Fuel Cell Vehicle Hydrogen Emissions Testing

David Pearman [a], William Buttner [a], Aaron Loiselle-Lapointe [b], Aaron Conde [c], Kevin Hartmann [a]

[a] National Renewable Energy Laboratory, Golden, Colorado USA
[b] Environment and Climate Change Canada (ECCC), Ottawa, Ontario Canada
[c] Transport Canada (TC), Ottawa, Ontario Canada

International Conference for Hydrogen Safety – Fall 2023

GTR-13
Regulated Hydrogen Levels in FCEV Exhaust

Section 5.2.1.3.2: Vehicle Exhaust System

At the vehicle exhaust system's point of discharge, the hydrogen concentration level shall:

- Not exceed 4 per cent average by volume during any moving three-second time interval during normal operation including start-up and shutdown;
- And not exceed 8 per cent at any time (para. 6.1.4. test procedure)

It was also stipulated that the analyzer have a response time (t_{90}) of 300 ms or faster.

- GTR-13 specifies testing up to 10cm from end of exhaust.
  - Inconsistency
  - Safety
  - Missed hydrogen
- Until recently, all testing has been with NREL's exhaust gas analyzer and transfer line.
  - No indoor releases due to safety concerns.

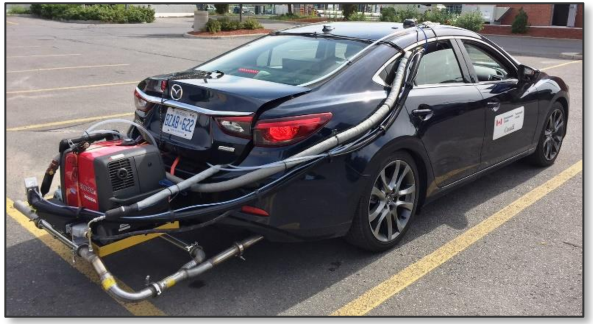
NOTE: A means to verify compliance is necessary to enforce a requirement

The NREL FCEV Exhaust Gas Analyzer.

ECCC Vehicle Emission Program

Role ERMS / ECCC Now

- Conducts compliance audit testing for vehicles and engines sold in Canada administered by ECCC.
  - Four light-duty chassis dynamometers in environmental chambers
- Collaborates with Transport Canada to investigate new technologies and fuels for safety and regulatory developments and to inform policies.
- R&D for mobile emission reducing technologies and fuels.



ECCC helps with verification of FCEV emission requirements. TC provides the FCEVs for testing

Brief Project History (NREL, ECCC, TC)

2019

- Prototype Analyzer deployed at ECCC
  - Chassis dynamometer
- Successfully monitored FCEV exhaust
  - Water entrainment was an issue
  - Results presented at ICHS 2019

2021

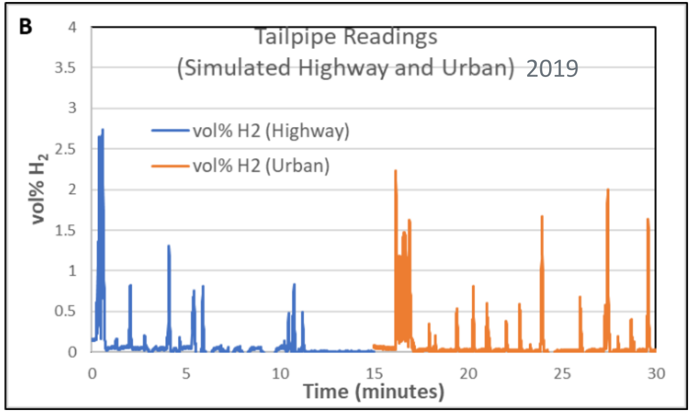
- Modified sample collection system to mitigate water entrainment
  - Demonstrated in laboratory and at ECCC
  - Basis for an NREL record of invention

