Welcome to Aprovecho Research Center's Spring Webinar Series!

Emissions Testing

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Agenda

- An overview of the ISO 19867-1 cookstove test methodology.
- A look at the equipment needed to perform the test and gather data.
- A discussion of the of the quality control procedures needed for validating the data.
- Introduction to data processing applications
- Questions & Answers

ISO 19867-1 is generally:

- Testing procedures for the laboratory
- Equipment specifications
- Data validation procedures
- Test metrics and calculations

- Some equipment is related to gathering data
- Some equipment is related to validating data

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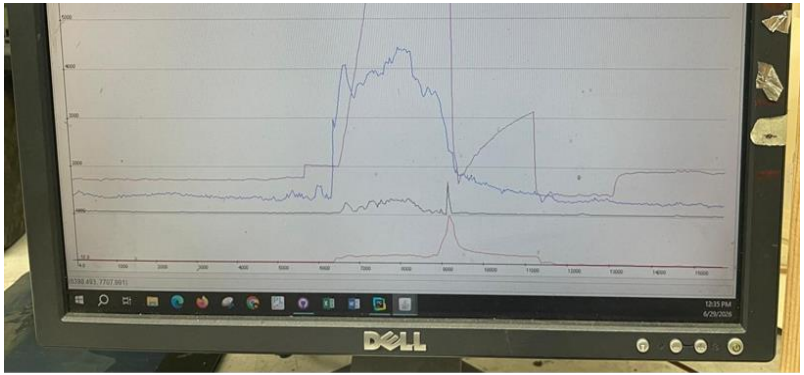
Uses and properties of the test

- The ISO WBT provides a method for comparisons of different cooking systems, but does not necessarily represent the way the stove will actually get used in the field.
- It is optimized for continuous fed wood burning stoves, but it also contains methods for batch fed stoves.
- The protocol is flexible since it prioritizes instruction from the manufacturer to describe the cooking system and how it is used.
- It is a voluntary international standard that must be adopted by a specific country.

Determine Cooking System

- Use a cooking vessel similar to what is identified as being used in the field

- Use a fuel that is representative of what is used in the field.



- The stove operator is an important factor in the cooking system as well!

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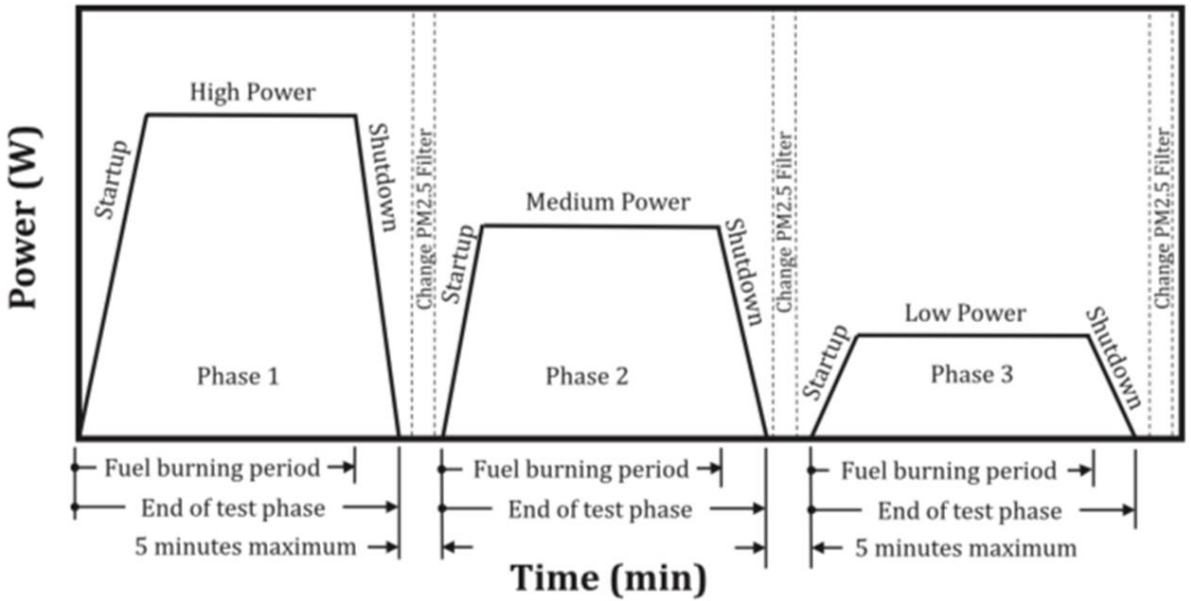
Standard Test Sequence



- Boiling water takes high power. Simmering water takes low power.
- Stove performance is strongly dependent on firepower.

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Defining three firepower levels

- High
  - High power is maximum possible by the stove, normally defined by the manufacturer, but if field data is available use that.
  - The water does not need to boil during the 30 minute test.
  - Firepower must be high enough to bring the water to within 1 degree of boiling without a time limit (if the water does not reach this temperature after 30 minutes a separate test must be performed to prove that it is possible after more than 30 minutes).

- Medium
  - Half way between high and low firepower.

- Low
  - Lowest possible firepower.

