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## Innovative Research Projects Focused on Decarbonization

FRA Workshop *Rail: On Track for Decarbonization* Denver CO, May 16 and 17, 2023

Presented by: E. Toma, M. Hernandez, and I. Jimenez,





### The National Research Council of Canada

03 63 NRC IRAP OFFICES RESEARCH FACILITIES AND NRC IRAP OFFICES Government of Canada's largest R&D organization with over 100 years experience

2,151 scientists, engineers, technicians and specialists

179 buildings, 22 sites

### NRC mandate in Canada's innovation landscape









#### Automotive and Surface Transportation (AST)

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#### Energy, Mining and Environment (EME)

#### **Rob James**

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### **Advanced Transportation System Programs**





#### NRC Hydrogen Applications (Vancouver and Boucherville)

Vision:

Accelerate transportation electrification supported by an innovative and costcompetitive world-class hydrogen technologies ecosystem in Canada.

Fuel cell simulation, modelling & testing

Hydrogen codes, standards, HAZOP analysis, and safety

Fuel cell component diagnostics (including Quality Control)

Proton Exchange Membrane (PEM) manufacturing

Air filter sensors

Hydrogen refueling

Hydrogen storage

Fuel cell component recycling



Thin films fabrication



Hydrogen-safe facilities



Testing and modeling capabilities



### NRC Rail, Road and Off-Road Expertise

(Boucherville, London, Ottawa, Saguenay, Winnipeg)



## Canada green initiative: 2030 emissions reduction plan • rail sector

"Building on successive voluntary agreements with industry, develop an action plan to decarbonize rail in line with Canada's net-zero by 2050 goal, which could include efforts to **advance zeroemission locomotives and locomotive electrification**."



## EXAMPLES OF RELEVANT NRC DECARBONIZATION CAPABILITIES & WORK

Road Vehicles: Lithium Battery Abuse Testing Laboratory [M-48 Ottawa, ON]

#### Aviation:

- SAE G-27 Standards Committee [M-48 Ottawa, ON]
- HEAT [U-61, Ottawa ON]
- NRC ARC Hydrogen Supply Facility [M-49 Ottawa, ON]

#### **All Applications**

Hydrogen Embrittlement Capabilities [Vancouver, BC]

## Road Vehicles: Lithium Battery Abuse Testing Laboratory Area of Focus

- Designed to test energy storage devices and systems OUTSIDE their operational range;
- Unique facility across Canada that permits us to work 12 months of the year;
- Experience developed during a 30+ year collaboration with DND;
- Facility consists of 3 individually controlled test bays and a thermal oxidizer to treat emissions;
- For larger testing requirements, we use outdoor facilities at YOW or NRCan or other;
- Growth areas: larger systems, fundamentals, new characterization techniques, modelling abuse.
- Video available:<u>https://youtu.be/ugvBhlucl0k</u>
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## Aviation: SAE G-27 – AS6413 – Performance-based packaging standard for lithium batteries as cargo on aircraft

 Research results are used to develop evidence-based recommendations to support the TDG Directorate program initiatives, including recommendations on: changes to the TDG Act and Regulations and associated technical standards; development and improvement of compliance and enforcement procedures/tools and activities; and emergency response processes and advice.



#### **Aviation: HEAT**

Replaced rear engine in twin-engine Cessna 337 Skymaster with equivalent-power batteryelectric system (160 kW = 210 hp peak)

800V, 85kWh battery, NRC battery safety system

Emrax 348 axial flux; Cascadia PM150DZ inverter; front IO360 unmodified

Operating under Experimental Flight Permit issued by Transport Canada







#### Aviation: NRC ARC Hydrogen Supply Facility

- Highly automated technology demonstration facility designed to supply high pressure hydrogen
- Supporting the development of low emission aerospace / energy sector technologies (e.g. low emission turbine engines, fuel cell systems)



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#### All Applications: Hydrogen Embrittlement Capabilities

- Electrochemical Hydrogen Permeation Test (ASTM G148)
- Measurement of Diffusible Hydrogen (ASTM F1113)
- Burst Disk (ASTM F1459)
- Fracture toughness and crack tip opening displacement (CTOD) (ASTM E1820)
- Fatigue
- Modified Tensile Tester (in-house)
- Hydrogen Charging Chamber (in-house)



Barnacle Cell (ASTM F1113)



Burst Disk (ASTM F1459)



Modified Tensile Tester



Permeation Test (ASTM G148)

#### All Applications: Hydrogen Embrittlement Capabilities

#### **Modified Tensile Tester**

- ASTM G142 does not simulate the actual operation
- Hollow dog bone (simulate hoop stress inside transmission and distribution pipes)
- With and without notch
- Weld, HAZ, base metal and hard spots
- Environmental chamber to simulate summer and winter operation







Tensile test



Finite element modeling analysis on the tensile coupon with internal gas pressure and 4000 N of tensile load.



