Development of a Mini-PEMS with High HC Capacity

11th Annual International PEMS Conference
Riverside, CA

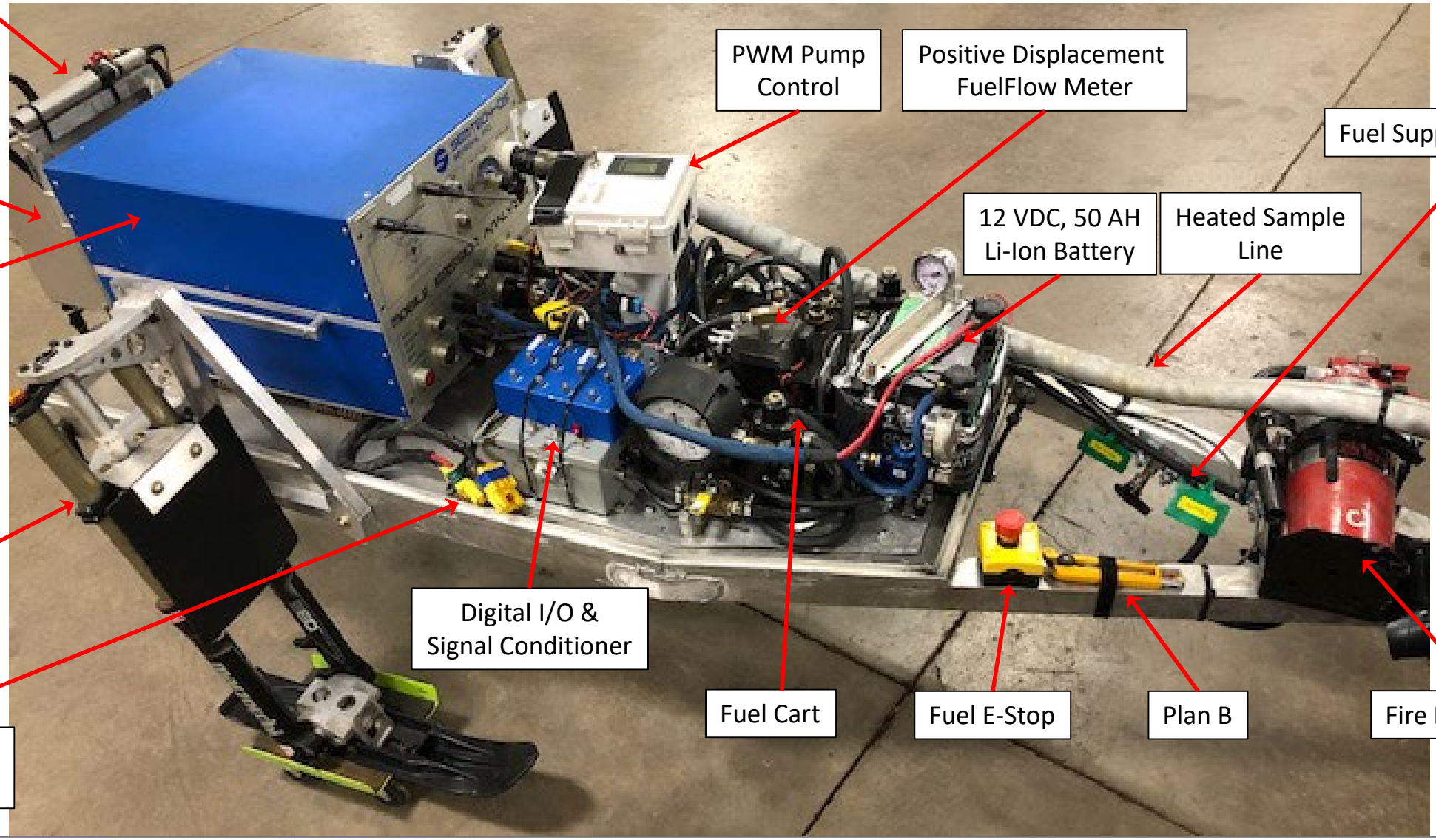
March 17 – 18, 2022

Scott A. Miers, Associate Professor
Brian J. Eggart, Research Engineer

The Starting Point

- Michigan Tech began in-use emissions testing in 2009, at the SAE Clean Snowmobile Challenge
- In 2018, Michigan Tech was contracted to develop a procedure for conducting in-use emissions testing of snowmobiles, for the European Commission - Joint Research Center in Italy
- A pull-behind sleigh was used to measure in-use emissions of four snowmobiles

On-Snow PEMS Testing: Emissions Sleigh*



*Additional specifications provided in supplemental slides

Why Did Michigan Tech Develop a Mini-PEMS?