ISO Tier Ratings

	Tier	Thermal efficiency (%)	Emissions	
			CO (g/MJ_d)	$PM_{2,5}$ (mg/MJ_d)
Better performance 	5	≥50	≤3,0	≤5
	4	≥40	≤4,4	≤62
	3	≥30	≤7,2	≤218
	2	≥20	≤11,5	≤481
	1	≥10	≤18,3	≤1030
	0	<10	>18,3	>1030

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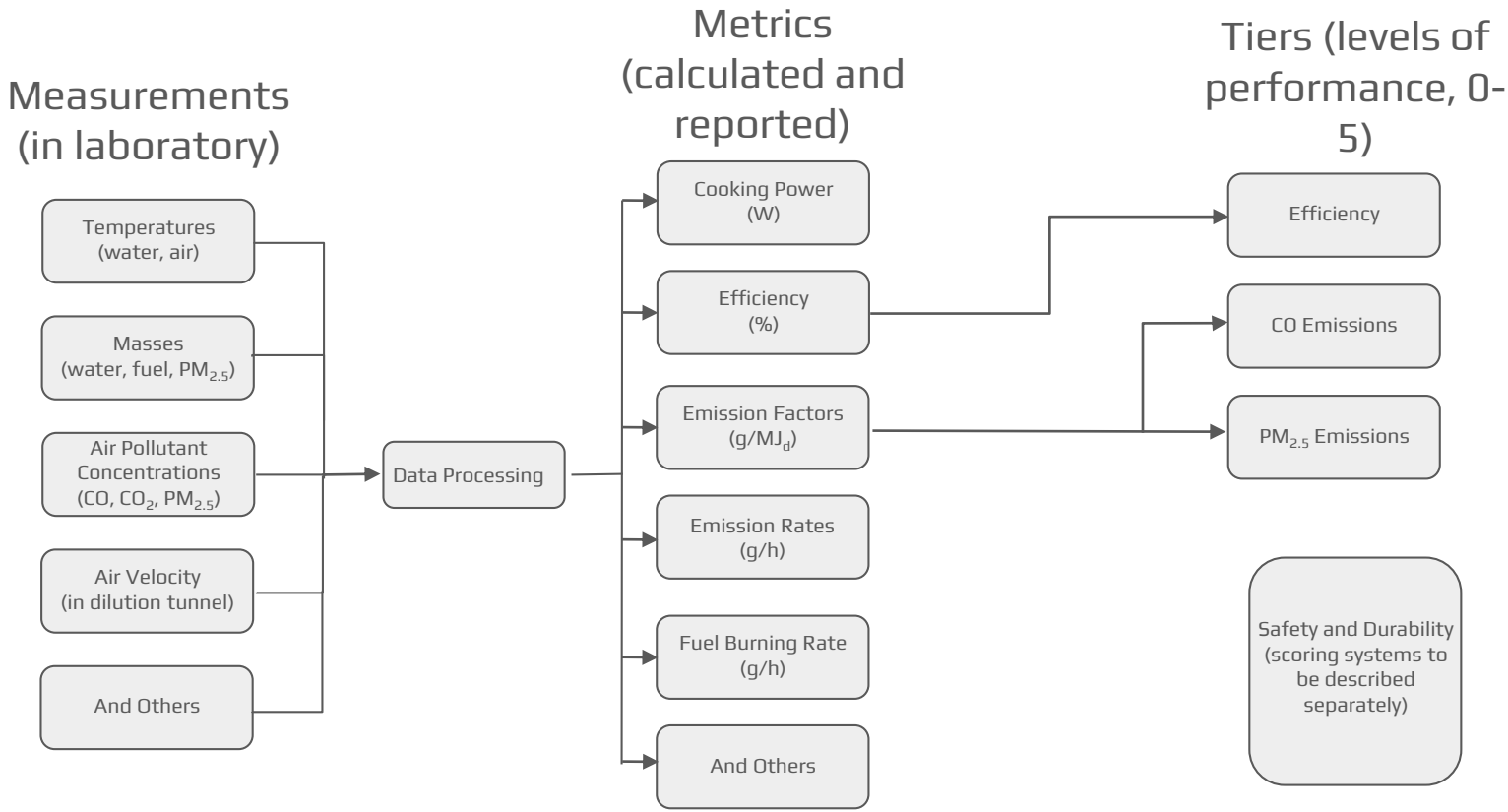
ISO Data Collection and Analysis



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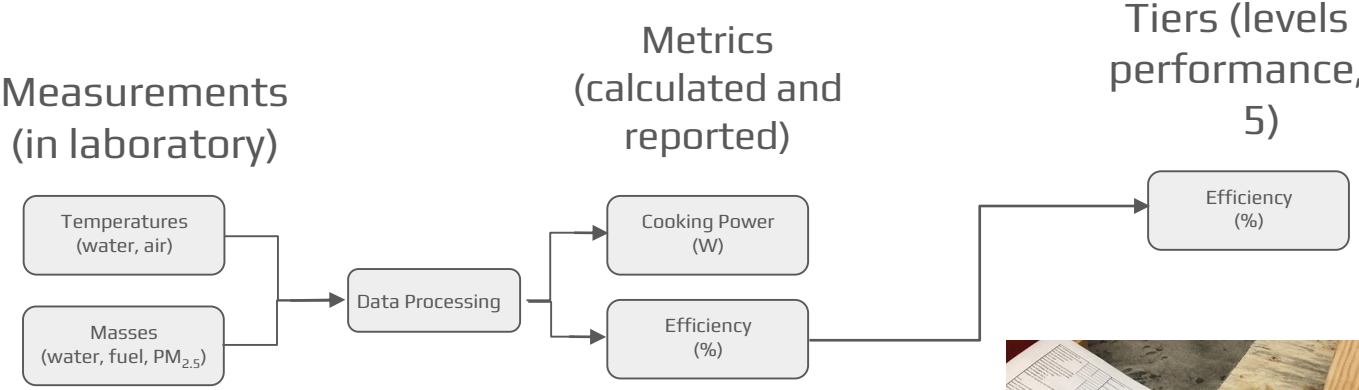
Thermal Efficiency Measurements