Hollow dog bone after failure

Test specimen

Test setup

## RECENT RESEARCH WORK IN THE HYDRAIL SPACE

STANDARD COUNCIL OF CANADA (SCC) -NATURAL RESOURCES CANADA (NRCan) HYDROGEN CODES AND STANDARDS WORKING GROUP

Hydrogen Strategy for Canada

- Launched in 2019
- 8 sector wide themes
  - Codes and standards is one theme

### **Co-chairs**



Natural Resources Canada

#### &

## Standards Council of Canada

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### Stakeholders



- Industry
- Academia
- Standards Development Organizations
- Inspection and certification bodies
- Authorities having jurisdiction
- International experts
  Over 200 members

### **Coordinated approach**



- H<sub>2</sub> Technology advancement
- H<sub>2</sub> Adoption
- H<sub>2</sub> Leadership

#### Task Forces:

- 1. Production
- 2. Storage Delivery & Distribution
- 3. End Use [Led by NRC-UBC]

#### **Meetings and CSWG Guest Presentations**



#### **Gap Analysis Methodology**



#### **NRC H<sub>2</sub> Value Chain Classification System & Website**

Home ES in Canada	CSR Search	✓ HVC in Canada Terminology ✓ Publishers My account Log out	
HVC in Canada → Canadi	ian Hydrogen Value	e Chain	
C&S Inventory Industry Presence	*	Canadian Hydrogen Value Chain codes, Standards and Industry Presence Inventory	
		Zoom in/out and drag the map up and down	for more Applications.
Hydrogen Value Chain Seg	iment		
		+	
Type of Document			
- Ally -			
Document Nationality			
- Ally -	<b></b>		
SDO			
- Pally -			
Applicability			
- Ally -	<b></b>		
Standard Coverage		· ·	
- Ally -	<b>~</b>		
Type of Equipment			
- ANY -	<b>~</b>		
Company Type			

Access to information for all elements:

- Industry presence in the hydrogen value chain
- 2. Codes and standard documents
- 3. Gaps
- 4. Priority
- 5. Suggested course of action



#### **NRC H<sub>2</sub> Value Chain Classification System & Website** Transition (ACT) H. Conversion Carbon Intensity Vind vdroelectric Grid Electrolysis Photo Microbial Biomass Photobiological Centralized or Thermochemical electrochemical Conversion ecentralized Hydrogen For Electrolysis **Biomass** gasification **Biomass-derived** Natural Gas Reforming Refined Industrial Offshore liquid reforming Offshore Wind NATIONAL RESEARCH COUNCIL CANADA

Codes and standards identified through gap analysis to be added to NRC

- mapping Users will be able to submit requests for updates as standards evolve
- Link shared with **CSWG** members for beta-testing





Link: https://csres-cnrse.nrc-cnrc.gc.ca/en

### **RAIL FOCUSED RESEARCH WORK**

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## Hydrail phase 1 • Objectives

- Build a foundation of knowledge about the risks and hazards;
  - Quantify severity
  - Identify appropriate means and best practices for mitigation
- Assess current industry codes and standards landscape;
  - Identify gaps





## Hydrail phase 1 • Reports

#### **Reports published:**

- Risk Assessment of Hydrogen and Battery Power in Locomotives Part 1 – Literature Review
- Risk Assessment of Hydrogen and Battery Power in Locomotives Part 2 – Risks and Hazards Assessment
- Risk Assessment of Hydrogen and Battery Power in Locomotives Part 3 – Codes and Standards

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## Hydrail phase 1

#### **Risk Assessment of Hydrogen and Battery Power in Locomotives:**

- Literature Review
  - Identified key literature related to hydrogen use in rail applications
  - summarized a proposed design, operation, maintenance, and fueling of a hydrail and battery locomotive alternatives
- Risks and Hazards Assessment
  - develop a risk and hazards assessment for hydrogen fuel cell powered locomotives;
  - included the risks and hazards introduced to locomotive operations due to the addition of the fuel cell, hydrogen, and battery systems

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## Hydrail phase 1

#### **Risk Assessment of Hydrogen and Battery Power in Locomotives:**

- Codes and Standards
  - review of codes and standards that are applicable to hydrogen use in rail applications
  - found that there were numerous overarching standards, but also a number of gaps
  - Gaps were related to highly prescriptive standards that may need additional classifications for hydrogen use as a fuel similar to other fuels (i.e. compressed and liquified natural gas).

## Hydrail phase 2 • Objectives

- For battery-electric and hydrogen fuel cell electric locomotives
  - Categorize the hazards, estimate their risk, evaluate risk mitigation techniques, and conduct a risk assessment framework according to nationally accepted guidelines and methodologies.
- Identify physical testing that is needed or would assist in advancing the adoption of hydrogen fuel cell and battery locomotives



# Transportation of Cryogenic hydrogen and anhydrous ammonia by Rail

Literature review on the current regulations and standards in Canada applicable to the bulk transport by rail of:

- liquid hydrogen; and
- anhydrous ammonia

## Identify gaps in regulations and standards



## Application of Risk Assessment and Mitigation Process

- Use the process described in Phase 1 and 2 to: identify risks and hazards; mitigate risks and hazards; identify gaps in knowledge.
- Current application is observation of design/build conversion of a hybrid switcher locomotive to hydrogen fuel cell power ongoing at the University of British Columbia and Southern Railway of BC



Transport Transports Canada Canada



https://www.railwayage.com/mechanical/locomotives/southern-railway-of-bc-going-green-with-switcher-retrofit/

## Application of Risk Assessment and Mitigation Process

- NRC is participating in development of new standards:
  - CSA SPE-602, Onboard Traction Battery Task Force
  - CSA SPE-601:23, Hydrogen fuel cell power systems for rolling stock



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## **THANK YOU**



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