- The pull-behind sleigh impacted the vehicle operation
  - Complete pull-behind system is approximately 360 lbs
  - Deteriorated handling (speed and terrain) with limited operational environment (groomed trail use)
  - Increased fuel consumption (added weight and drag) → increased emissions (higher power consumption)
- Current, compact solutions (Mini-PEMS) had at least one of the following issues:
  - Limited measurement range or no measurement of total hydrocarbons (THC)
  - Inconsistent test-to-test results
- Michigan Tech decided to build a Mini-PEMS that easily installed on snowmobiles for in-use emissions testing, provided five-gas analysis with high hydrocarbon measurement capability, and produced consistent and repeatable results
  - Additionally, it was designed to be an excellent fit for other small vehicles such as:
    - On and off-highway motorcycles, ATV/UTV's, and small watercraft

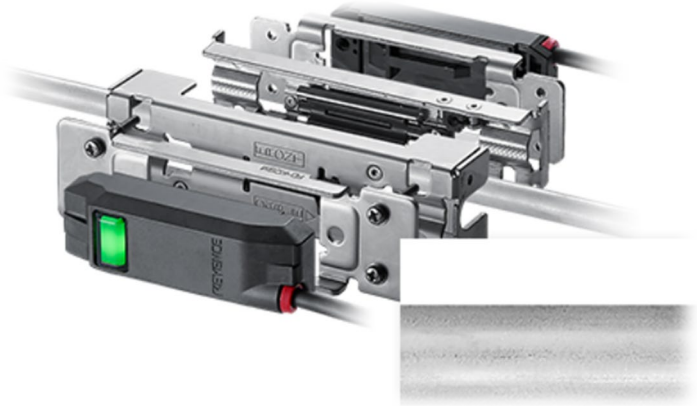
Note: This device was not initially intended to be a replacement for a laboratory-grade emissions analyzer.

Gen1 Mini-PEMS: General Specifications

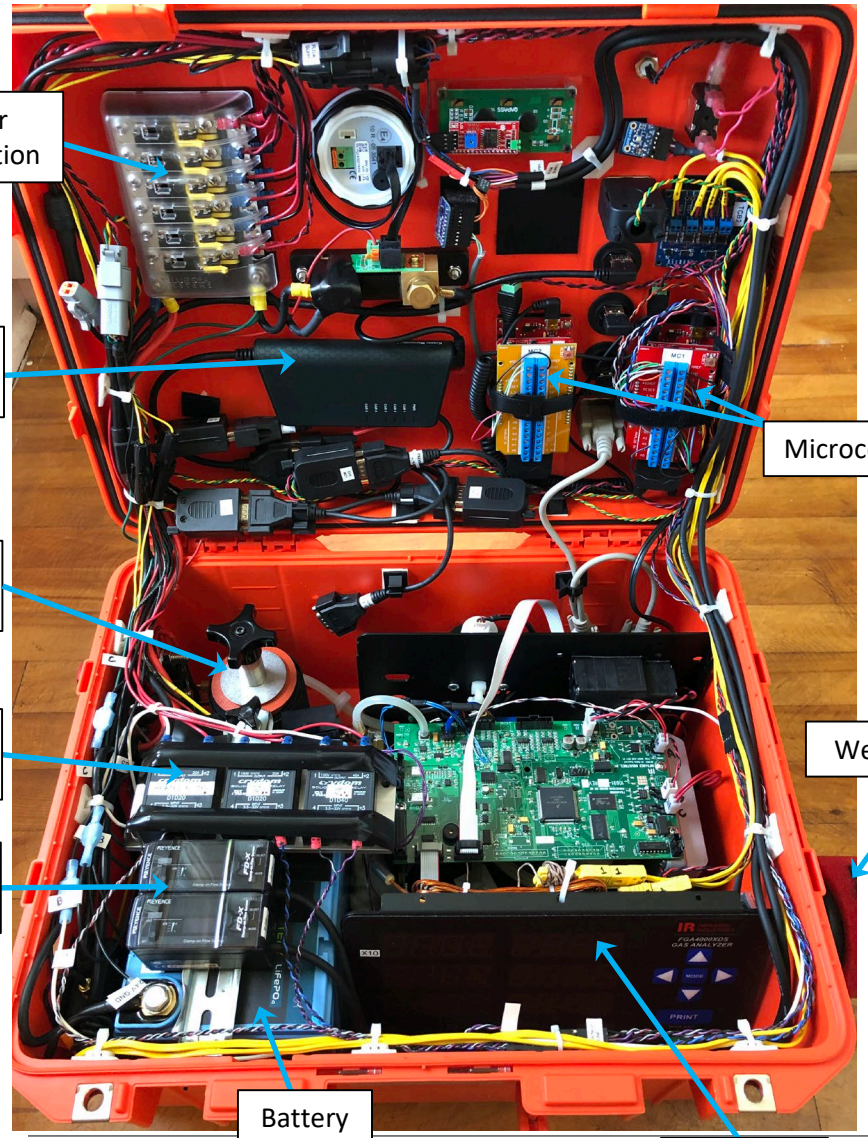
- Compact, Portable, Self Contained, Weather proof
  - Ready-to-run weight: 44 lbs
  - Approximate outside dimensions: 19" W x 16" D x 10" H
  - 1.5+ hour run time on a single battery charge
- Measurement Technology, Ranges and Response Time:
  - NDIR: CO_2 (0-20%), CO (0-10%), THC (0-120,000ppmC1)
  - Chemical Cell: O_2 (0-25%), NO_x (0-5,000ppm)
  - Measurement response time (T_{90}): ~1 second
- Heated sample path
  - Improves total hydrocarbon measurement accuracy and repeatability