2022

- Another model of FCEV was tested
  - Concerning levels of hydrogen in exhaust

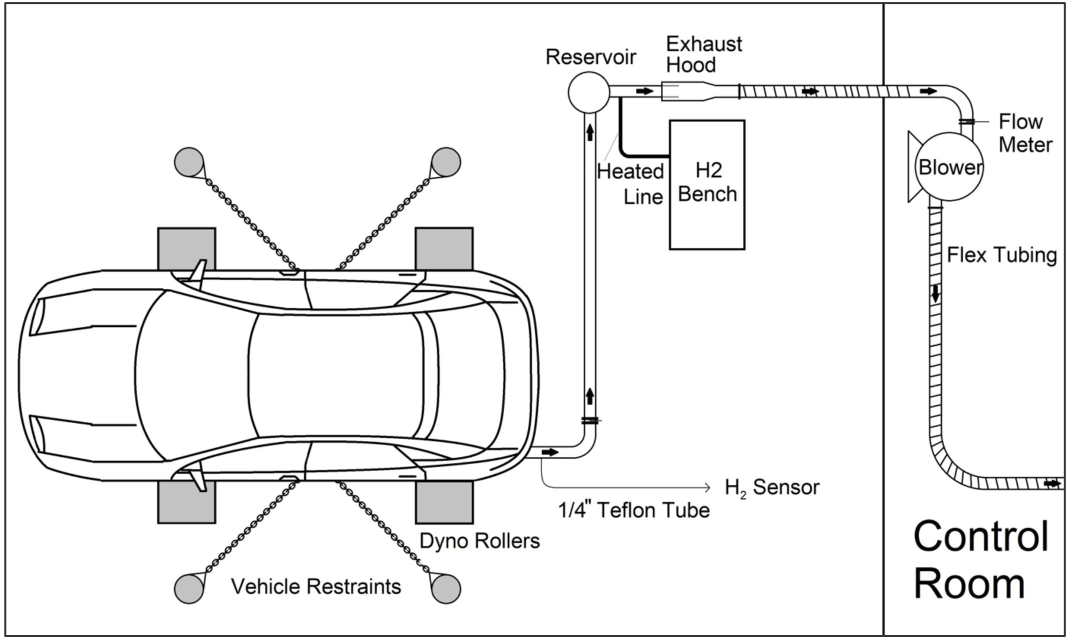
2023

- Concentration and flow data taken to estimate total hydrogen emissions at ECCC
  - Complications with calculations
- Testing at TC to show affects of various testing methods



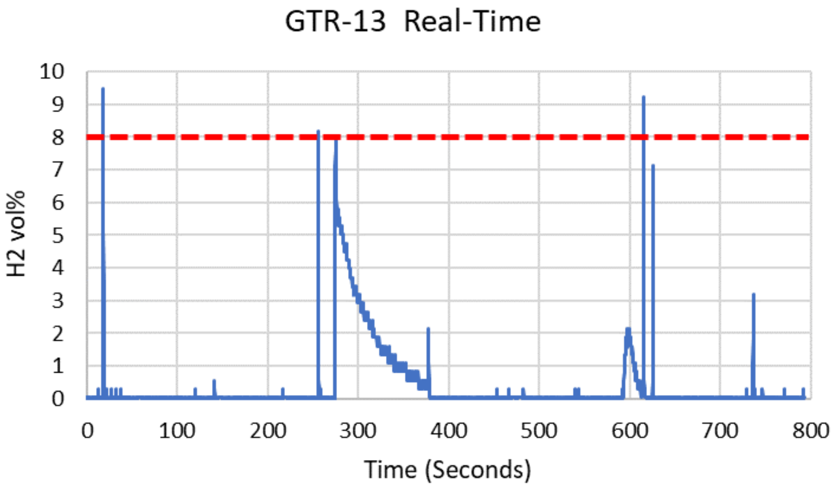
Deployment at ECCC

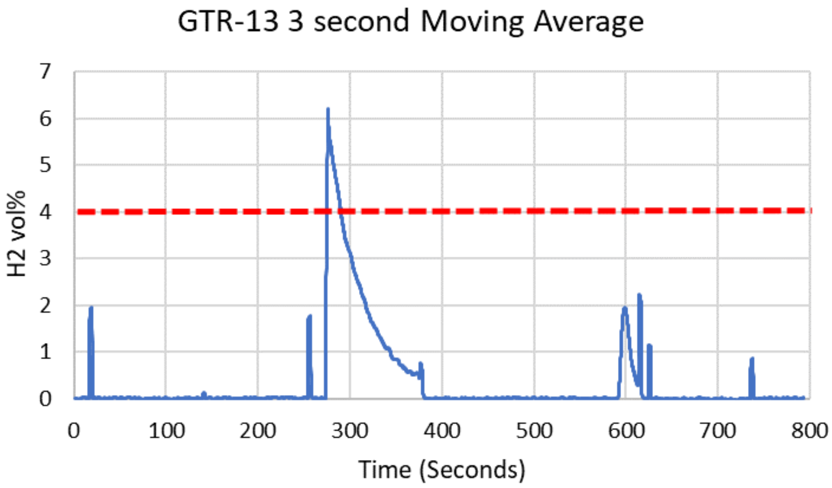
- Vehicle operated on chassis dynamometer
  - Allow testing under simulated driving conditions (urban, highway, static)
  - All drive cycles are defined by US EPA.
  - Standard test procedures have been developed for ICE vehicles
- The Transfer Line connects to the tail-pipe. Test samples are drawn from the transfer line. In this project, the gas stream is vented outdoors.
- Gas Sampling Tube transports test gas to Analyzer
  - Adapted to include moisture mitigation strategies.



NREL's analyzer has been deployed multiple times at ECCC.

