NZ Transport Knowledge Hub Talk

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Sustainable Transport Safety Lab
Laboratoire de Sécurité dans les Transports Durables

SMARTer Growth Partnership

Agenda

1. Why might we even consider Hydrogen?
2. How do we get ‘green’ hydrogen production?
3. How does a Hydrogen Fuel Cell work?
4. How does H2 fit into Canada’s GHG emission reductions plan & budget?
5. Why decarbonize rail transport?
6. Why hydrail regional inter-city ZE passenger rail?
7. Reflections on New Zealand

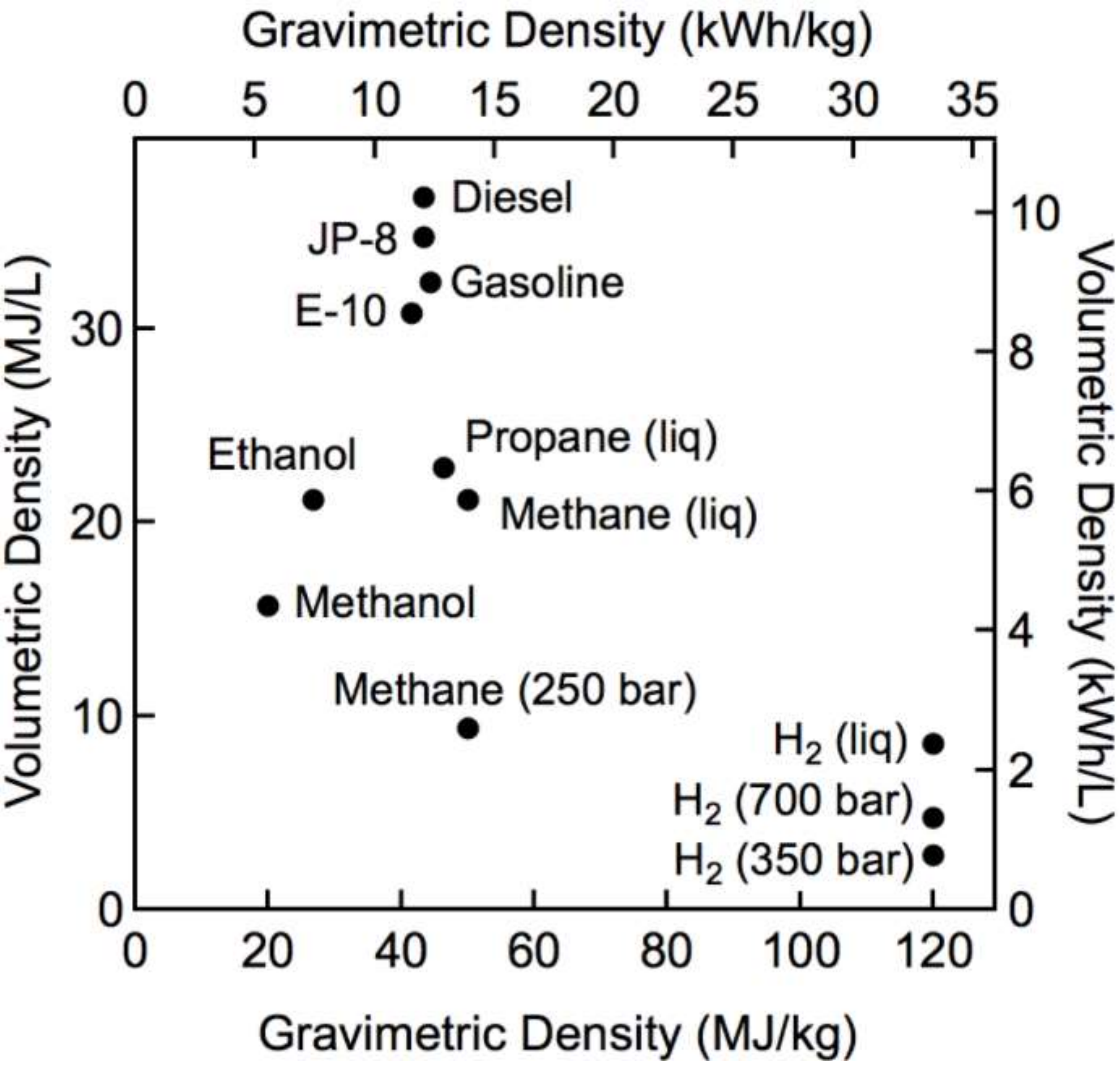
1. Why might we consider Hydrogen?

- ❑Safer than conventional fuels
- ❑Zero Emissions
- ❑Ubiquitous
- ❑Longer distances, heavier loads
- ❑Multiple production pathways
- ❑Higher power efficiency than diesel
- ❑International Hydrogen Agreement
- ❑Canadian Hydrogen Strategy
- ❑Just Transition for our Energy Sector

Why not H2? (Short term challenges)

- ❑Currently 4x the cost of diesel to produce (at current scales)
- ❑ At higher pressures, balance of plant and tanks cost more & need more space onboard for long distances (requires use of tenders)

https://www.cleanenergyministerial.org/initiatives-campaigns/regional-and-global-energy-interconnection-rgei-initiative/