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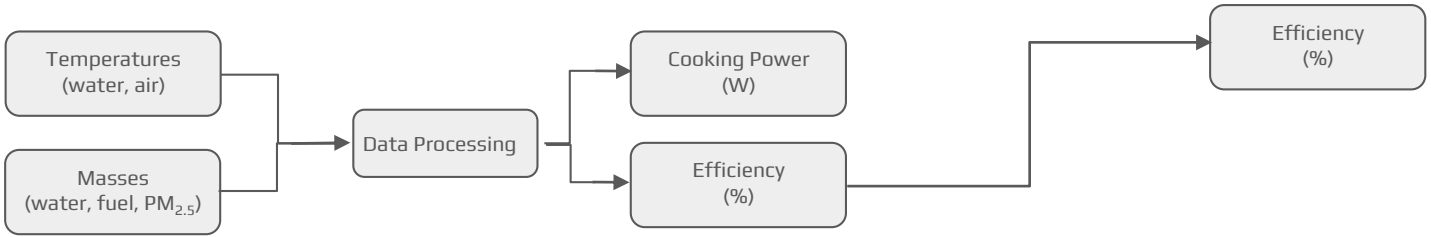
Measurements (in laboratory)

Metrics (calculated and reported)

Tiers (levels of performance, 0-5)



Digital, automatically recorded measurements help with quality control

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What is the LEMS?

A way to measure cookstove emissions rates following ISO 19867-1

- Developed by Aprovecho engineers in 2005
- Total capture cookstove emissions sampler
- Measures CO, CO_2, PM, *Water temperature*, dilution tunnel volume at 0.5Hz
- $PM_{2.5}$ is also measured with pump and filter (0.01 mg balance)
- CO, CO_2 sensors are calibrated against reference gasses

The LEMS is an integrated platform of digital measurements for cookstove evaluations

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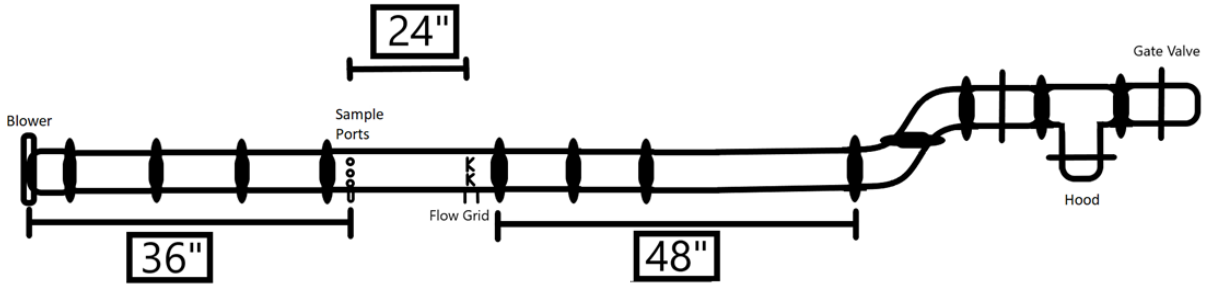
LEMS Dilution Tunnel Schematic



Long Dilution tunnel helps to ensure that the sample is adequately mixed

Mixing baffles ensure that sample is adequately mixed

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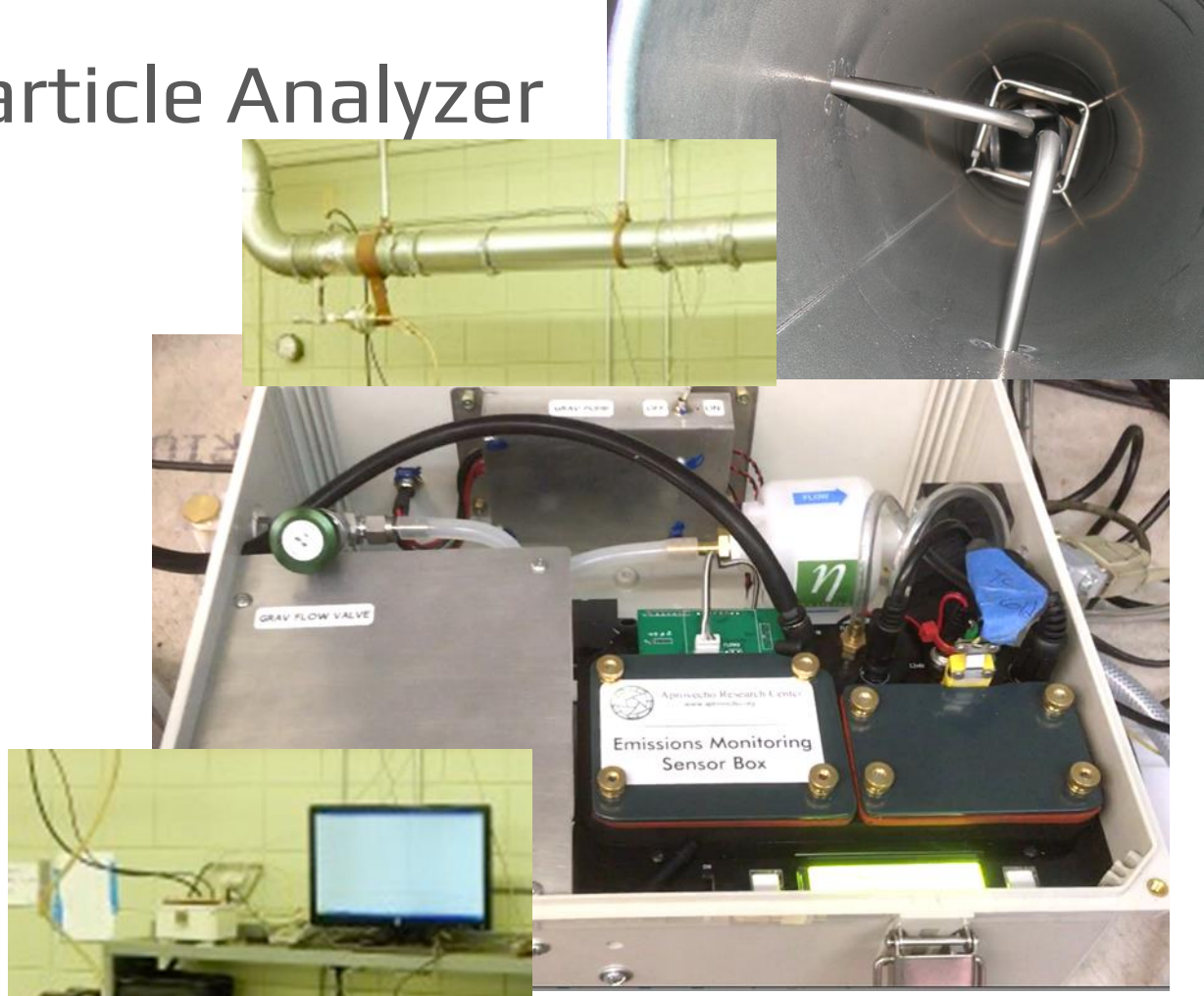
LEMS Gas and Particle Analyzer Sensors

