of early prototypes significantly.
- ✓ Determined that there are no inherent regulatory barriers to the deployment of the locomotives in Canada, but that rules and codes and standards for their design and operation are not well defined.
- ✓ Determined that the cost of operating a hydrogen locomotive would generally be higher than a diesel locomotive unless the cost of diesel were to increase dramatically compared to hydrogen.
- ✓ Provided recommendations to inform future work, which included investigating high-level design, hydrogen capacity, hydrogen demand, and costs and benefits, which were out of scope for this report.

The report is available from Transport Canada's report database.



B2. Hydrail Railway Transition in Canada: Technological, Operational, Economical, and Societal (TOES) Barriers and Opportunities

Project Description

Examine what would be necessary to shift rail in Canada to be fueled by hydrogen instead of diesel, with the associated cost estimates, transformations required, and the associated benefits and challenges that would need to be overcome. The time horizon for this outlook are the years 2030 and 2050.

Results

- ✓ Hydrogen conversion is technically feasible as many of the components are at a high technology readiness level but low commercial readiness level as an integrated system; hence the need for demonstrations and pilot projects under operating conditions.
- ✓ The estimated overall capital cost for converting the rail industry is approximately $32B.
- ✓ Rail produces 6.8 Mt of GHG annually. From 2030 to 2050, 78 Mt of GHG emissions could be averted.
- ✓ Canada will be able to produce sufficient low-carbon hydrogen to meet the 0.5 Mt needed by rail. There will be sufficient generation of low-carbon electricity to produce four Mts of hydrogen if suitable electrolysis plants are installed.
- ✓ The cost of hydrogen will be comparable to diesel under favourable conditions, or twice as expensive under less favourable conditions. While a few thousand new jobs can be created during the conversion, other diesel related employment will gradually decline; the net effect not known.
- ✓ By focusing on the development of hydrail systems, Canada may be able to rapidly build out a domestic market to complement and support its established leadership in fuel cell and electrolysis system development.
- ✓ While this report provides an evolving evergreen roadmap for the conversion, more work will be required to verify the findings with real world applications from pilot demonstrations, including costing profiles, especially hydrogen production and distribution.
- ✓ The report provides an evergreen roadmap for the conversion, highlighting the need for need for US-Canada collaboration on standards and government supported pilots to demonstrate:
    - Technological efficacy - overall performance is similar to (or better than) diesel
    - Economical practicability - hydrail systems can generate positive returns on invested capital
    - Safe operability - comprehensive testing, simulation and analysis informs risk assessment and mitigation strategies.
- ✓ Please see the following link for more information Hydrail Railway Transition in Canada - Technological, Operational, Economical, and Societal (TOES) Barriers and Opportunities

Transport Canada Transports Canada

B3. Hydrogen Powered Locomotives Assessment of Risks, Mitigation Strategies, and Analysis of Applicable Standards

Project Description

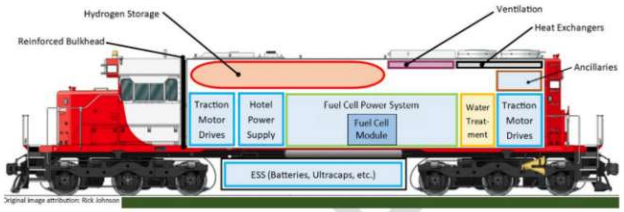
The Government of Canada and NRC are conducting a literature review of existing fuel cell locomotive deployments to date to assess design and operational profiles. They are undertaking a preliminary study of technical and operating risks associated with freight locomotive deployments and use a comparative risk analysis methodology to quantify and rank severity of the risks.

Scope

Review risk and hazards of mainline and yard fuel cell switching operations, including associated delivery to fueling sites, storage on site, on-board the locomotive, personnel training, emergency response, crashworthiness, fire prevention, etc.

- **Collaborators:** NRC is conducting the research. Steering committee present with various government departments providing support and guidance.

Identify approaches for evaluating risks and best methods to mitigate risks. Assess how existing codes and standards could be leveraged to support deployment in near-term tests.



Results

Three reports were generated from this work

- ✓ The first report summarized the present state of freight diesel-electric locomotives, and the proposed design, operation, maintenance, and fueling of a hydrail and battery locomotive alternative.
- ✓ The second report drew from available literature to develop a risk and hazards assessment for hydrogen fuel cell powered locomotives, and included the risks and hazards introduced to locomotive operations due to the additions of fuel cell, hydrogen, and battery systems.
- ✓ The third report presented a review of codes and standards that are applicable to hydrail applications. It was found that there were numerous overarching standard, but also a number of gaps, particularly related to highly prescriptive standards that may need additional classifications for hydrogen as a fuel similar to other fuels (i.e. compressed and liquified natural gas).
- ✓ Created an open, and evergreen dialogue between government, railway companies, and the broader rail industry about the risks and hazards associated with the operation of hydrogen and battery powered locomotives in Canada.

All three reports have been published on Innovation Centre's report database.

Next Steps

1. Phase II of the project; which includes risk assessment for battery-powered locomotives, and an expansion of risks for hydrogen fuel cell locomotives is underway.
2. It has become clear that, at this point, physical testing is needed to build knowledge for how to mitigate risks and hazards.

B4. Hydrogen and Battery-powered Locomotives: Detailed assessment of Risks and Mitigation Strategies (Phase II)

Project Description

Build upon the previous Phase I work by evaluating the risks and hazards for battery locomotives:
This will include a literature review, and compilation of risks and hazards using the formats listed above.