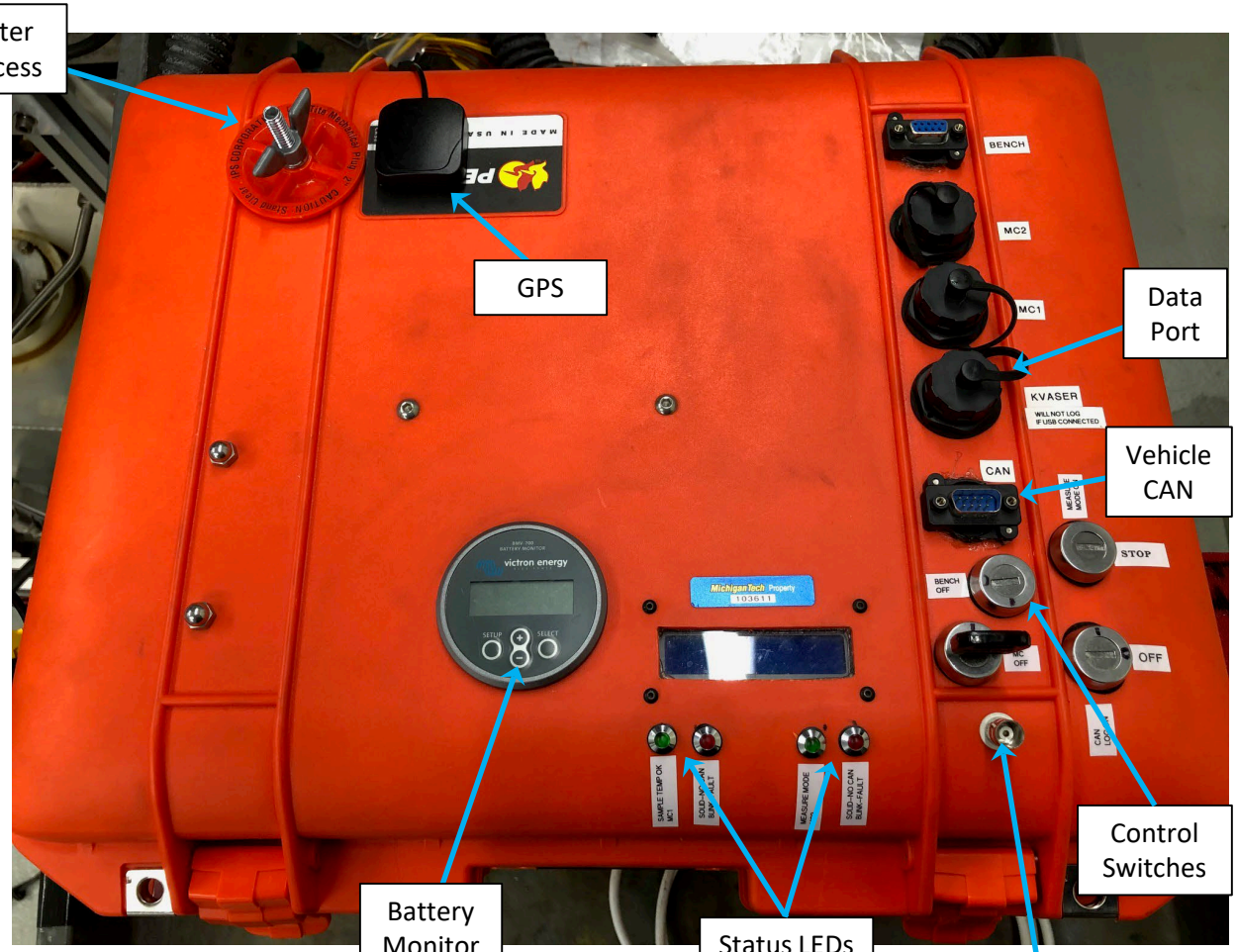
Gen1 Mini-PEMS: Data Acquisition and Fuel Measurement

- Multi-channel CAN Logger
  - Records emissions bench data at a rate up to 4 Hz
  - Records GPS latitude, longitude, and speed
  - Records micro-controller data
    - Ambient temperature, pressure, relative humidity
    - Sample gas temperature and relative humidity
    - Enclosure box temperature, pressure, relative humidity, and VOC's (leak detect)
  - Records CAN data stream from OEM ECU
    - Fuel flow, torque, and engine speed (if available)
  - Single file output for ease of data processing
- Fuel measurement system
  - Lightweight and low power consumption
  - Ultrasonic sensors utilized for minimal impact to factory fuel system