Test Results from ECCC – GTR Protocol (2022)

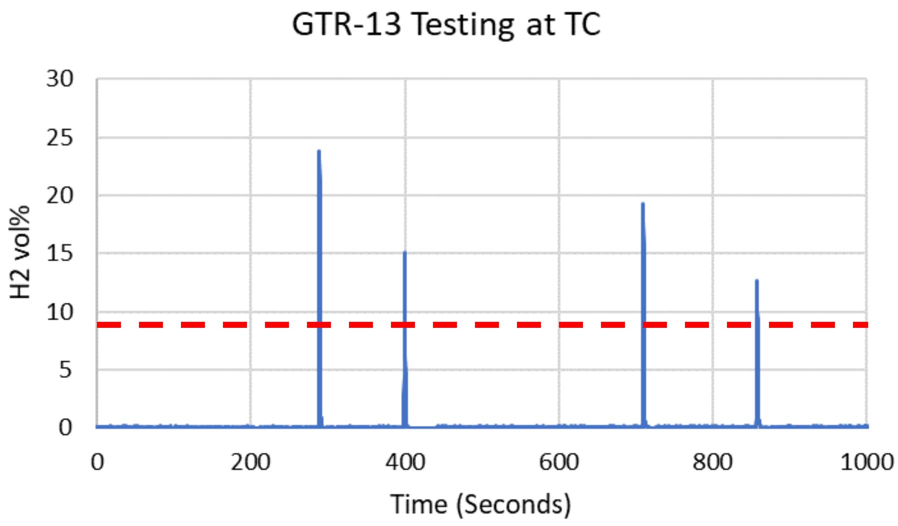




- Hydrogen transients observed with the NREL's analyzer.
  - Startup/Shutdown procedures follow GTR-13. Sample collection methods differ from GTR-13.
  - Discussion with manufacturer led to interest in comparing different test methods.

Test Results from ECCC at TC – GTR-13 (2023)

- ECCC tested an FCEV using ECCC and NREL analyzers.
  - This testing more closely follows the exact GTR-13 testing protocol.
- The FCEV was started and shut down multiple times.
- Samples were taken 5cm inside of the exhaust pipe and at the end of the exhaust pipe (0cm).
- The FCEV was then warmed up and retested.
  - Releases during startup/shutdown were less frequent after driving the vehicle.
- FCEV manufacturer performed the GTR-13 test and measure ~0.1 vol% hydrogen.

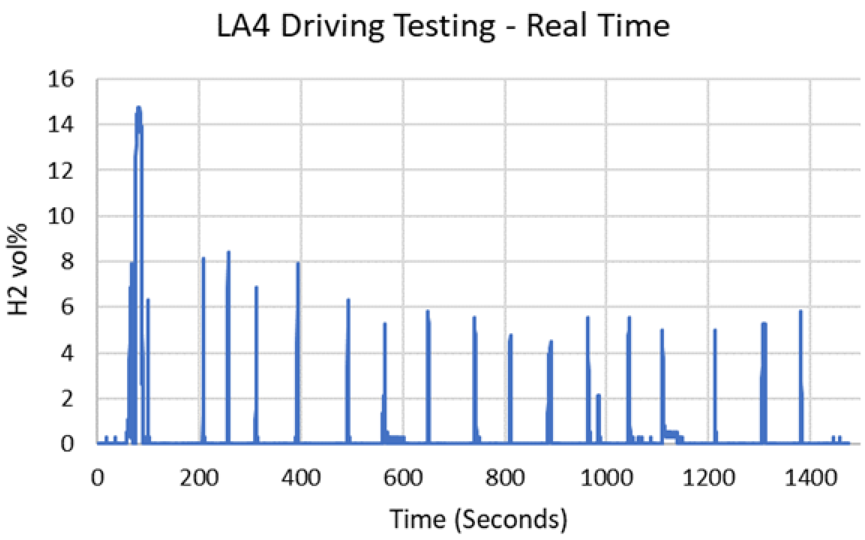


Peaks 1 and 2 - GTR-13 testing where the sample point is 5cm inside of the exhaust pipe.

Peaks 3 and 4 – GTR-13 testing where the sample point is taken directly as the exhaust pipe (0cm).

Test Results from ECCC – LA4 Drive Cycle (2022)

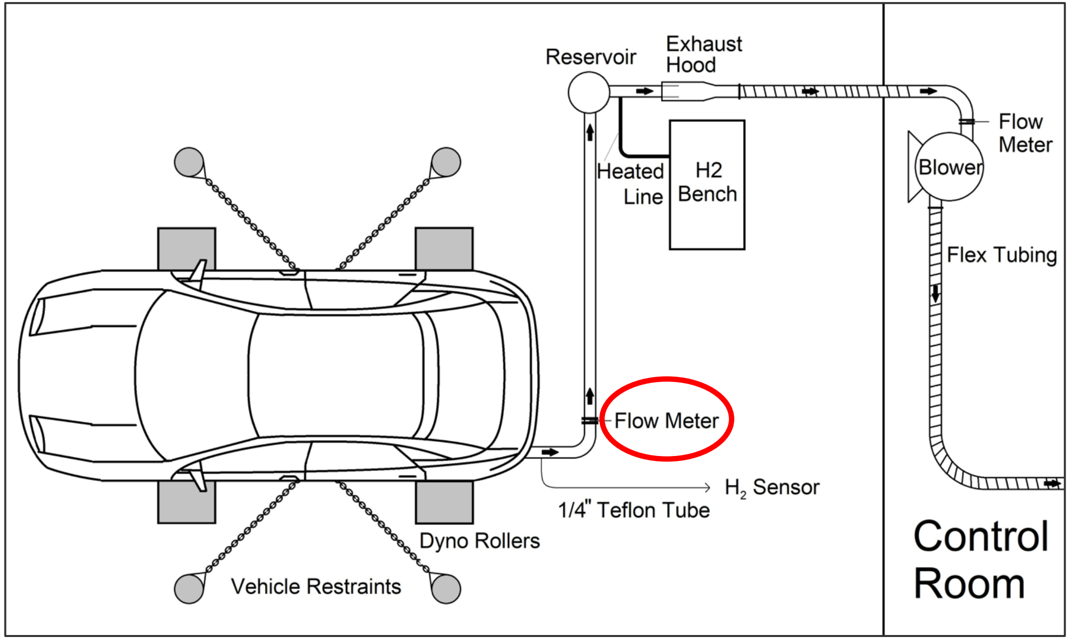
- Exhaust concentrations during drive cycles are not regulated by GTR-13 due to a lack of safety concerns while driving.
  - Emissions as the start and end of drive cycles could be considered for safety.
  - This drive cycle could simulate a real driving experience.
- Hydrogen emissions from drive cycles are not currently regulated by any governing body.
  - Due to concerns regarding the environmental impact of hydrogen releases, overall emissions during drive cycles will likely be monitored and regulated.