Hydrogen ‘packs’ much more energy ‘punch’, with no GHG nor particulate emissions

Specific Energy, Energy Density & CO2

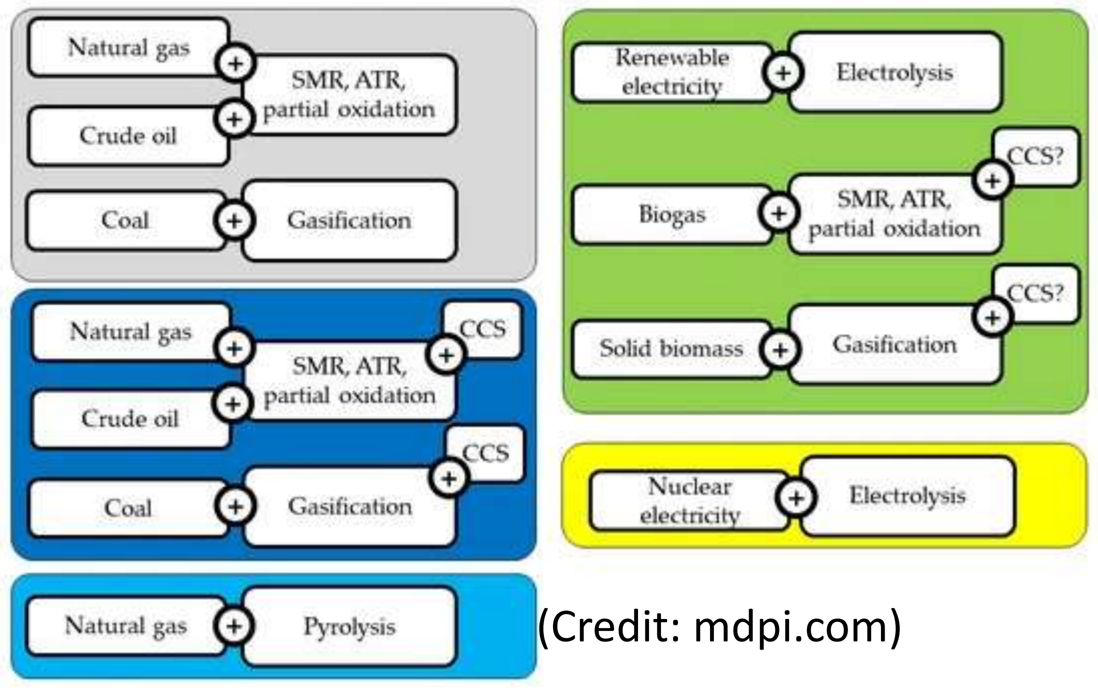
Fuel	Specific Energy kj/g	Density KWH/gal	Chemical Formula	lbs CO2/gal
Propane	50.4	26.8	C3H8	13
Ethanol	29.7	24.7	C2H5OH	13
Gasoline	46.5	36.6	C7H16	20
Diesel	45.8	40.6	C12H26	22
Biodiesel	39.6	35.0	C18H32O2	19
Methane	55.8	27.0	CH4	3
Oil	47.9	40.5	C14H30	20
Wood	14.9	11.3	approx weight	9
Coal	30.2	22.9	approx weight	19
Hydrogen	141.9	10.1	H2	0

Source: DOE, Stanford University, College of the Desert, & Green Econometrics research

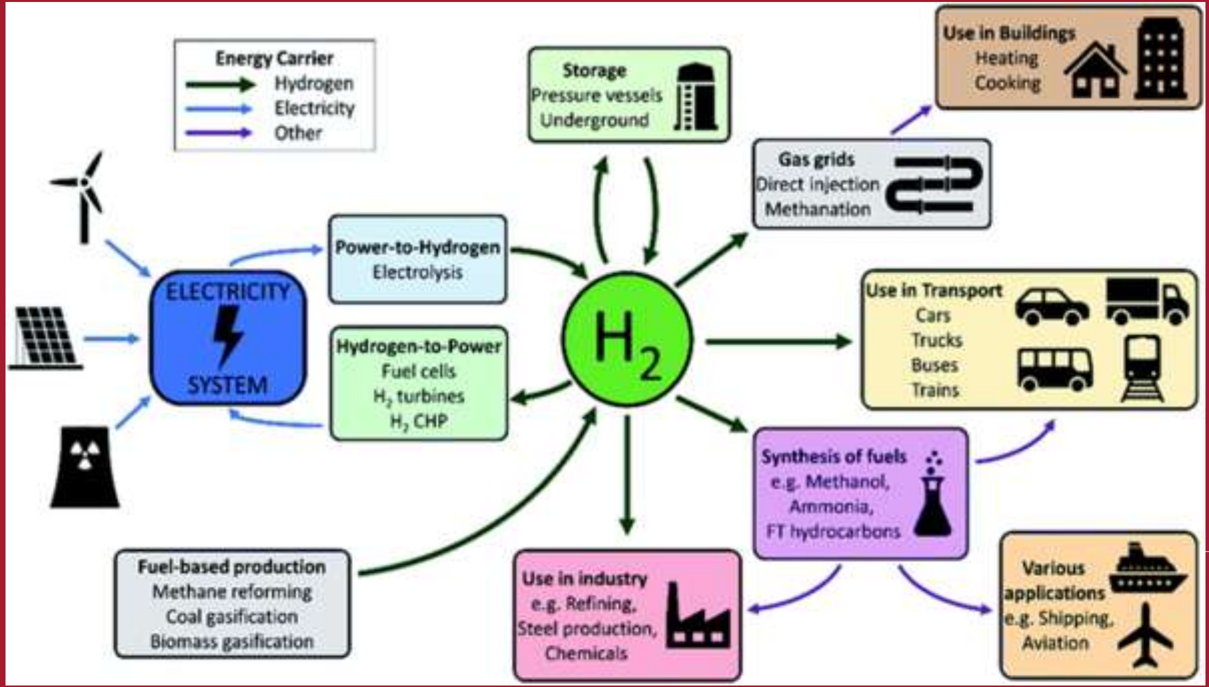
Hydrogen Fuel Tank Leak Ignition Safety – YouTube Video available from: https://www.youtube.com/watch?v=OA8dNFiVaF0

2. Renewables = Green Hydrogen Production

- ✓ Hydro-electric (off-peak)
- ✓ Solar electrolysis
- ✓ Wind electrolysis
- ✓ Bio-mass
- ✓ Bio-gas