Dilution tunnel collects stove emissions and supports sample probes

Sensor box measures:

- CO concentration
- CO_2 concentration
- $PM_{2.5}$ concentration
- Flow rate in duct
- Temp in duct
- Temp of water in pot



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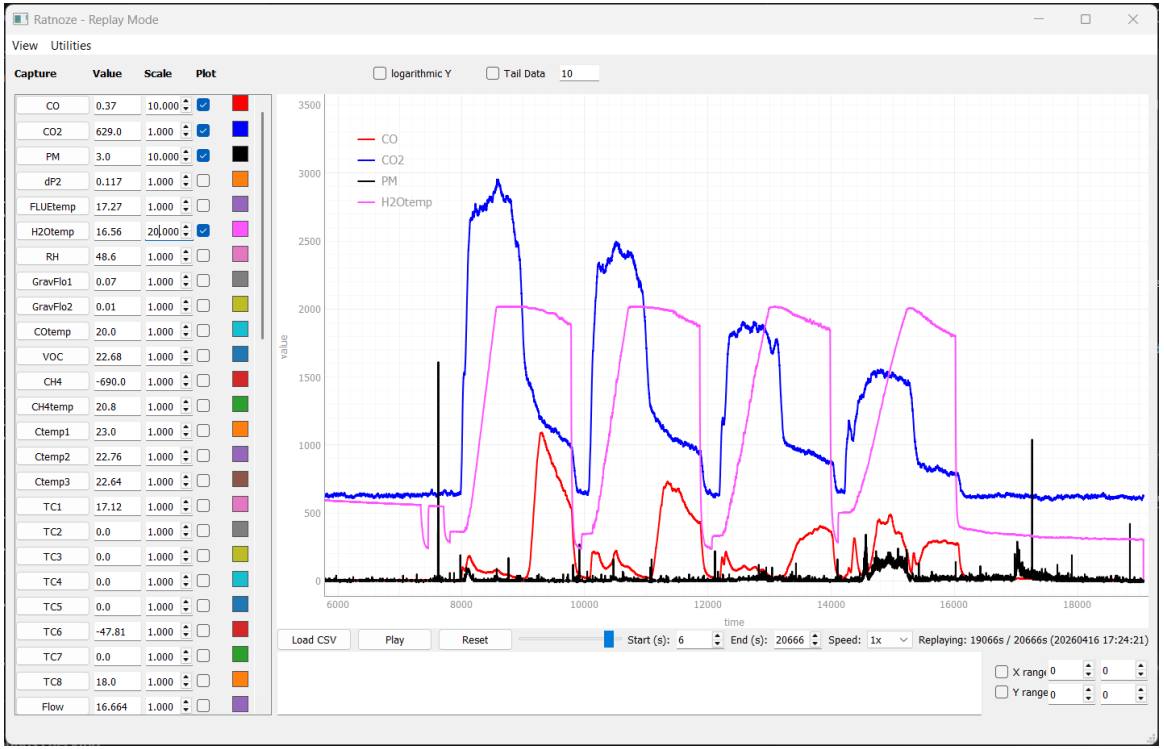
Plotting digital data during a test

- MusaPlotter (or Live Graph) is used to read the data from the computer file as it is being written
- The data can be scaled for a better view without changing what is written to the file



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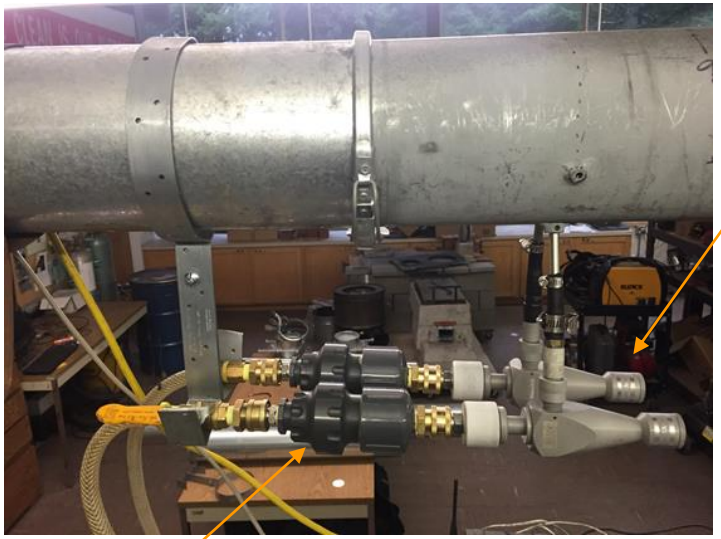
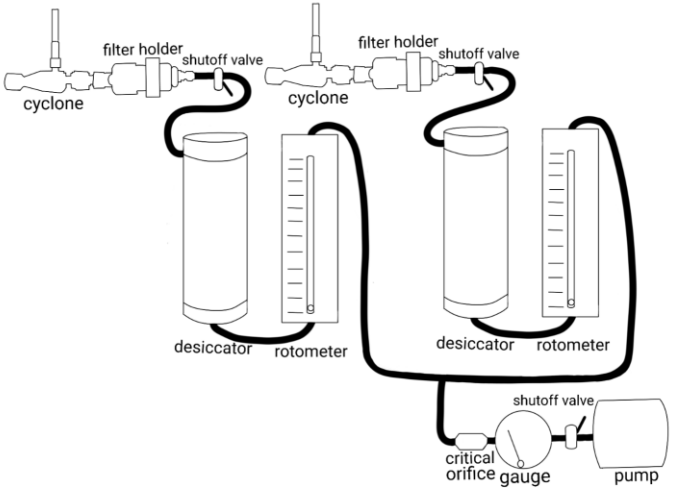
Gravimetric System Equipment