Large releases at the start of a driving test could be a concern for safety.

Deployment at ECCC – Emissions Testing

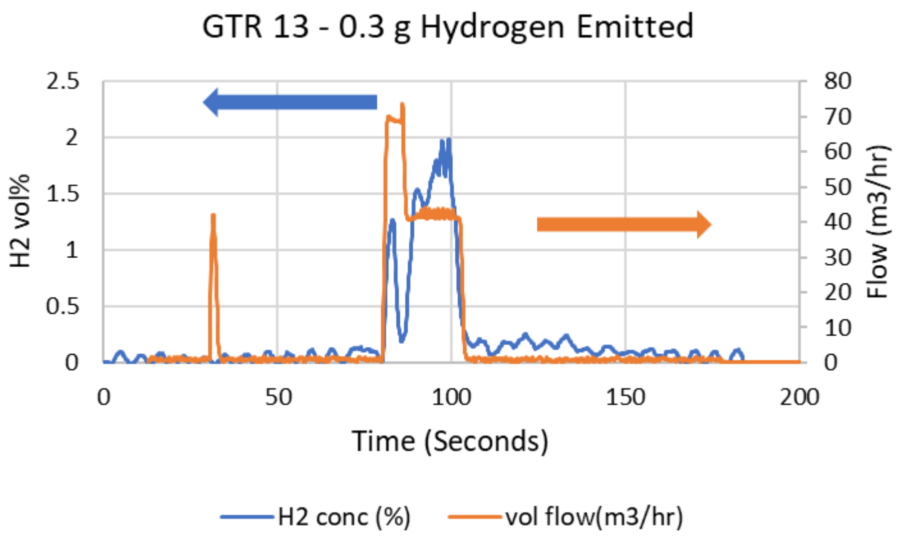
- When testing FCEVs for concentration/safety, no flow data was collected.
  - With the current analyzers, the amount of hydrogen vented cannot be measured.
- The addition of a flow meter (located just behind the vehicle) coupled with concentration data would allow for the overall amount to be calculated.
  - Issues with time synchronization made this calculation very unreliable for longer tests.



NREL's analyzer and flow rate data allow for overall hydrogen emission calculations.

Test Results from ECCC – Calculating Hydrogen Emissions (2023)

- Timestamps had to be manually synced.
  - Much easier to do on shorter tests.
  - Mass calculation is highly sensitive to timestamp syncing errors.
- Future test plans include adding a simple flow meter to NREL's analyzer to easily sync timestamps.
  - ECCC's flow meter data will still be used to more accurately calculate the amount vented.
- Current test methods could be an effective way to monition hydrogen concentration for safety and overall emissions for environmental/efficiency concerns.



- NREL's hydrogen concentration data (Blue) paired with ECCC's flowrate data (Orange) allows for overall hydrogen emission calculations.

Summary

Safety

- For safety reasons, the FCEV exhaust should be captured when testing indoors.
- Sensing for hydrogen 10cm away from tailpipe could be problematic.
  - Inconsistent, Safety, Missed hydrogen.
- Rethink testing for safety (GTR-13) to accommodate simulations emissions testing.
  - Test apparatus similar to NREL/ECCC's can monitor for safety and emissions.
  - Concentration limits would then need to be reconsidered.

Emissions

- GTR-13 test protocol is incapable of measuring overall emissions from FCEVs.
- Addition of a simple flow meter to NREL's analyzer would allow for accurate mass calculations
  - Currently, time stamps are hard to synchronize.
- FCEV manufacturers should consider/limit the amount of hydrogen vented.
  - Currently no emissions requirements for drive cycles.

Acknowledgements

- The NREL Sensor Laboratory and the work on the NREL FCEV Exhaust Gas Analyzer has been supported by DOE-EERE Fuel Cell Technologies Office, SCS Sub-Program (Laura Hill, Program Manager). The development and preliminary testing of the FCEV Exhaust Gas Analyzer was also supported by the US DOT through IAG-17-2046.
- The authors would like to thank Trevor Connolly, David Buote, Gilles Marcotte, Maurice Osborne, Mike Van Zandvoort, and Jonah Veenendaal at the Emissions Research and Measurement Section of Environment and Climate Change Canada for undertaking this work.