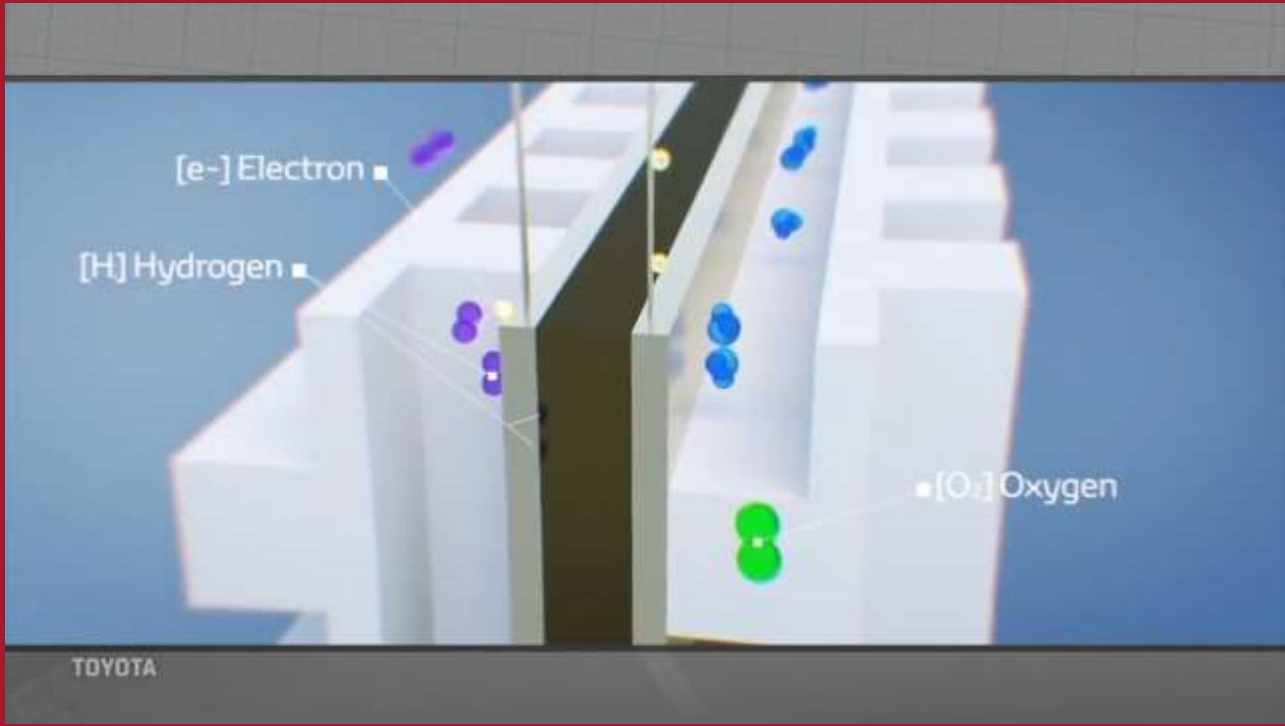
(Credit: mdpi.com)



(Credit: Quarton et al, Sustainable Energy Fuels, 2020, 4, 80-95)

3. How does a Hydrogen Fuel Cell Work?

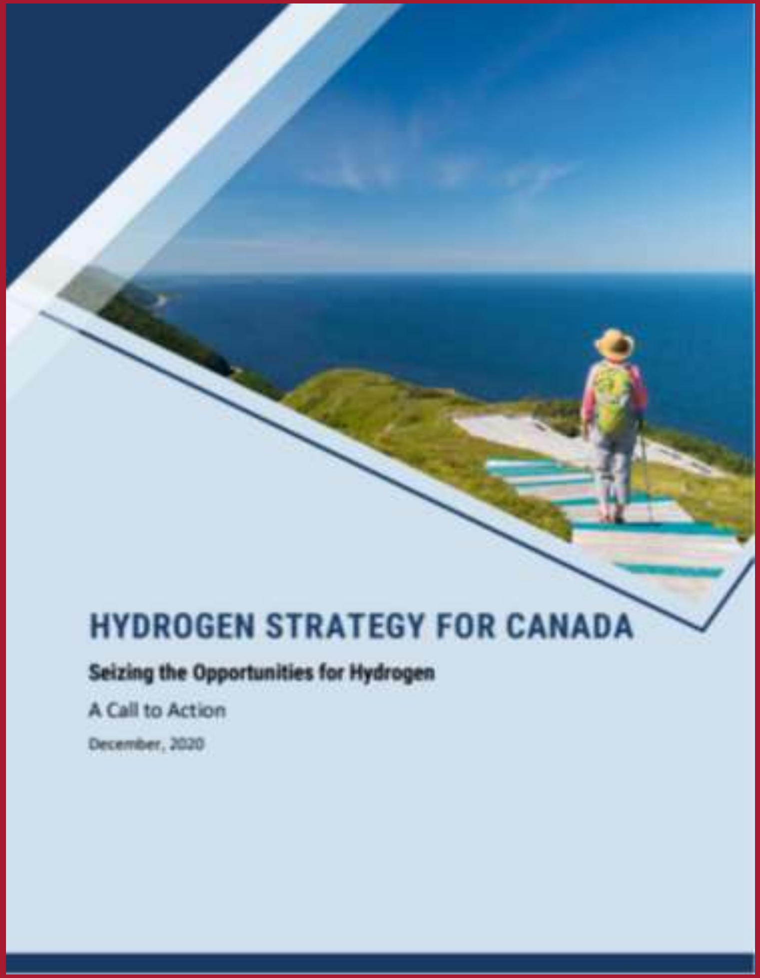
- Hydrogen in ZE transport used via HFCs
- $H2 + O2 \Rightarrow$ Heat + Electricity + Water
- Many great (3 minute) YouTube videos
- Power-train efficiency approaching 60% (30% for diesel engines)
- For longest life & lowest lifecycle cost, HFCs are often paired with batteries in a hybrid power train



Basic diagram of a PEMFC.
Source: http://www.toyota.com/fuelcell/fcv.html

4. How does Hydrogen Fit into Canada's Net Zero Future & Budgets?

- ❑ Strategic partnerships
- ❑ De-risking of investments – funding to partner with industry & provinces
- ❑ Innovation – funding for R & D – academics, industry, government
- ❑ Codes and standards
- ❑ Enabling policies and regulations
- ❑ Awareness
- ❑ Regional hydrogen hubs
- ❑ International markets & partners