Filter cassette holders

Particle separator discards particles greater than 2.5 micron in diameter.

Sample size doubled for stoves with less than about 5 mg/min when the 10 ug resolution balance is used, or one can use a 1 ug resolution balance



Filter cassette seals around filter and collects $PM_{2.5}$ sample

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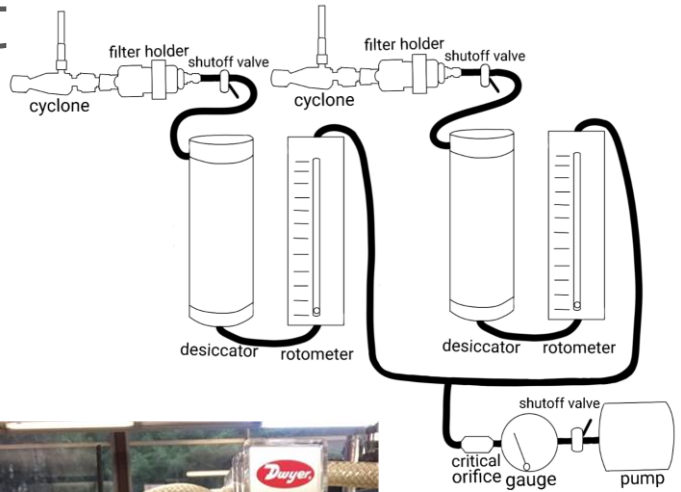
Gravimetric System Equipment

Vacuum pump draws sample onto filter and maintains sufficient flow rate at critical pressure drop over control orifice



Flow rate is controlled by critical orifice (not shown), but is monitored by a rotameter. Rotameter is not accurate if sample air is wet

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Weighing filters to measure PM2.5 sample

Balance - 0.01mg works well in office with AC

Desiccator

- Use 10 ug balance for T4 stoves, 1 ug for T5
- Condition filters in dessicator for 24 hrs to control moisture on filter
- Record environmental conditions during weighing session
- Weigh certified calibration weight 5 times
- Weigh filter 5 times (label dish instead of writing on filter)
- Weigh filter 5 times again after conditioning for an additional 6 hrs to see if the two weighing sets agree within the precision of the balance
- A dessicator with a lower humidity dries the filters faster

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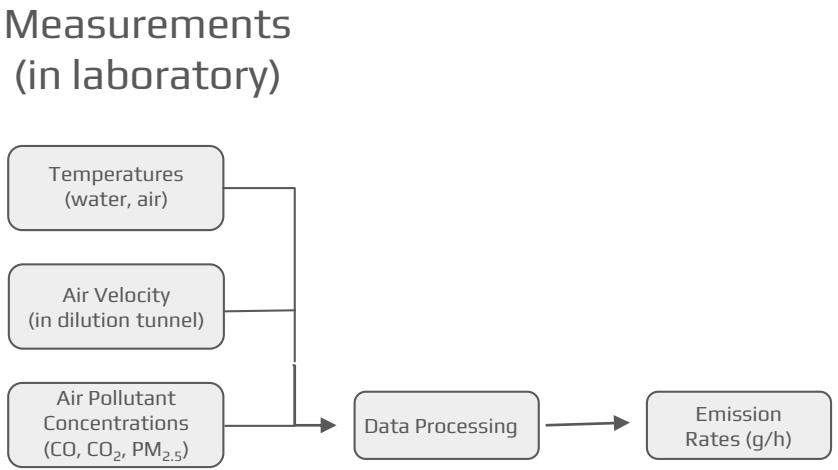
Quality control activities are needed for each measurement:



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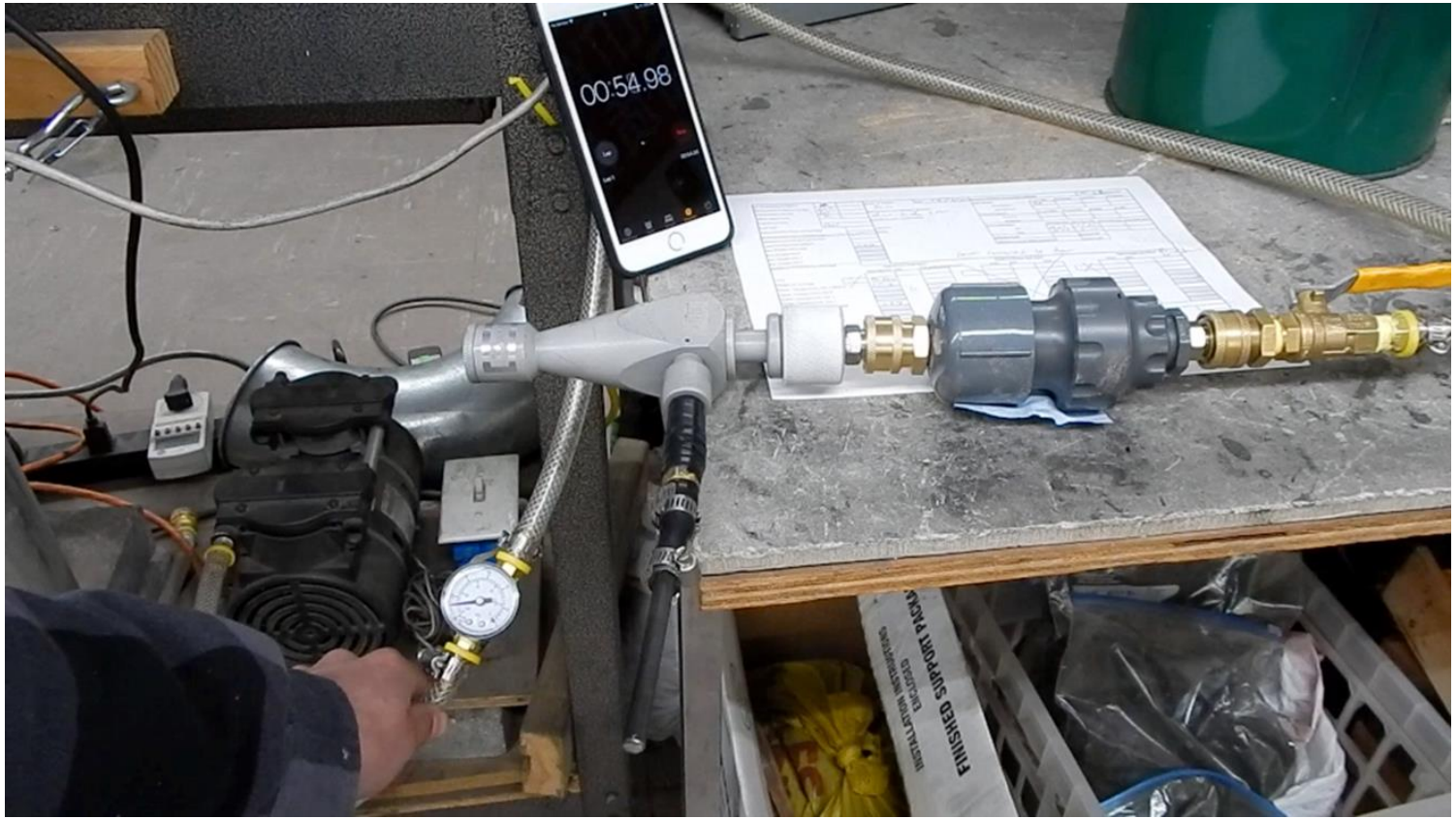
Leak checks – looking for <=0.1 % of sample flow rate



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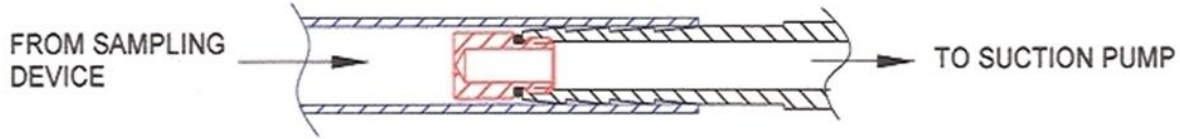
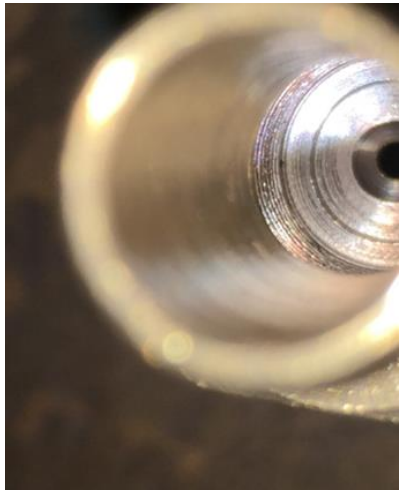
Gravimetric flow rate monitoring



Cut Away View of Critical Orifice in 3/8" Barbed Nipple with Hose Pressed Over Assembly



- LEMS uses a critical orifice to control gravimetric flow and a rotameter to directly monitor flow
- Gravimetric flow rate must be within 3% of nominal throughout the test

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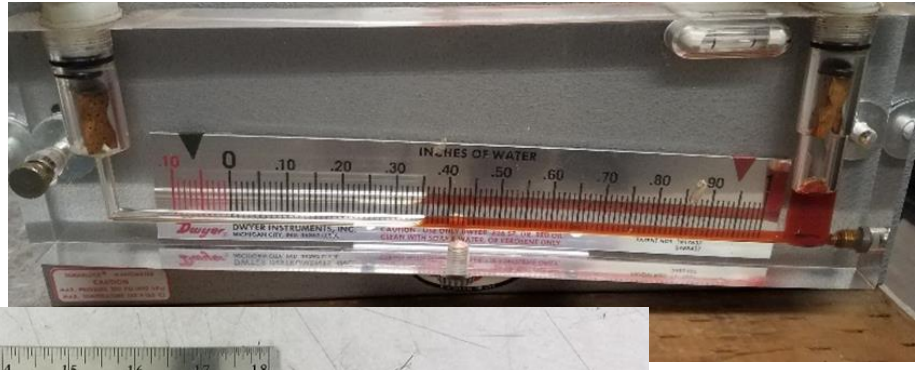
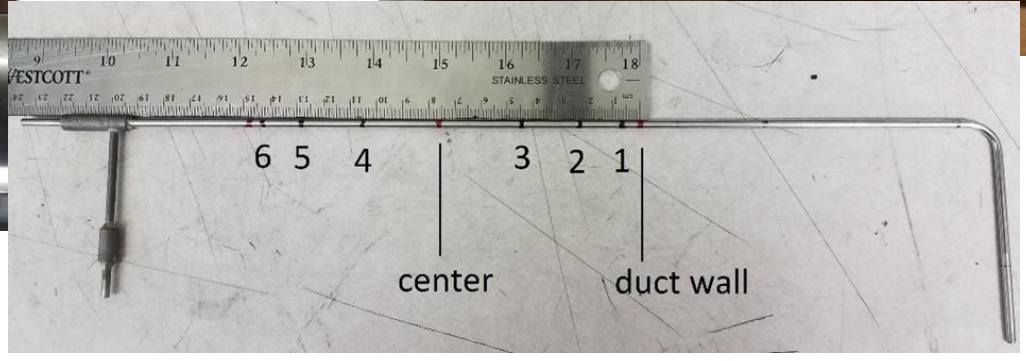
Dilution tunnel flow calibration