Thank you!

QUESTIONS?

David.Pearman@nrel.gov

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Hydrogen and Fuel Cell Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

The NREL Hydrogen Sensor Laboratory (the NREL Hydrogen Safety Research & Development)

Laboratory Sensor Testing and Deployment Capability

- Hydrogen sensor performance and field deployment research
- Extensive International stakeholder engagements and collaborations

Representative Outreach and Stakeholder Collaborations (ICHS Talks)

- ICHS #202: Fuel Cell Vehicle Hydrogen Emissions Testing, David Pearman, W. Buttner, Aaron Loiselle-Lapointe, Aaron Condec, Kevin Hartmanna
- ICHS #194: The NREL Sensor Laboratory: Hydrogen Leak Detection for Large Scale Deployments; Matt Post, W Buttner, D. Pearman, K Hartman
- ICHS #159: Hydrogen Equipment Enclosure Risk Reduction through Earlier Detection of Component Failures; K. Hartmann, Andrei Tchouvelev, K. Hartmann, W. Buttner, B. Angers
- ICHS #183: Visualization and quantification of wind-induced variability in hydrogen clouds following releases of liquid hydrogen; I. Palin, Kierien Lyons, W. Buttner, S. Coldrick, J. Hall, G. Atkinson, J. Thorson, M. Royal
- ICHS #232: Design and Requirements of a Hydrogen Component Reliability Database (HyCReD), Ahmad Al Douri, Katrina Groth, Kevin Hartmann, William Buttner, Genevieve Saur
- ICHS #299: Overview of International Activities in Hydrogen System Safety In IEA Hydrogen TCP Task 43 Groth, K. M., Buttner, W. , Dutta, K., Hartmann, K., Runefors, M., Tchouvelev, A.V., van Wingerden

The SSTA

Testing capability of the NREL Sensor Laboratory

HITRF

Hydrogen Infrastructure Testing and Research Facility

The NREL Sensor Laboratory provides a unique capability to the hydrogen community not otherwise available

Requirements for an FCEV Exhaust Gas Analyzer

Required
- Range of 0 to 10 vol% Hydrogen
- t_{90} < 300 ms
- Not significantly impacted by likely interferences (physical & chemical)

Desirable
- Integratable into FCEV exhaust (and test systems for vehicle exhaust measurements)
- Convenient user Interface

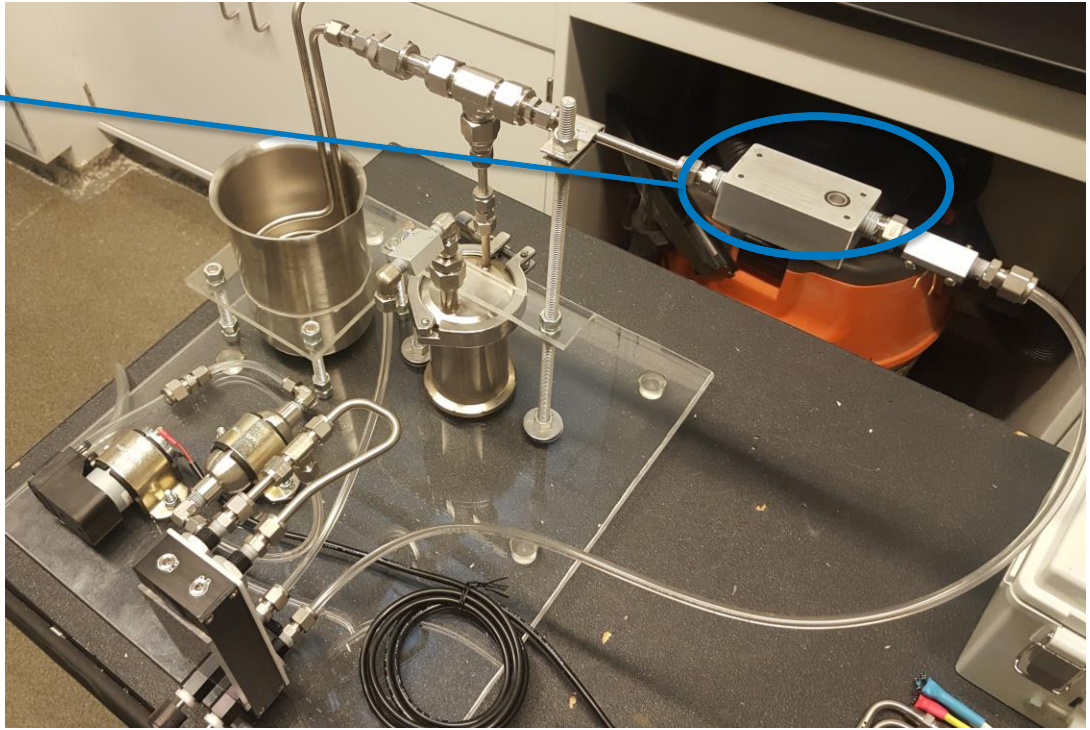
H_2 Sensing element for the Prototype FCEV Exhaust Analyzer