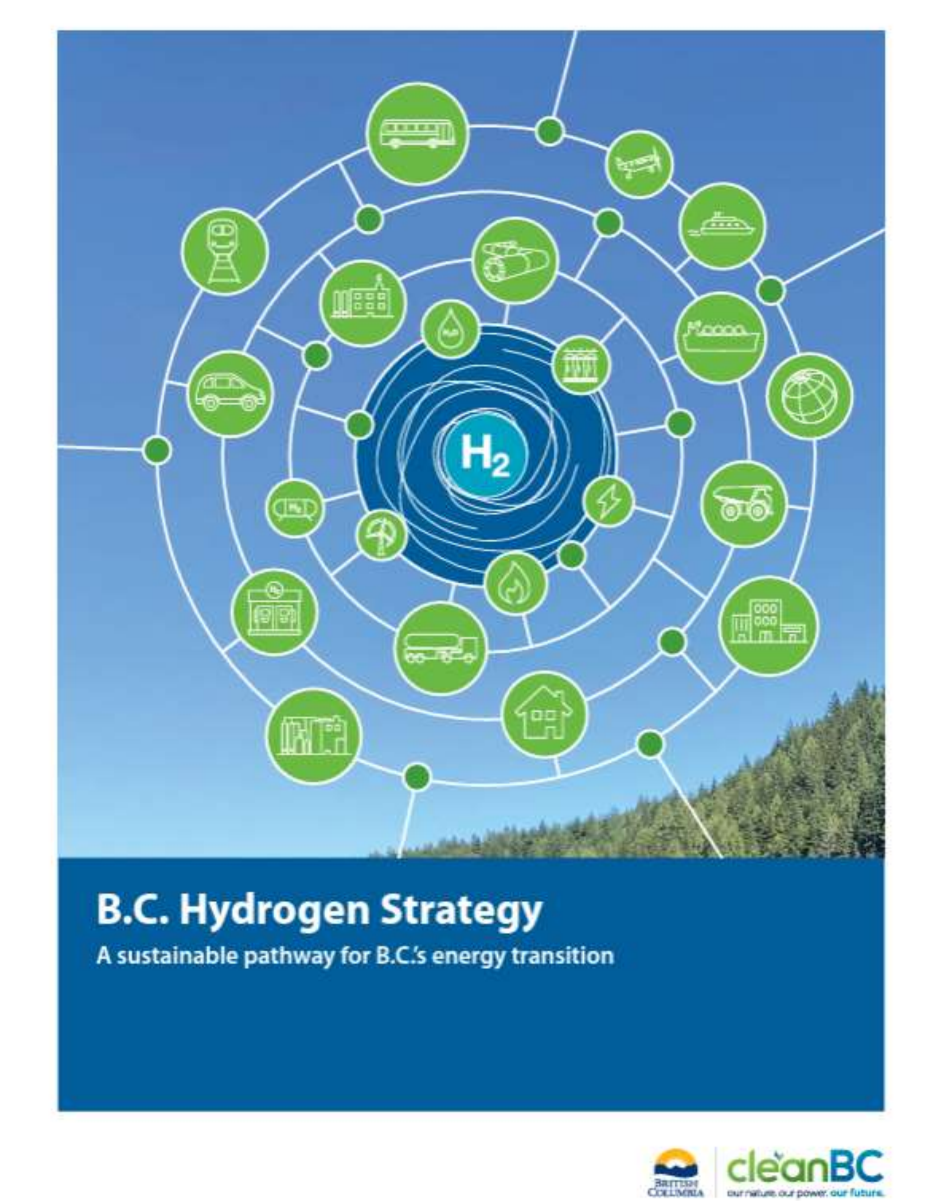
https://www.nrcan.gc.ca/climate-change-adapting-impacts-and-reducing-emissions/canadas-green-future/the-hydrogen-strategy/23080

Federal Budget 2022

- Incentives:
  - $1.7 billion over five years, starting in 2022-23, for Zero-Emission Vehicles (iZEV), including fuel cell electric vehicles.
  - investment tax credit of up to 30% on clean hydrogen production
- Strategic Partnerships:
  - Canada Growth Fund - $15 billion
  - Canada Innovation and Investment Agency - $1 billion
  - Canada Infrastructure Bank (CIB) to invest in private sector-led infrastructure projects for hydrogen production, transportation and distribution
- Industry-Academia-Government:
  - $547.5 million new purchase incentive program for medium- and heavy-duty ZEVs to help trucking companies purchase zero-emission trucks, including fuel cell electric trucks that provide the range, payload and fast-fill capability they may need to maintain the efficiency of their operations.
  - Support for hydrogen hubs and the funding for zero emission transport infrastructure including hydrogen refueling infrastructure
- Regulations: At least 20 % of new light-duty vehicle sales will be zero-emission vehicles (ZEVs) by 2026, 60 % by 2030 and 100 by 2035.

Province of BC H2 Strategy

- Hydrogen BC was established with provincial support in 2020
  - B.C. is a global leader in hydrogen and fuel-cell R & D.
  - Over 50% of Canada's H2 and HFC companies are in B.C.
  - BC accounts for 60% of H2 & HFC research investment
  - Incentives
    - renewable and low-carbon hydrogen;
    - fuel cell electric vehicles and infrastructure;
  - Hydrogen hubs
    - Where production and demand are co-located;
    - B.C. Centre for Innovation and Clean Energy
  - Strategic Partnerships
    - drive the commercialization of new hydrogen technology; and
  - Regulations – Zero-Emission Vehicles Act, & CCS



https://news.gov.bc.ca/releases/2021EMLI0045-001306

BC Interior Hydrogen Hub:

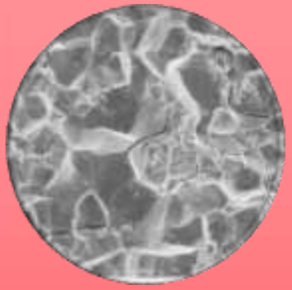
UBC Okanagan Hydrogen Training and Research Knowledge Network (H2-TREK)