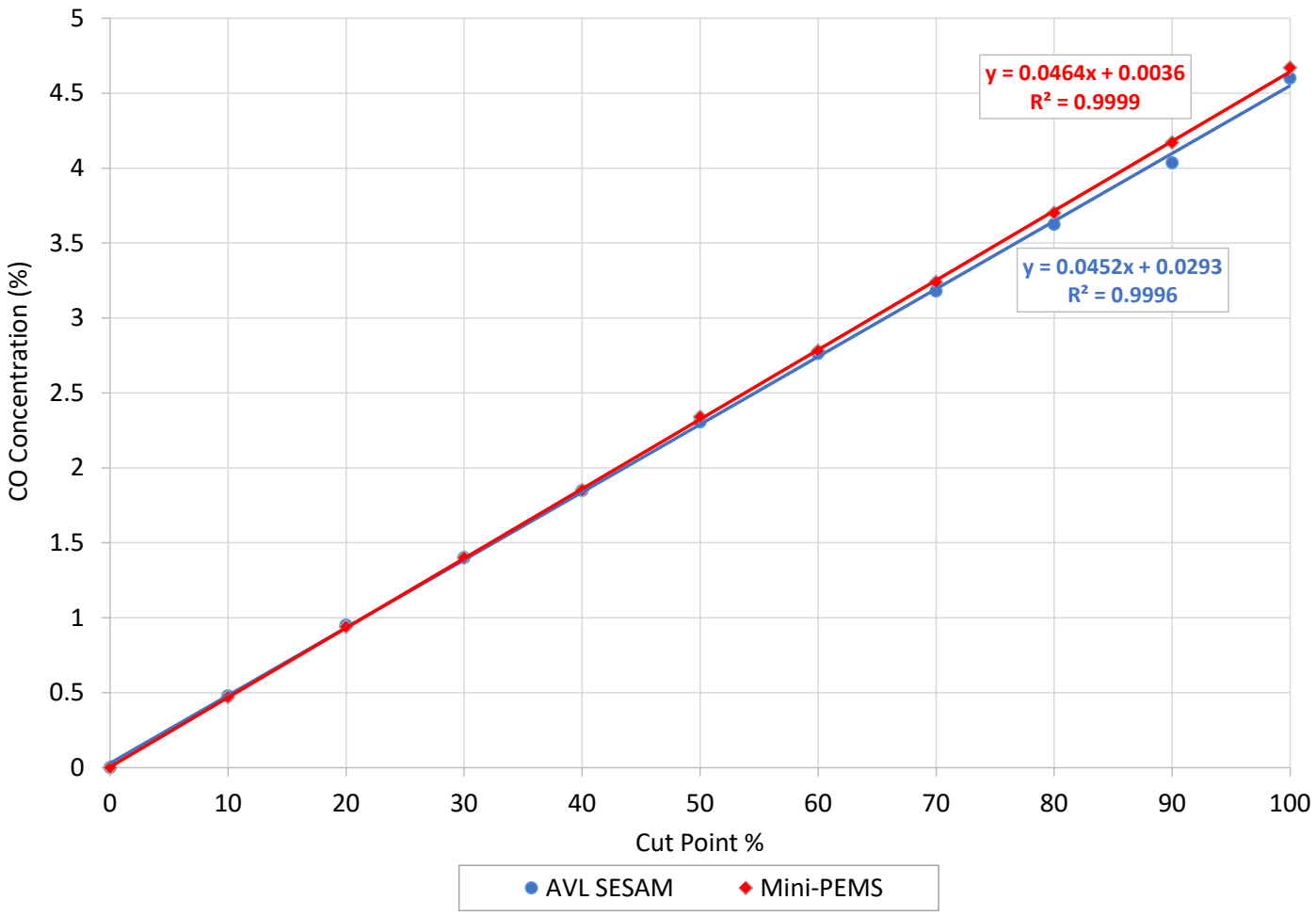


Michigan Tech Mini-PEMS: Gen1



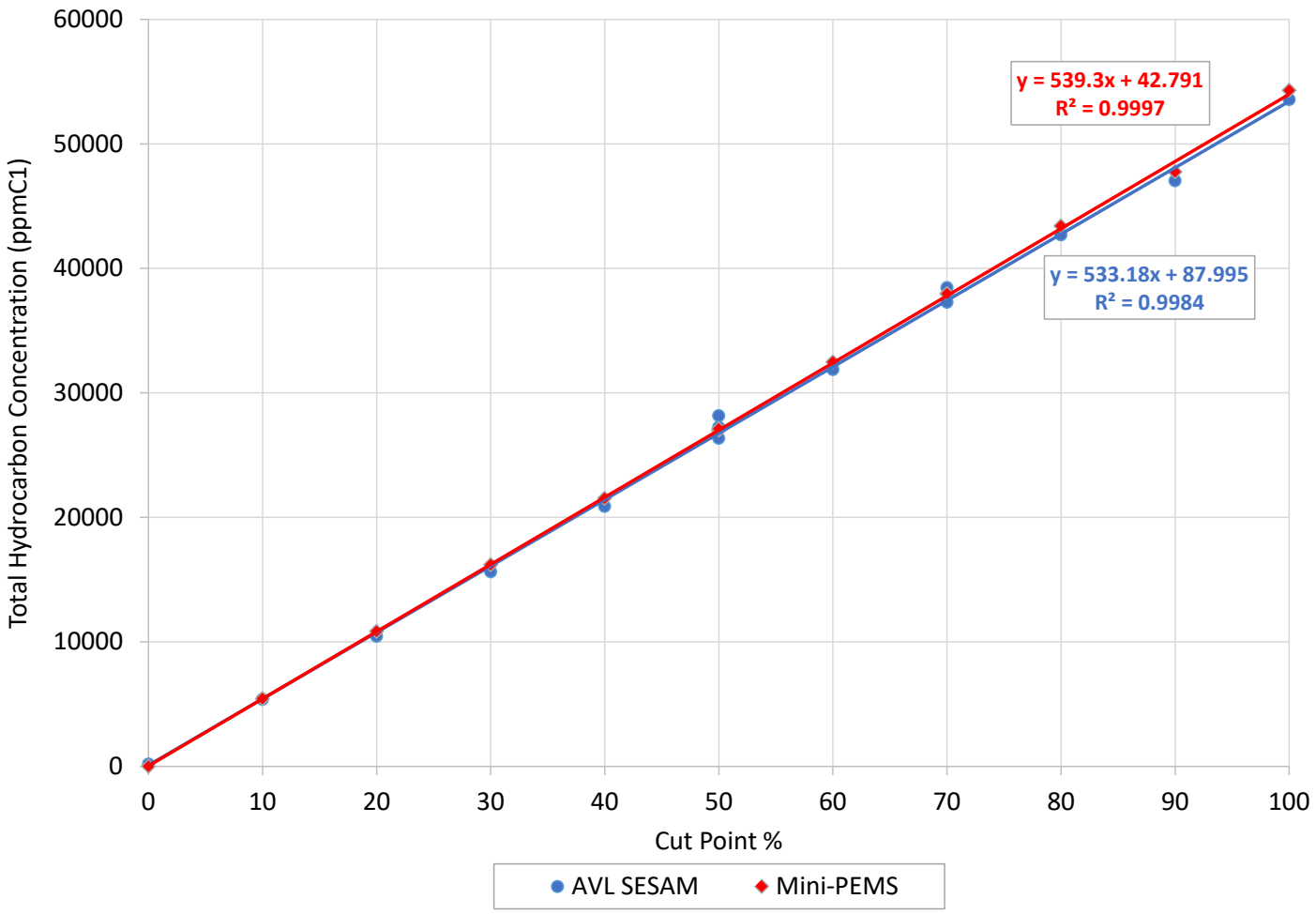


Calibration Result – CO Span Gas



- CO certification span gas was supplied at 11 different concentrations to the Mini-PEMS as well as to an AVL SESAM (laboratory-grade) emissions analyzer
- The maximum CO gas concentration was ~4.5%
- The calibration was nearly linear for both benches with R^2 exceeding 0.999
- The relative error between the two measurement systems was less than 3.5%