Commercial Thermal Conductivity Sensor
- Low-cost hydrogen sensor
- Fast response (t_{90} < 250ms)
  - Verified at JRC & NREL
- Linear to 10 vol% (measurement range to 100 vol%)
- Minimal effects from changes in T & RH
- Low power, miniature size

The NREL Sensor Laboratory has been developing a prototype FCEV Exhaust Gas Analyzer based upon a commercial thermal conductivity (TC) Sensor

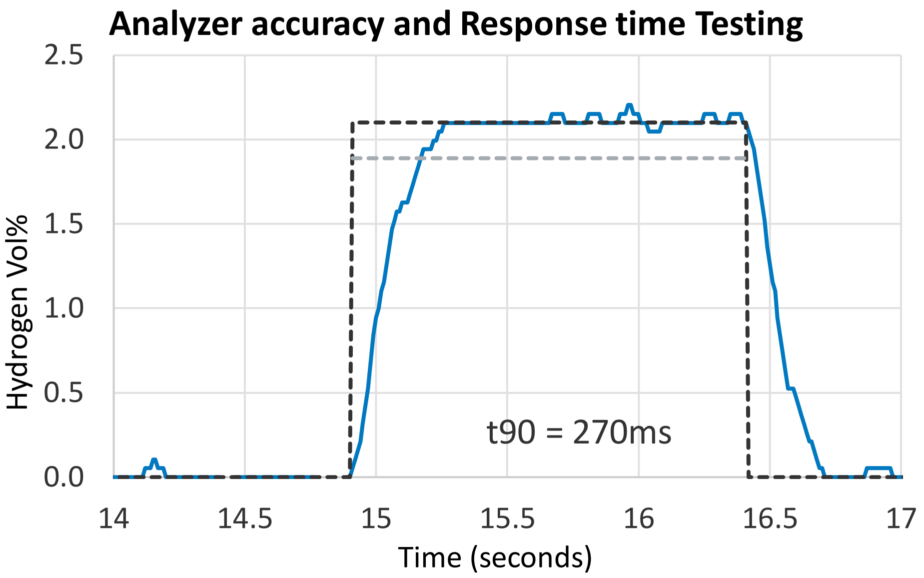
Revised FCEV Exhaust Gas Analyzer

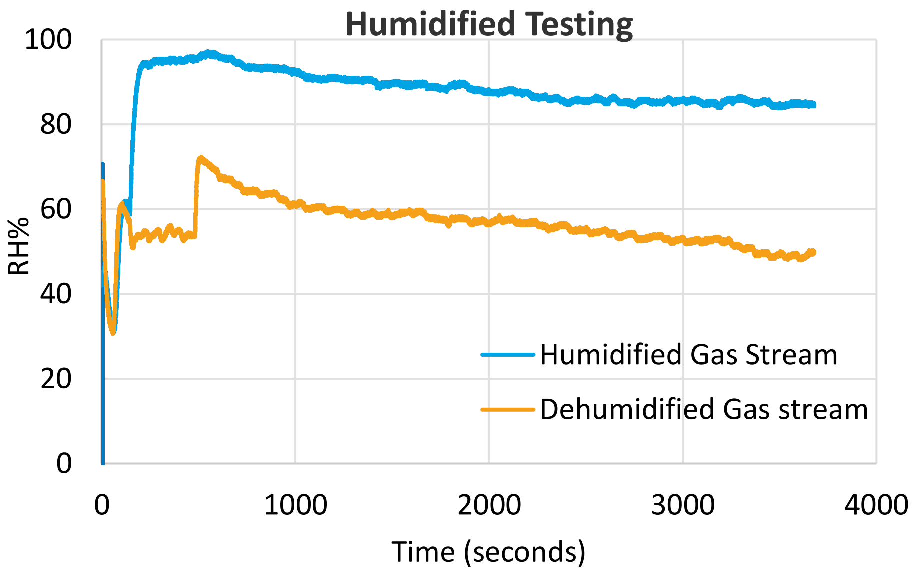
- FCEV exhaust gas analyzer consists of:
  - Hydrogen sensing element.
  - Sample collection system.
- NREL has developed a test apparatus that simulates FCEV exhaust conditions. (e.g., simulated tail pipe)
- Laboratory demonstrations of the analyzer including the sample collection system were performed using the simulated FCEV tail pipe.
- Sample collection system is designed to be compatible with the laboratory fixture and the ECCC exhaust gas collection system.



Gas Collection sample system for FCEV exhaust gas analyzer was designed to mitigate water entrainment.