Blending

- Renewable hydrogen production
- Blending processes
- Membranes for hydrogen removal

Combustion

- Combustion stability of hydrogen-enriched fuels
- Renewable and bio-derived synthetic fuels
- Synthetic fuels



Materials

- Storage materials
- Pipeline embrittlement
- Cryogenic materials
- Composites

Applications

- Low-carbon aviation
- Hydrail
- ZEB
- Heavy-duty vehicles
- Marine

Safety

- Spills and accidents
- Detonation and flammability
- Trace gas sensing
- Cryogenic safety
- Boil-off gas management

Training

- Recuritment
- Outreach
- Public Engagement
- Curriculum
- Codes, Regulations

UBC Okanagan Hydrogen Research and Training Centre

Figure 27 – Canada's Coast to Coast Rail System

Excerpt from Canada's H2 Strategy

Passenger rail transport in Canada serves 450 communities, with 12,500 km of rail. The most widely used passenger rail is along the Quebec City – Windsor Corridor, moving some 4 million passengers/year. Toronto, Montreal and Vancouver are host to commuter rail systems, and Calgary, Edmonton, and Ottawa currently have light rail systems in operation with new systems in construction in Edmonton, Waterloo and Toronto.

The most comprehensive look at Hydrail in Canada to date has been through the Metrolinx Hydrail study, published in 2018 to look at the feasibility of using hydrogen fuel cell (HFC) trains to electrify the GO networks as an alternative to electrification using conventional overhead wires in Ontario. The study concludes that it is technically and economically feasible to build and operate the GO network using HFC-powered rail vehicles, and the costs of building and operating a Hydrail System are equivalent to that of a conventional overhead electrification system. Implementation of a Hydrail system of this scale and complexity would be innovative and provides a unique set of risks and benefits that Canada could be at the forefront of studying. While no firm commitment to selecting Hydrail has been made, Metrolinx is intending to engage a contractor to upgrade the GO network using a Design-Build-Finance-Operate-Maintain (DBFOM) model. As part of the tender process, bidders will be able to propose both hydrail and overhead wire technology to electrify the GO network.

While no concrete hydrail projects have been initiated in Canada, it is expected that advancements led by Europe and Asia using Canadian core IP will eventually lead to domestic deployments. Applications in Canada could include: rail yard switchers / shunt locomotives, passenger rail, and freight locomotives. Early studies assessing freight applicability of hydrail concluded that hydrail for freight switching is technically and economically feasible.[1] Retrofitting locomotives and replacing diesel engines with zero-emission fuel cell engines is a viable and cost-effective alternative to purpose built hydrail trains, which is an important opportunity given the long (50 year+) lifecycle of locomotives.

[1] Change2Energy Services, Assessment of the Design, Deployment Characteristics and Requirements of a Hydrogen Fuel Cell Powered Switcher Locomotive, June 2020

5. Why decarbonize rail transport in Canada?

- ❑ Rail emits less than 3% of Canada's GHG emissions, but this will grow as other sectors and modes decarbonize
- ❑ Our North American trade partners are decarbonizing, we must stay competitive
- ❑ Mobile E - Battery, Overhead wire, HFC/Battery hybrid (hydrail) – exists and is being implemented globally
- ❑ Fuel savings, emission penalties, retrofits are creating attractive business cases
- ❑ Shareholders, neighbors, the public, and national climate action plans are demanding it
- ❑ It's the right thing to do for our 'Common Future'

Railpower GG20B Green Goat

Hydrogen Fuel Cell Retrofit

Natural Sciences and Engineering Research Council of Canada
Conseil de recherches en sciences naturelles et en génie du Canada
Canada

SRY Rail Link

Hydrogen In Motion

DB Engineering & Consulting

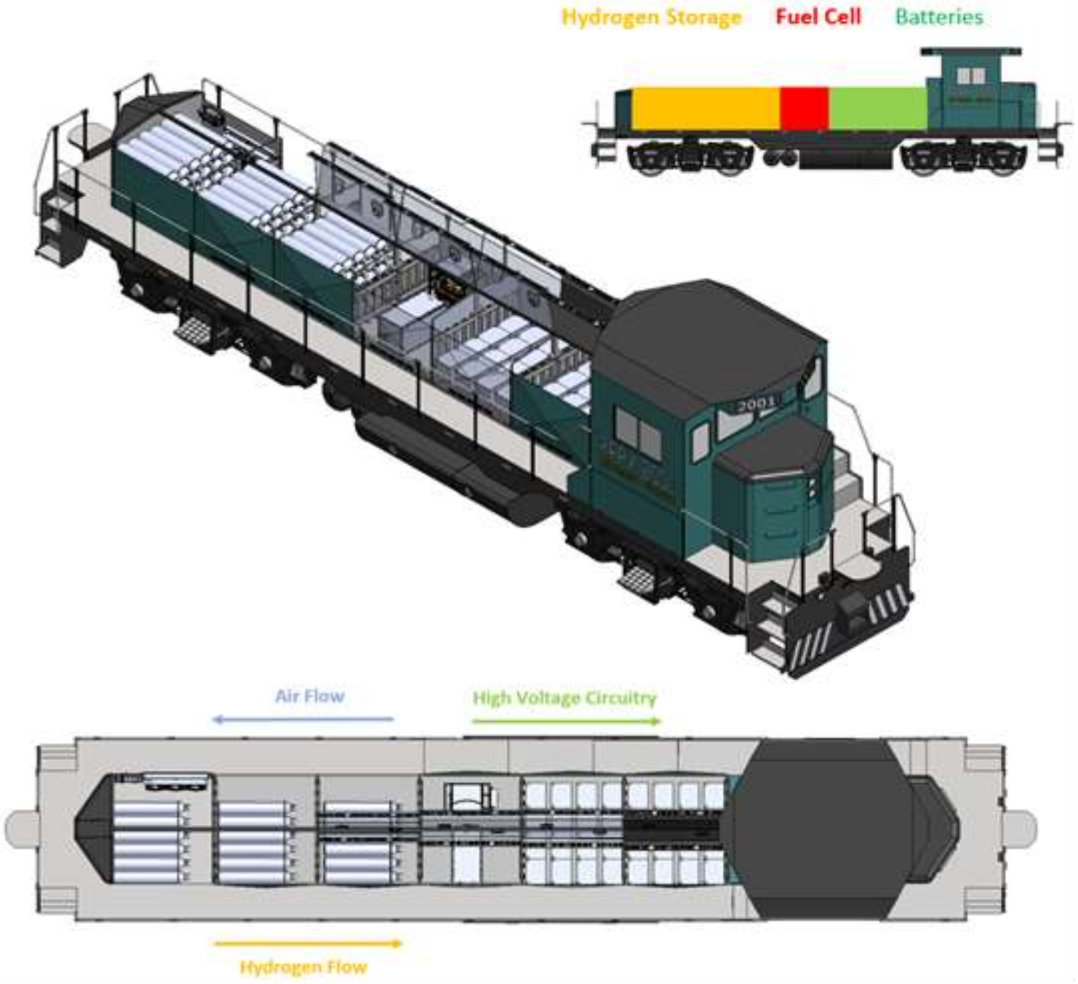
Tye Boray (BASc student)
Cassidy Murrell (BASc student)
Kaden Workun (MASc student)
Mohamed Hegazi (PhD candidate)
Dr CS Wang (PDF)
Dr Joshua Brinkerhoff (Co-PI)
Dr Gordon Lovegrove