Calibration Result – Propane Span Gas

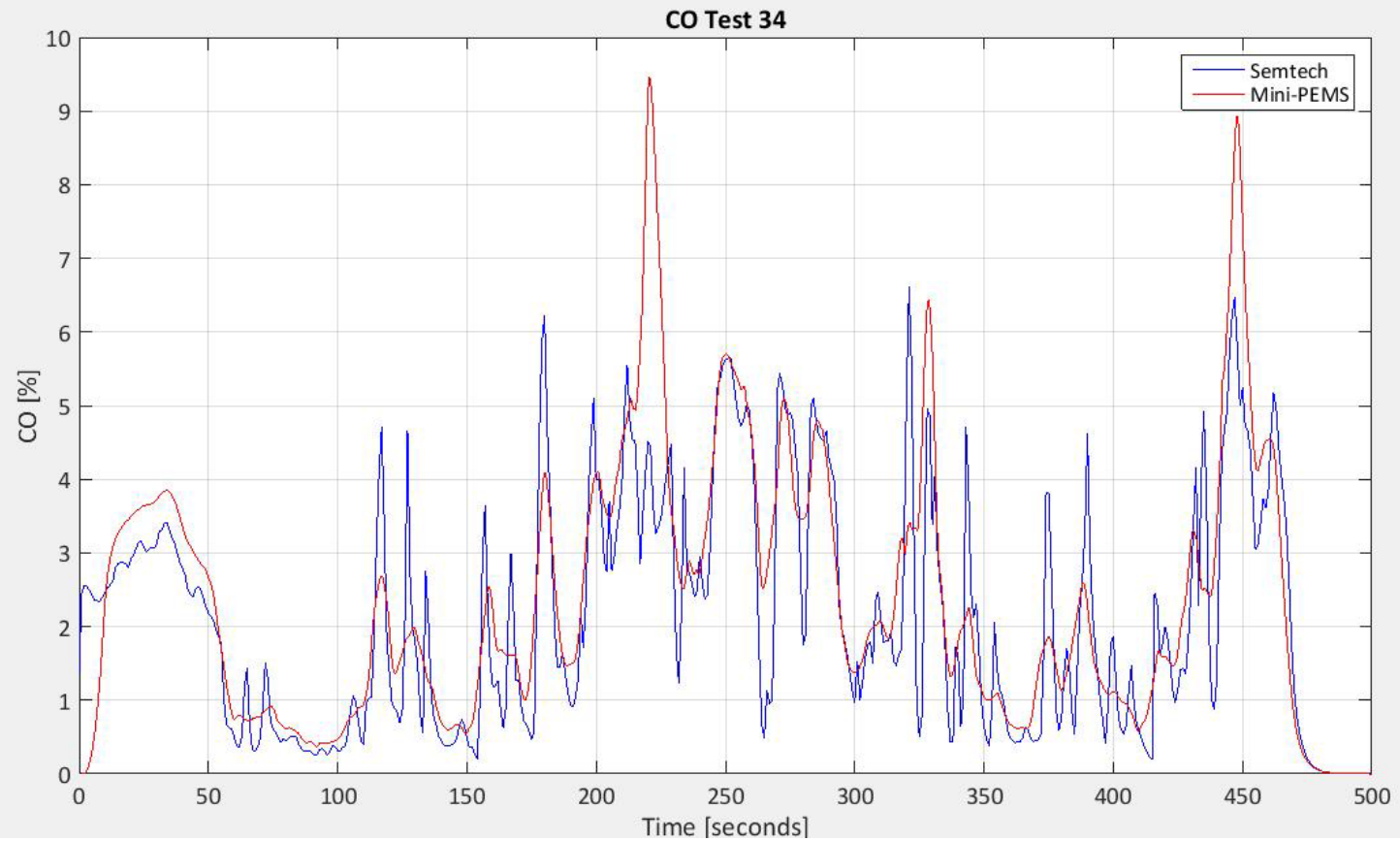


- Propane certification span gas was supplied at varying concentrations to the Mini-PEMS as well as to an AVL SESAM (laboratory-grade) emissions analyzer
- The maximum gas concentration was ~54,000ppmC_1
- The calibration was nearly linear for both benches with R^2 exceeding 0.998
- The relative error between the two measurement systems was less than 4.0%