Improve the risk assessment framework

- Produce a risk management framework for hydrogen and battery locomotives which follow nationally-accepted guidelines (i.e. ISO 31000:2018)
- Document hazards, estimate their risk, and evaluate risk mitigation techniques using a nationally accepted methodology (e.g. ISO 12100:2010, CSA EXP11:20).

Carry out targeted consultations with rail industry to accomplish the following:

- Assist with calibrating and adding to the risk & hazards documented to date
- Obtain initial impressions of the type of physical tests needed by industry to better understand the best ways to mitigate hazards associated with components or to identify component designs that are better optimized for rail.

Scope

- Includes freight, line-haul, switcher, and commuter passenger rail
- Systems within the locomotive envelope or associated with fuel storage locomotive operations (e.g. tender car) which will need to be altered in a hydrogen and/or battery powered locomotive compared to a diesel locomotive.
- Operational factors, including human factors considerations, and operations, maintenance, and fueling/defueling of the locomotive will also be investigated.

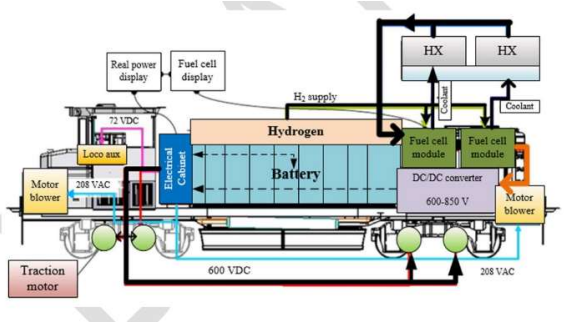
Collaborators: NRC is conducting the research. Steering committee present with various government departments providing support and guidance.

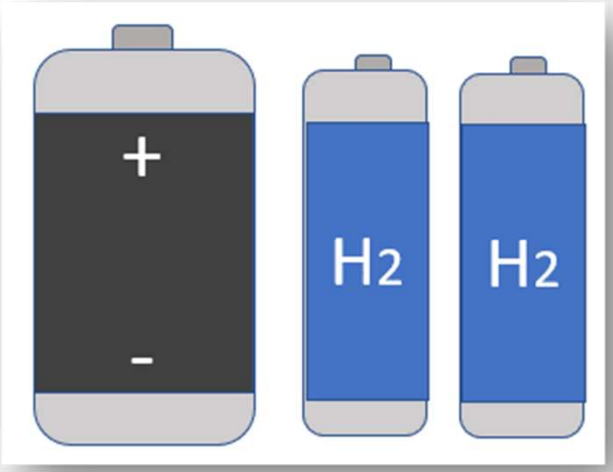
Results

✓ Review of battery locomotive deployments is complete
✓ Preliminary assessment of battery locomotive risks and hazards has been prepared

Next Steps

1. Begin preparation of consultation materials
2. Refine battery and hydrogen fuel cell locomotive risk assessments





Transport Canada Transports Canada

CTS-RD Projects – Theme #2

Clean Transportation System – Research and Development Program (CTS-RD)

The CTS-RD program provides grant funding to advance scientific knowledge, and the development of technologies, that reduce greenhouse gas (GHG), and/or criteria air contaminants (CAC) emissions from the aviation, marine, and rail modes of transportation. The rail projects that received grant funding in 2021 related to advancing hydrogen and battery locomotives are described in the following two slides:

B5. Ballard Power Systems:
The project is a feasibility study to assess the viability of replacing diesel generators with hydrogen fuel cell (HFC) power generators to manage the train's auxiliary power demands, i.e. lighting, heating, power. The purpose is to study the technical feasibility and potential benefits, in order form a potential future demonstration project.

B6. Canadian Nuclear Laboratories (CNL):
CNL is conducting a high-level quantitative risk assessment of the use of hydrogen as a fuel in freight trains. Hydrogen detection and mitigation measures, and relevant regulations, codes and standards are being assessed to develop appropriate risk mitigation strategies where required. To further support this work, CNL is developing a quantitative risk assessment tool designed to be used for case studies. This forms a part of CNL's in-kind contributions to the project. The analysis from this work will help to determine fatalities per year for a given hydrogen installation. The project is engaging industrial partners to provide operational data and feedback to support the risk assessment.

CTS-RD Projects – Theme #2

Clean Transportation System – Research and Development Program (CTS-RD)

B7. CSA Group:
CSA Is developing technical specifications for hydrogen fuel cell and battery-powered locomotives. Working groups include members from railway companies, manufacturers of locomotives, fuel cells, academia, and National Research Council of Canada. In another part of this project, CSA Group is conducting a project to identify codes and standards from international sources that could be used to inform safe design and operation of hydrogen fuel cell and battery-powered locomotives. They will produce a roadmap for developing a more robust codes and standards ecosystem and identify gaps where North American homegrown standards may be needed.

B8. University of British Columbia (UBC):
UBC is investigating the technical feasibility of a hydrogen-powered locomotive pilot project by analyzing the technical parameters, operational constraints, and safety risks as well as mitigation strategies for the fuel cell and battery retrofits to be utilized in the locomotive. A techno-economic analysis and life cycle costing of the retrofits is being conducted in order to examine the economic viability of the hydrogen-powered locomotive, along with a study of the environmental sustainability and social acceptability of the retrofits. The project is also developing a multi-criteria decision support system for future hydrogen-powered locomotive projects considering their technical, economic, environmental, and social aspects.