Green Goat Switcher Hydrail Retrofit

School of Engineering UBC Okanagan

Funding Sources & Research Focii

- NSERC (Discovery, Engage, Alliance)
- CFI
- Industry: SRY, H2M, DB, Cariboo
- BC: KDF, ARC



WP 1: Mechanical integration of fuel cell system (HFC)	• Supervisor: Dr. Gordon Lovegrove + Dr. Joshua Brinkerhoff • HQP: MASc 1, PhD1 • Industry Partner: H2M, SRY
WP 2: Hydrogen storage and delivery sub-system (STORAGE)	• Supervisor: Dr. Joshua Brinkerhoff • HQP: MASc1, PhD1 • Industry Partner: H2M, SRY
WP 3: Electrical integration of powertrain components (ELECTRICAL)	• Supervisor: Dr. Gordon Lovegrove • HQP: MASc2 • Industry Partner: SRY • Consultants: DB
WP 4: Locomotive in-service demonstration (DEMO)	• Supervisor: Dr. Gordon Lovegrove • HQP: PDF, USRA1, PhD1 • Industry Partner: H2M, SRY • Consultants: DB

Schedule:

- System Components Testing – 2022
- Full Locomotive Operation – 2023
- Certified for Commercial Use - 2024

Hydrail Success Stories

1999-2002: Fuel cell mining locomotive. By Vehicle Projects LLC

2003: Successful test of a hydrogen powered motorized bogie by Railway Technical Research Institute (RTRI), and East Japan Railway Company (JR East)

2005-2007: Fuel cell-battery hybrid shunt locomotive, Vehicle Projects LLC & BNSF Railway Company

2006: Fully functioning Hydrail railcar, Railway Technical Research Institute (RTRI) in Japan.

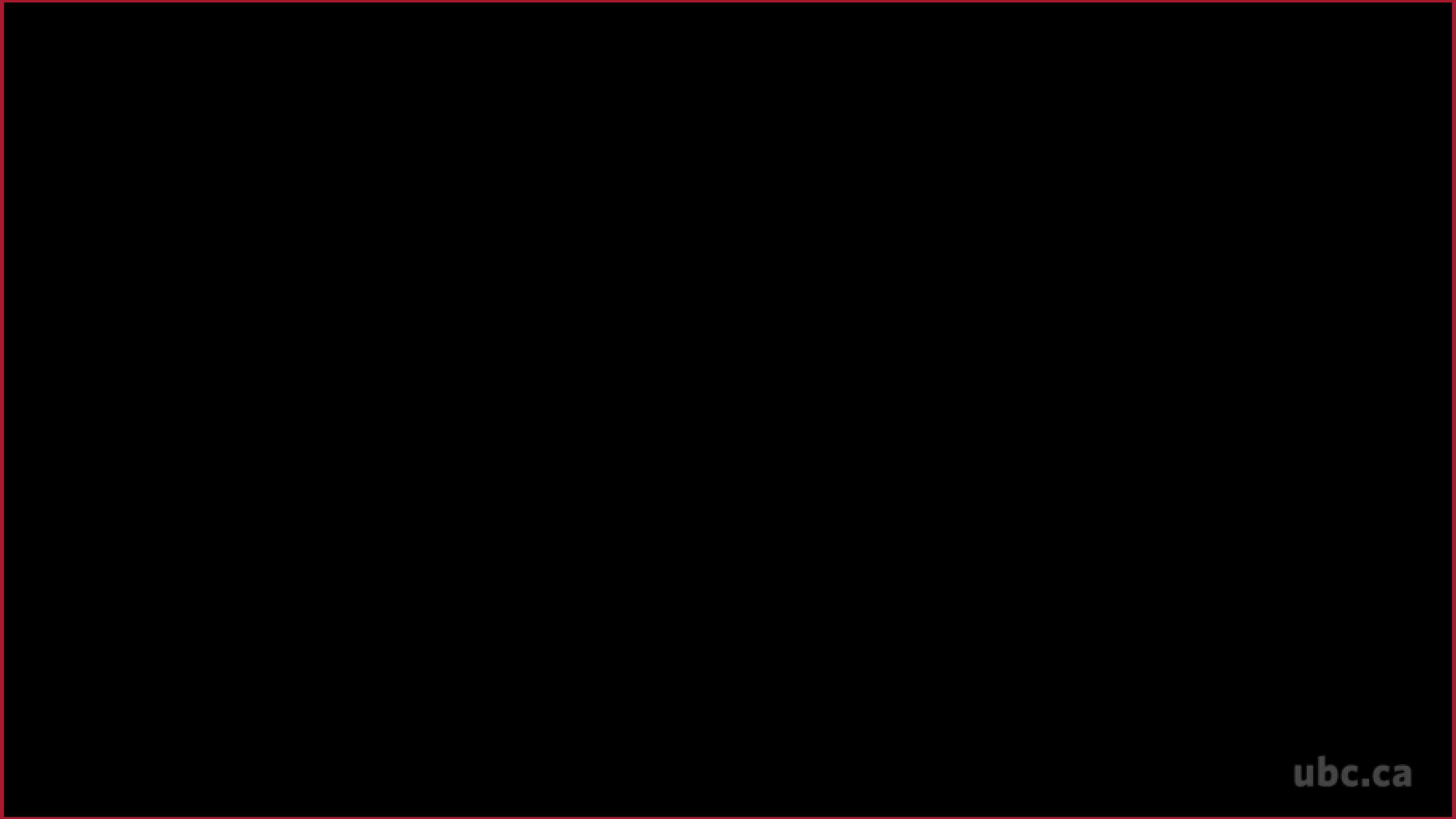
2007: A retrofit railcar to Hydrail, East Japan Railway Company (JR East).