- LEMS uses a Pitot-static flow grid to continuously measure dilution tunnel flow rate. It requires an initial calibration.
  - Calibration holds as long as the grid is clean, not deformed, and free of leaks
  - A horizontal and vertical velocity traverse (12 points total) with a standard Pitot-static probe is used to measure volumetric flow rate at a given dilution setting





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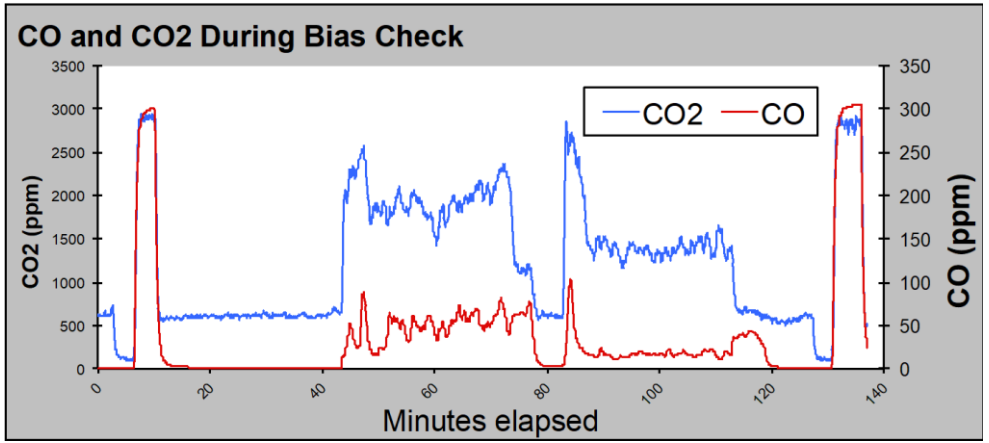
Gas Sensor Bias Checks

- A bias check compares a sensor's reading against a known-concentration gas to measure how far off its readings are.
- Check zero and span using compressed gas cylinders before and after a period of stove testing.
- Large tanks ensure a multi year supply.
- The bias and drift checks take two (2) reference points



- Zero bias - ± 5% of scale
- Span bias - ± 5% of scale
- Zero drift - ± 3% of scale
- Span drift - ± 3% of scale

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Weighing filters to measure $PM_{2.5}$ by gravimetric method

The standard says that a certified **calibration weight** shall be weighed at the beginning of the weighing session and at least **every tenth filter** to check the accuracy and precision of the balance.

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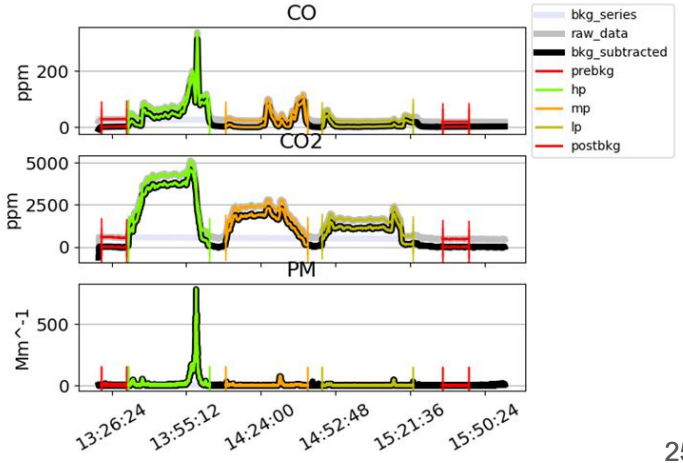
Software and a computer are needed to generate results

Measurements (in laboratory)

- Temperatures (water, air)
- Masses (water, fuel, $PM_{2.5}$)
- Air Pollutant Concentrations (CO, CO_2, $PM_{2.5}$)
- Air Velocity (in dilution tunnel)
- And Others

→ Data Processing

Stove type/model		HOT A 5.26.20
Date		5.26.20
ISO Performance Metrics	**units**	**Value**
Thermal Efficiency With Char	%	35.9%
Thermal Efficiency Without Char	%	35.6%
CO per Energy Delivered to Cooking Pot	g/MJd	4.79
PM per Energy Delivered to Cooking Pot	mg/MJd	44.3
CO Measured Emissions Rate	g/min	0.4
PM Measured Emissions Rate	mg/min	3.4
		Tier
Thermal Efficiency With Char		3.5
Thermal Efficiency Without Char		3.5
CO per Energy Delivered to Cooking Pot		3.8
PM per Energy Delivered to Cooking Pot		4.3