On-Snow Validation

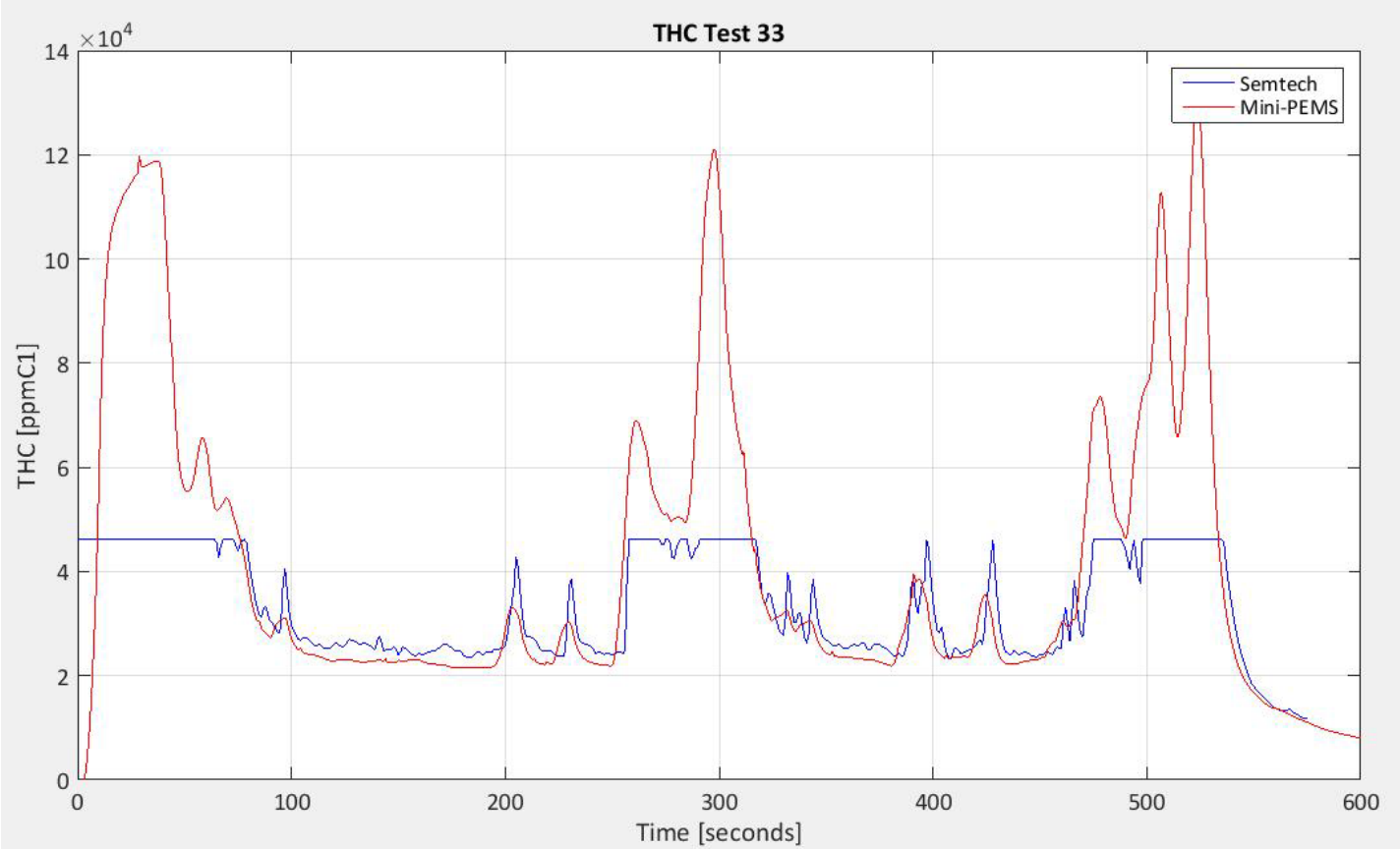
- Pull-behind sleigh was used to collect emissions
- Gen1 Mini-PEMS was also installed to simultaneously sample emissions
- Vehicles included a 600cc two-stroke and 998cc four-stroke snowmobile

On-Snow Four-stroke Testing Results: CO



- Four-stroke snowmobile
- On-snow emissions comparison using Semtech-DS emissions analyzer (sleigh) and Mini-PEMS
- Very good dynamic response from Mini-PEMS
- Test Averages:
  - Semtech: 1.87%
  - Mini-PEMS: 1.89%
    - A difference of 0.02%!