2016: Hydrail passenger tram-train in service (Coradia iLint, Alstom) in Europe

6. Why Inter-City Passenger Rail & NOT more highways?

- Transport 2030
  - Transport Equity & Inclusion
  - Middle Class Affordability
- Tourism & Service Workers
  - Year-round affordable access
  - Access to affordable housing
- UN SDG
  - Climate Action 2050
  - Lower Environmental Impacts
  - Community resilience (fire, flood, heat, smoke, drought)
- Lower Lifecycle Costs
  - Social & Env Benefits
  - CAPEX, OPEX
- Aging in Place
  - Access to Regional Services
  - Social Connection
- Safety & Congestion
  - Vision Zero (road deaths)
  - Lost Productivity & Reputation
- Truth & Reconciliation
  - 94 calls to action incl transport

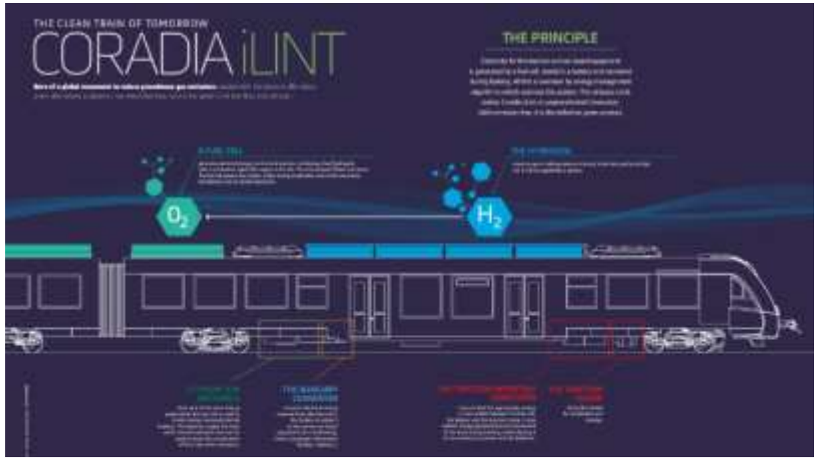
The Techno-Economic Case for Re-Deploying Inter-City Regional Tram-Train Passenger Rail in Canada - Case Study of the Okanagan Valley, BC



Available for viewing on YouTube: “The Future of Sustainable Transportation”

A 4 minute introduction to our vision for the OVER PR in not just the Okanagan Valley, but across North America – revitalizing passenger transit via tram-trains!

Technical Feasibility of OVER PR Tram-Trains ZE Hydrogen Fuel Cell / Battery Hybrid (Hydrail)



Similar to ZE Alstom iLint Coradia running in EU

- ~ 56 m, 50 tonnes, 160 passengers
- No regenerative braking (conservative)
- H2 low pressure onboard storage

Service Design

- Round-trip ~ 8 hours, 16 trains
- 30 to 60 minute headways

Results – can be done with:

- Engine Power: 1,000 kW max
- Powered axles 100%
- HFC efficiency of 50%
- ~ 2,400 kWh total energy consumed
- H2: 1,500 kg = 150 kg H2@ 50 bar