Laboratory Demonstration

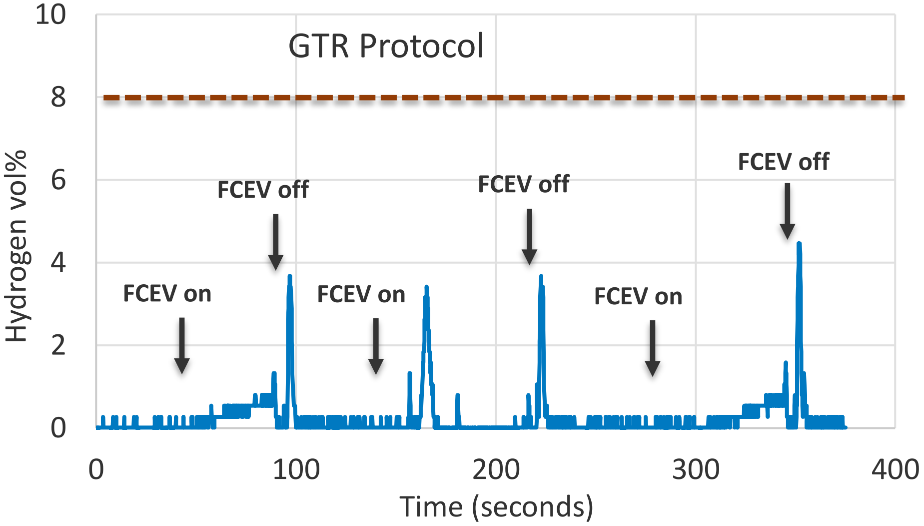


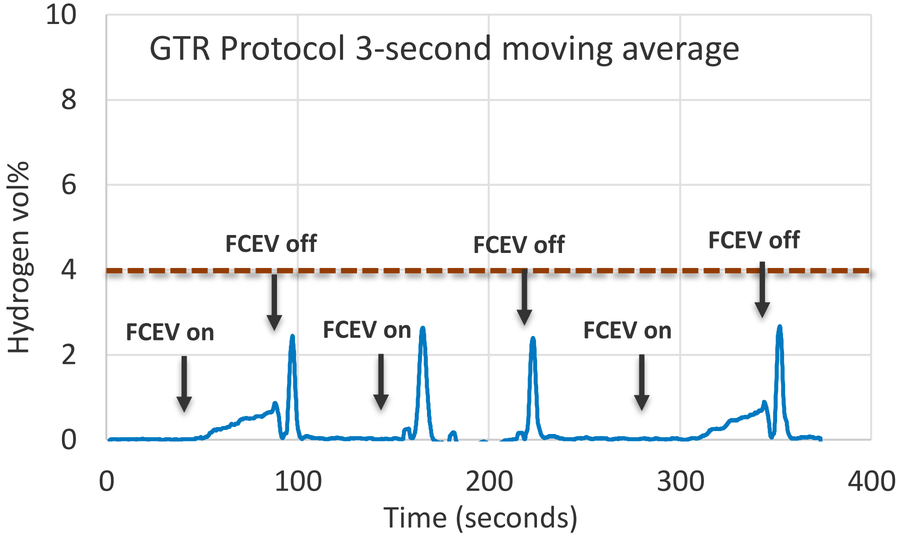


- Hydrogen exposures demonstrate compliance to GTR response time requirements and accuracy.
- Incoming exhaust test gas (60°C-70°C, saturated humidity with water droplets) is dehumidified (40%-60%, 25°C) for analysis.

GTR response time requirements are met without interference from water entrainment

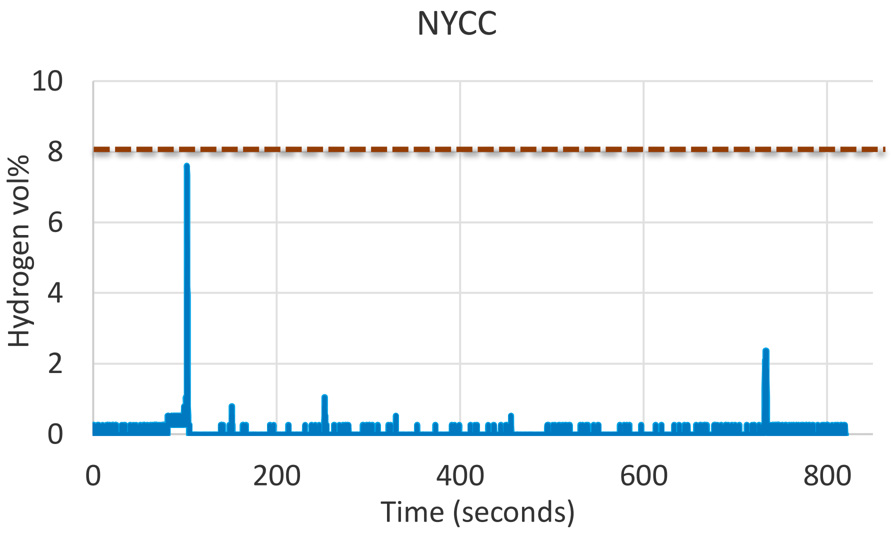
Test Results from ECCC – GTR Protocol (3 runs)