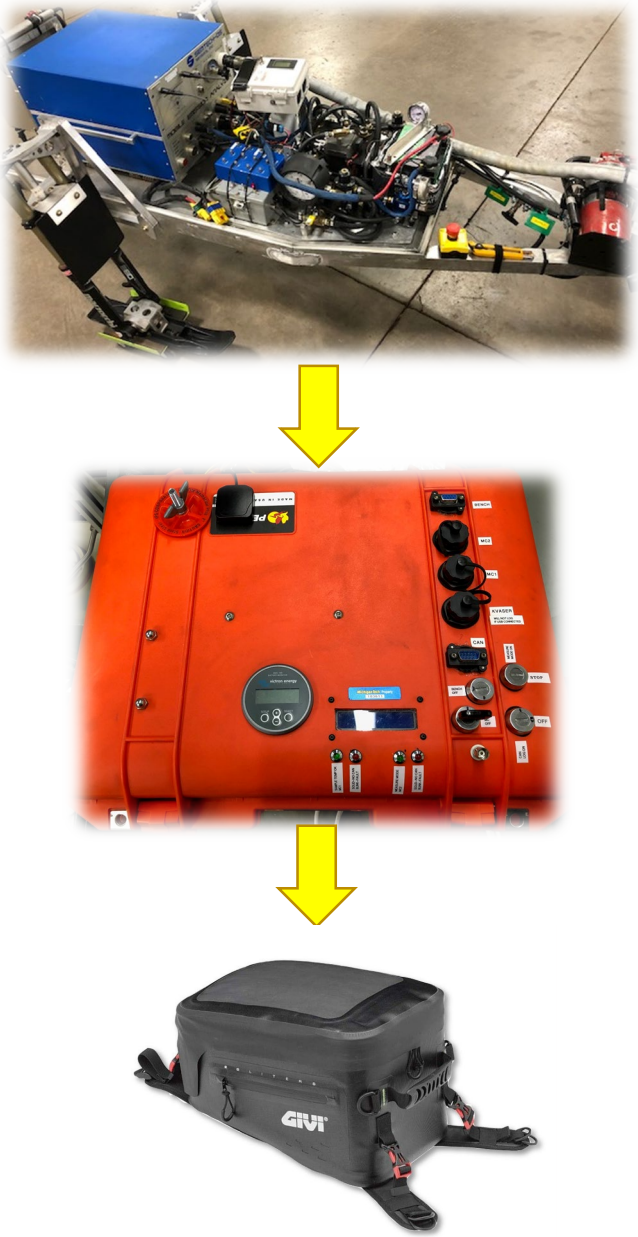
On-Snow Two-stroke Testing Results: THC



- Two-stroke snowmobile
- On-snow emissions comparison using Semtech-DS emissions analyzer (sleigh) and Mini-PEMS
- Very good dynamic response from Mini-PEMS
- Significantly better peak measurements with Mini-PEMS
  - Maximum measurement range for Semtech-DS is ~46,000 $ppmC_1$
- Test Averages:
  - Semtech: 34,121 $ppmC_1$
  - Mini-PEMS: 36,410 $ppmC_1$
    - An increase of 6.7% for Mini-PEMS

Michigan Tech Mini-PEMS: Gen2

- Gen1 was a success
  - Met the weight target
  - Exceeded measurement accuracy and repeatability targets
  - Generated interest in building Gen2…compliance verification?
- The goals for Gen2 are:
  - Be lighter than Gen1
    - Target weight = 25 lbs
  - Measure non-methane hydrocarbons
    - In addition to CO_2, CO, THC, O_2, & NO_x
  - Easily "mount" on and interface with a variety of vehicles
    - Snowmobiles
    - ATV's/UTV's
    - Watercraft
    - On and off highway motorcycles



Thank you!

Contact Information

Scott A. Miers, Associate Professor

1400 Townsend Drive

Houghton, MI 49931

Office: (906) 487-2709

Cell: (630) 310-0958

Email: samiers@mtu.edu

Brian J. Eggart, Research Engineer

32199 Airpark Blvd

Calumet, MI 49913

Office: (906) 487-2591

Cell: (906) 370-9522

Email: bjeggart@mtu.edu

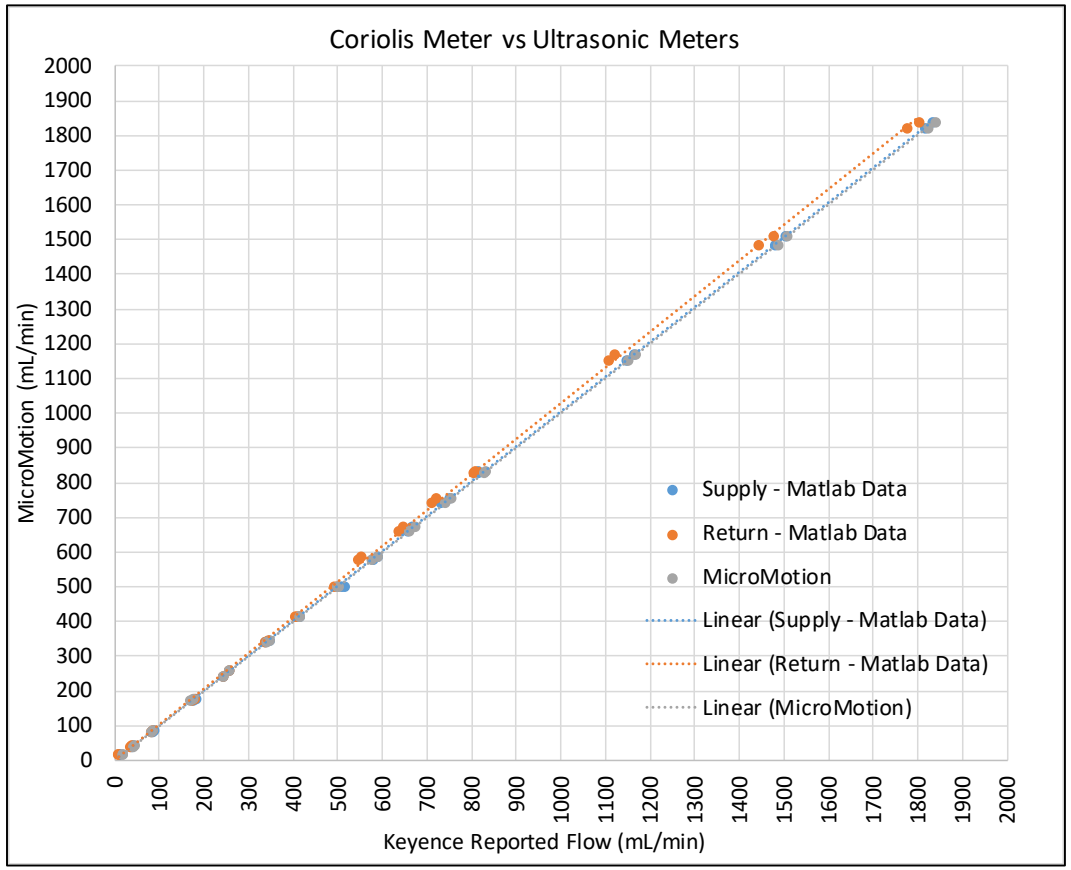
Supplemental Slides:

Michigan Tech On-Snow PEMS Testing: Emissions Sleigh

- Weight: 366lb (166 kg) w/ ½ tank of fuel
- Sensors Inc. SEMTECH 5-gas emissions analyzer
  - CO_2 (0-20%)
  - CO (0-8%)
  - HC (0-13,333ppmC_3)
  - O_2 (0-25%)
  - NO_x (0-3,000ppm)
- Run Time 30+ minutes
- Fully controlled and conditioned sample path
- Re-Sol custom fuel system

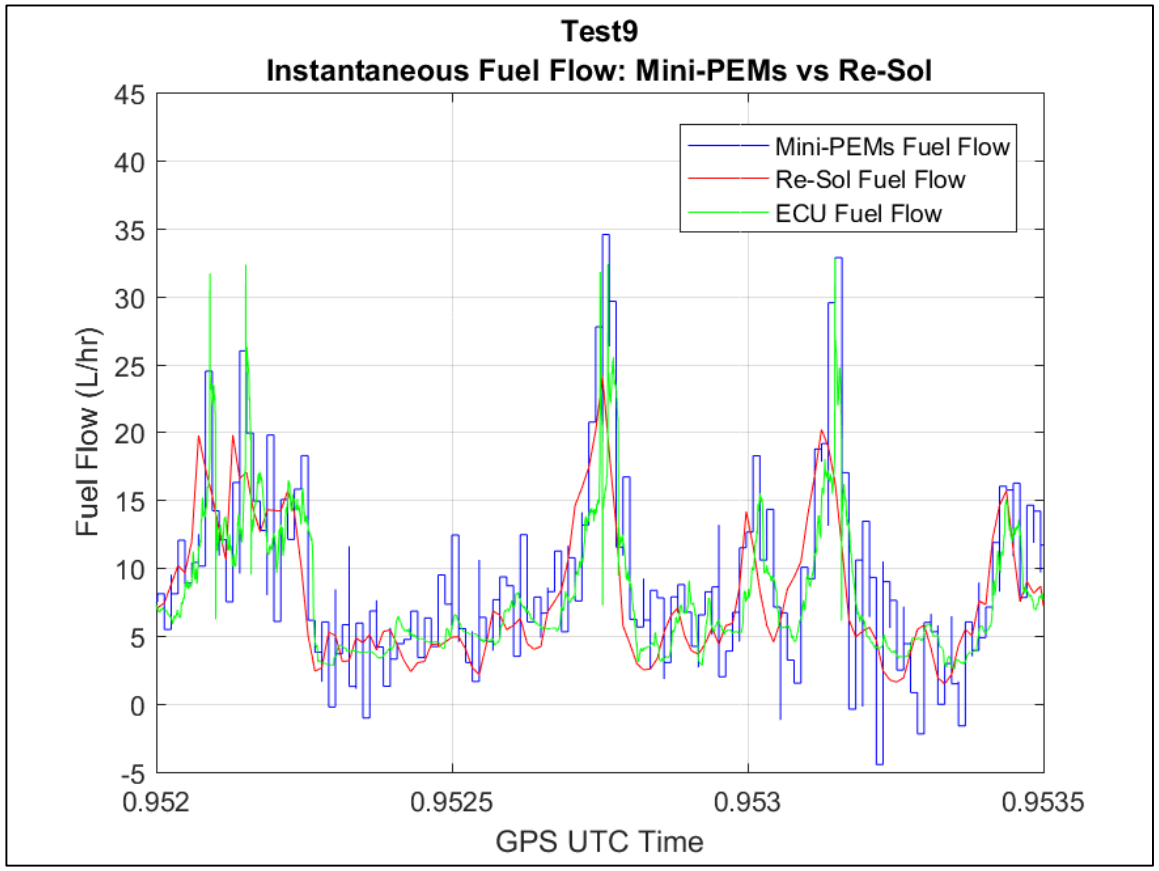
Fuel Flow Calibration and Data Comparison

Calibration using MicroMotion Coriolis flow meter



Typical range: 25 to 1,700 mL/min (+/- 5% above 40 mL/min)

Data comparison with Pierburg PLU126 flow meter & production ECU



Totalized Fuel Estimates:

Mini-PEMS: 2,540 mL, Re-Sol: 2,156 mL, ECU: 2,224 mL