Hydrail Visualization
Andrew Halfhide

Route

Route conceptual analysis

- Hwy 97 route = ~300 km
- Via Salmon Arm adds km
- 13 +/- stations

Speeds < 110 km/h

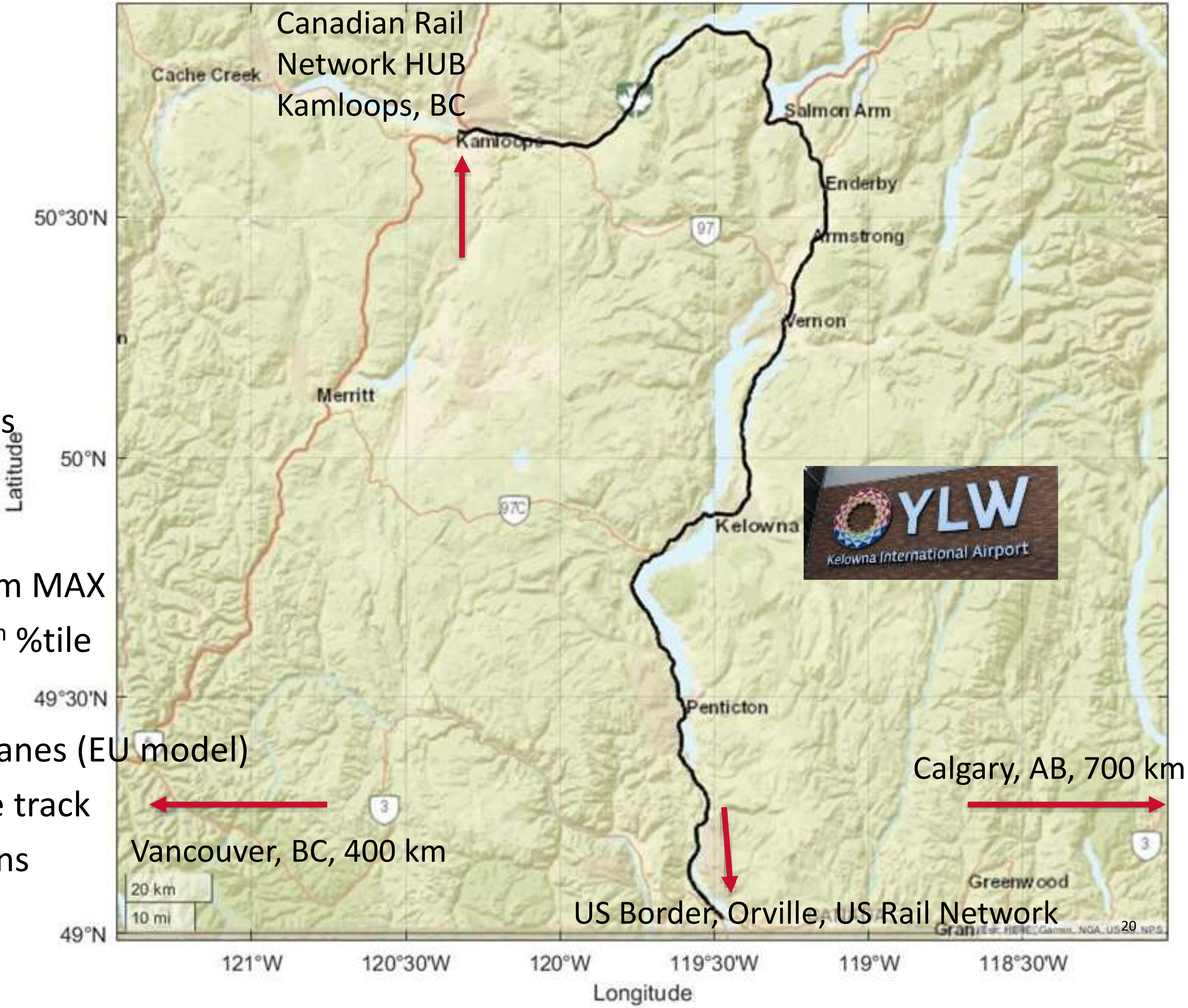
- In cities < 50 km/h imbedded rails
- On hwys at highway speeds

Telemetry

- Elevation change 40 m NET, 220 m MAX
- Grades – 10% ruling, 3.6% @ 95th %tile

Tracks

- Cities: Imbedded rails in shared lanes (EU model)
- Hwys: Medians, shoulders, single track
- Passing sidings at meets & stations



Economic Feasibility Results

Assuming

- 6% discount rate, 30 year life, 2025 start, 2021 base year, $CDN
- Fares of $0.20/pass-km, conservative @ ~9,000 per day (10 to 30% mode shift from existing Hwy 97 volumes)

OPEX – PV $1.3 Billion ($55 mill/year), includes: Maint. $0.20/ pass-km; H2 $5/kg; Staff 50

CAPEX - $1.7 Billion, includes Eng & Contingency – tracks, stations, running gear, yard, refueling, S&C

Benefits – PV $22 Billion (~$1.5 Billion/yr), includes Station rentals/sales, Salvage, Fares, Externalities

Externalities - Deferred Hwy 97 widening ($1 B), Safety ($0.6B/yr), Tourism ($0.6B/yr), GHG ($80m/yr); Auto ownership/parking ($100m/yr); Fares($50m/yr); TT ($30m/yr); Congestion ($100m/yr)

Results:

@6% discount rate givens an NPV = $19 Billion @ 6% with BCR = 7:1, PBP < 2 yrs;

@ 15% discount rate gives an NPV = $10 Billion, BCR 6:1, PBP 3 yrs

Testing our assumptions using MCS @ 95% of trails gives an NPV ~$6.7Billion, BCR > 3

Compare: Hwy 97 widening CAPEX $4 Billion, BCR = 5.5 using the same business case template (BC Gov’t.) Yet Hwy 97 does NOT address external IMPACTS of GHG emissions ($80m/yr), Fatal crashes ($600m/yr), nor do roads (and driving) address transport inequity or aging in place (Greyhound has gone)

Limitations & Next Steps

Lack of a final engineering design means more assumptions

- Mitigated uncertainty/limitations via MCS, and expert rail CAPEX/OPEX peer reviews

Next Steps

- Next 5 years:
    - Stakeholder engagement, Community consultations, MoUs, partnerships
    - Local, Regional, Provincial, Federal, FN
- Next 5 to 10 years:
    - P3 financing & corridor/route development
    - Segment construction over 300 km OK Valley
- Begin discussions on other corridors:
    - E.g. Northern ARC Passenger Hydrail for Remote/Northern Inuit/FN communities

7. Reflections on New Zealand

- ❑ Duty Cycle
- ❑ Corridor Capacity
- ❑ Hydrogen Supply
- ❑ Transport Equity & Climate Action
- ❑ SMARTer Growth Management & Tourism

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Teaching & Research in SMARTer Growth systems in support of UN SDGs:
hydrail (ZE rail), safety planning, engineering economics, business case development, cohousing, homelessness, sustainable transport & land use

Professional Background

1982-2005, special projects engineer – Vancouver, Langley, Kelowna, UBC Vancouver, UBC Okanagan

2005, helped start the UBC School of Engineering, Kelowna, (Okanagan Valley) BC

2005-Present, P-I, Sustainable Transport Safety Research Lab

Hobbies and Interests

Gord enjoys running, swimming, and cycling along the shores of 100 km long Okanagan Lake in Kelowna. He and his wife have four children. He serves on the Boards of several charitable organizations, including Kelowna's Gospel Mission (homeless shelter), Christian Service Brigade Canada & USA (boys clubs). He's also starred as guest rail expert on an episode of "Mighty Trains" discussing construction of the Rocky Mountains corridor.