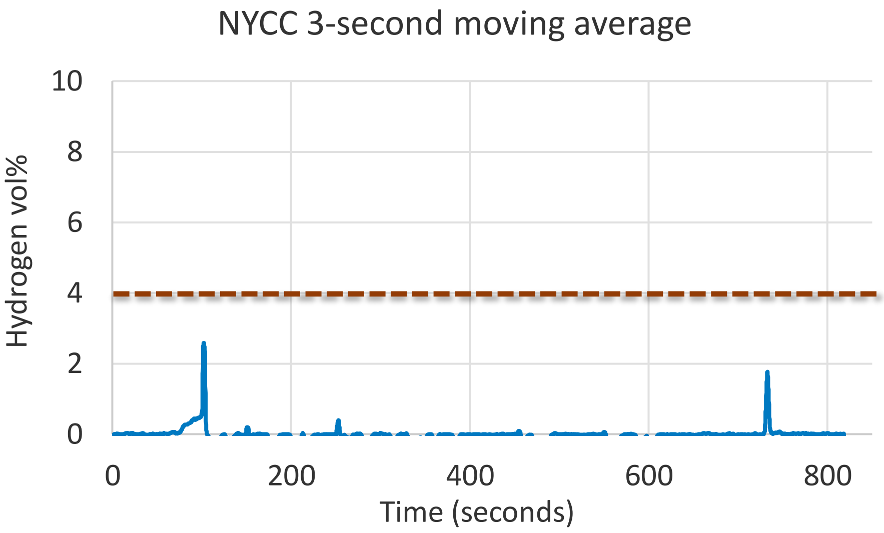




- Hydrogen transients observed with the FCEV per GTR-13 requirements.
  - Data logged 10 pt/sec

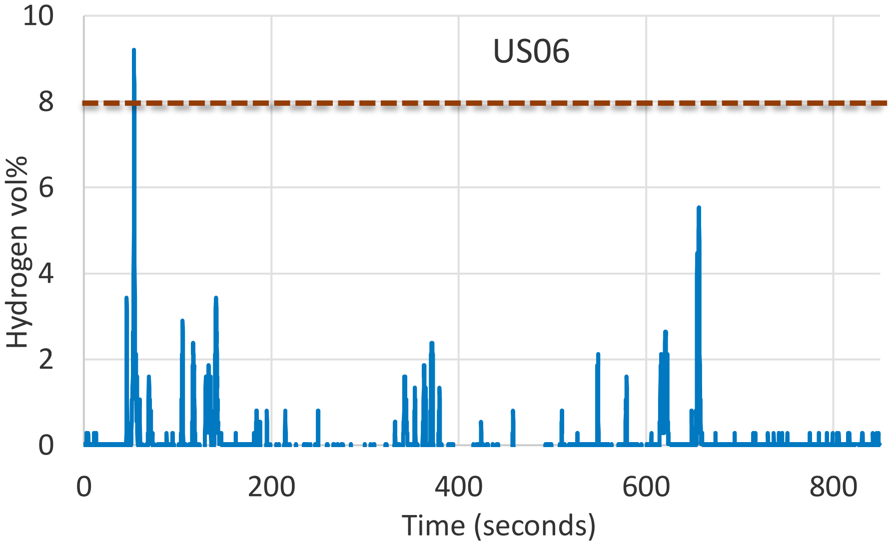
Test Results from ECCC – New York City Cycle (NYCC)

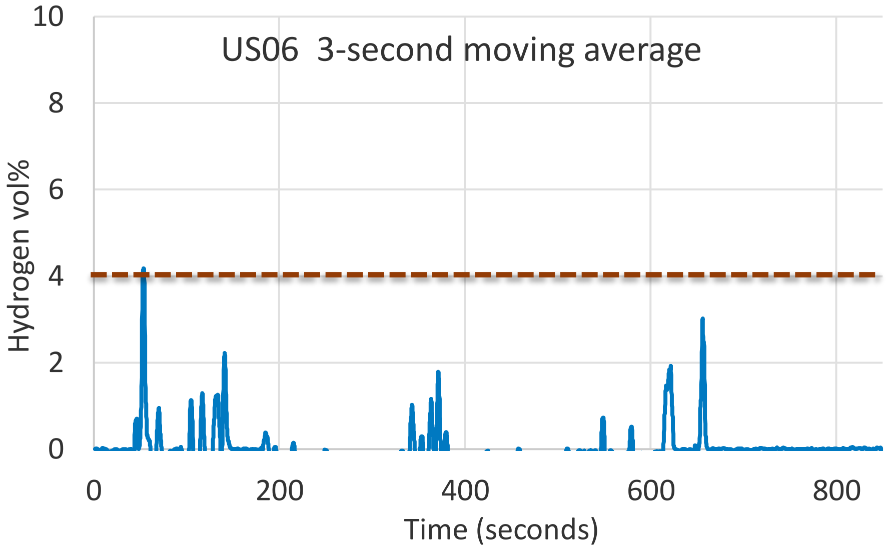




- Hydrogen transients observed with the FCEV driven to mimic city traffic patterns.
- Note: This test is not required for GTR-13 standards.

Test Results from ECCC – US06





- Hydrogen transients observed with the FCEV driven to mimic highway driving.
  - A large spike in the beginning of the test shows hydrogen concentrations over 8 vol% and the 3-second moving average peaks at just over 4 vol%
- Note: This test is not required for GTR-13 standards.