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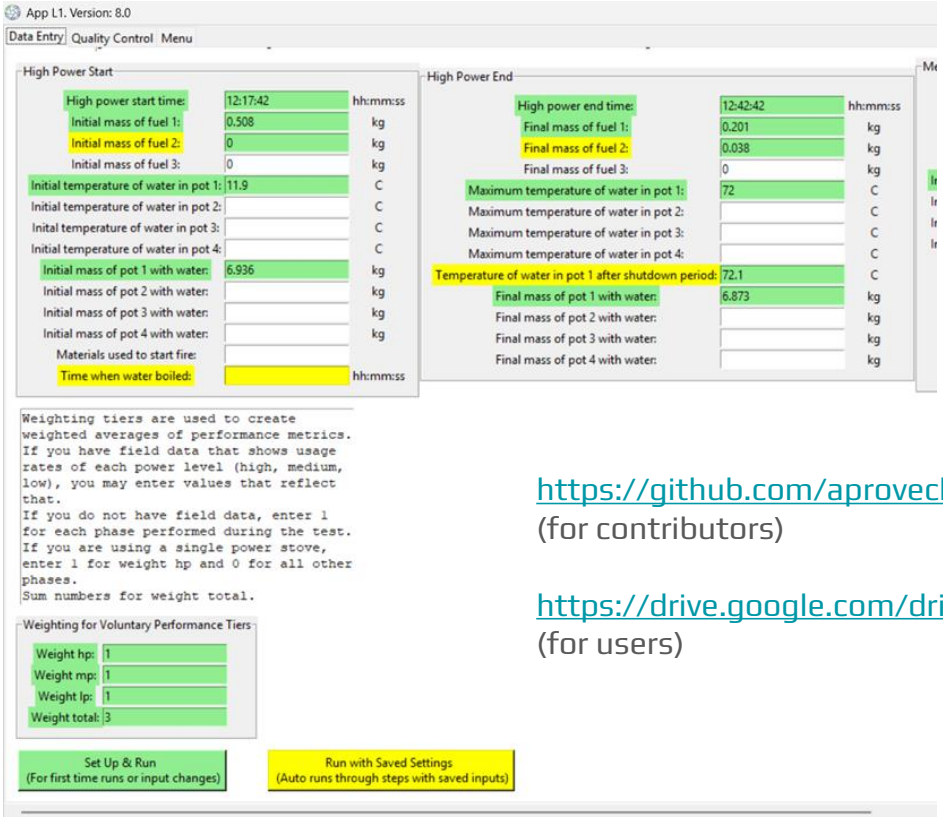
Data Processing App



https://github.com/aprovechodotorg/Data-Processing-Software
(for contributors)

https://drive.google.com/drive/folders/12hJTKqCsw6icbZ02twks7oiitPQT_r0s
(for users)

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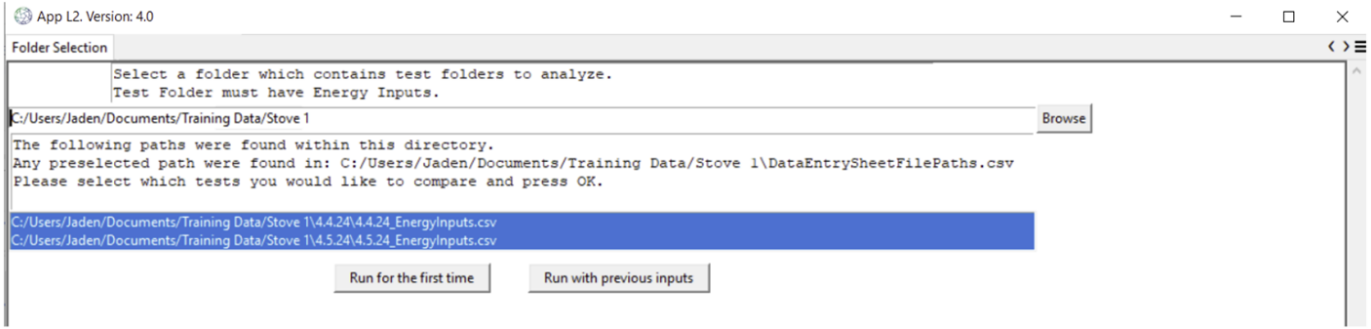
Create ISO Report Table



- Open level 2
- Select the folder with all processed tests in it
- Select which tests will be in the report

Metric		Test Sequence Phase				Tier Rating
		High	Medium	Low	Combined	
Thermal Efficiency without char (%)	Mean	50.8	46.7	45.3	48	4
	SD	0.4	1.3	0.2	2.3	
	90% CI	50.2 - 51.4	44.5 - 48.9	45.0 - 45.7	45.3 - 50.7	
Thermal Efficiency with char (%)	Mean	59.4	66.1	68.8	64.1	5
	SD	0.8	0.8	0.3	3.2	
	90% CI	58.0 - 60.8	64.7 - 67.4	68.2 - 69.3	60.3 - 67.8	
Char Energy Productivity (%)	Mean	17	41.5	51.7	34.3	N/A
	SD	0.9	2.8	1.1	12.8	
Char Mass Productivity (%)	Mean	9.1	20.3	24.4	16.8	N/A
	SD	0.5	1.1	0.4	5.7	
Cooking Power (kW)	Mean	3.7	2.7	1.9	N/A	
	SD	0.1	0.2	0		
Fuel Burning Rate (g/min)	Mean	20.6	14.7	10.2	N/A	
	SD	0.1	0.7	0		
PM2.5 per useful energy (mg/MJ)	Mean	17.1	25	40	26.6	4
	SD	4.8	2.7	14.7	9.6	
	90% CI	8.9 - 25.3	20.5 - 29.5	15.2 - 64.8	15.3 - 37.9	
CO per useful energy (g/MJ)	Mean	0.5	1.1	3.7	1.7	5
	SD	0.1	0.3	1.4	1	
	90% CI	0.4 - 0.6	0.6 - 1.7	1.4 - 6.0	0.5 - 2.9	
Safety	Score					N/A
Durability	Score					N/A

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Questions?

- Thank you!
- And thanks to the Osprey Foundation for supporting this webinar
- Feel free to reach out: travis@aprovecho.org
- Please join us in 3 weeks for Jaden's webinar on how to understand and check your data
    - **Thursday, July 23rd, 8am-9am PST**: Jaden Berger, A comprehensive explanation of the underlying calculations used to convert raw data to ISO tiers. Will include discussion on what values to check, what it means when those values are off, and how to fix them.

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