turning knowledge into practice

DOE Bioenergy Technologies Office (BETO)
2015 Project Peer Review

Thermoelectric-Enhanced Cookstove Add-on (TECA) for Clean Biomass Cookstoves

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Cookstoves

David Stokes
RTI International

Goal Statement

- This program seeks to demonstrate an innovative solution to enhance existing biomass cookstove performance through the use of RTI's Thermoelectric Enhanced Cookstove Add-on (TECA) device.
- Instead of developing a new cookstove, this approach targets the use of an accessory that can be added to existing cookstoves. The self-powered TECA device serves to capture a portion of heat from the stove and convert it to electricity through a thermoelectric (TE) device to power a blower.
- By carefully ducting and controlling air injected into the combustion chamber, we will enhance combustion in a biomass stove to reduce both CO and $PM_{2.5}$ emissions.
- The demonstration of clean cookstove performance with the Envirofit M-5000 and TECA device will serve as a proof of concept for future use of the add-on technology with a variety of stoves.
- By applying the TECA add-on device to existing stoves that are already in use, we have the opportunity to provide a solution that significantly reduces emissions for stoves that have already found user acceptance.

Quad Chart Overview

Timeline

- Project start date: **Jan. 1, 2013**
- Project end date: **June 30, 2015**
- Percent complete: **87%**

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	none	$144k	$357k	$284k
Project Cost Share (Comp.)	None Required			

Barriers

- Achieving Tier 4 PM emissions from a biomass cookstove
- Achieving self-sufficient operation for a forced draft stove
- Cookstove reliability – robust operation for 5 years
- Adoption – providing value to the end user

Partners

- Envirofit International
  - Emissions reduction design
  - Field reliability testing
  - Manufacturing and scale-up
- Colorado State University
  - Emissions reduction design
  - Emissions characterization

1 - Project Overview

- Develop an affordable add-on device to enhance biomass cookstove performance
- Demonstrate significant emissions reductions from the Envirofit M-5000 stove with the add-on in both the lab (USA) and the field (India) to approach Tier 4 standards for CO and $PM_{2.5}$
- Demonstrate field reliability and safety of the add-on device through testing a 24/7 burn lab in India
- Demonstrate the ability to crosswalk lab and field measurements to within 15%.
- Develop an effective approach to bring the solution to market through a manufacturing and scale-up plan – leverage RTI's field office and Envirofit's manufacturing facility in Nairobi, Kenya.
- Demonstrate auxiliary power production from the TECA device to power a light or recharge a cell phone to make the enhanced cookstove more attractive for long-term user acceptance and use.

2 – Approach (Technical)

- *Emission reduction through air injection:*
  - *Inject air into oxidation region of the flame*
  - *Chemical effect - extra O_2 enhances combustion*
  - *Enhances mixing and passes partially incomplete combustion species (PICs) back through the flame*
- *Power generation through thermoelectric (TE) device:*
  - *Heat is captured from the stove and passed through a TE device to generate electricity*
  - *Self-powers a blower and produces excess power*
- *Critical success factors*
  - *Ability to significantly reduce emissions – approaching Tier 4 standard*
  - *Ability to provide a robust solution – reliability*
- *Potential challenges*
  - *Difficulty to achieve Tier 4 emissions from a biomass stove*
  - *Difficulty to operate reliably in such a harsh environment*

2 – Approach (Management)

- *Partner with Envirofit International and Colorado State University:*
  - *Brings together expertise in thermoelectric system design (RTI), combustion and emissions characterization (CSU), and product development and deployment (Envirofit)*
  - *Leverage the international development work of both RTI and Envirofit*
- *Address reliability in stages:*
  - *Component level reliability evaluated in the lab*
  - *Prototype reliability evaluated in the field*
- *Critical success factors*
  - *Ability to develop a solution that will be adopted*
  - *Ability to market and commercialize the product*
- *Potential challenges*
  - *Difficulty to develop a cost effective solution*
  - *Difficulty to insure adoption and proper use in the field*

3 – Technical Accomplishments/ Progress/Results

- *Emissions Reduction Approach and Results*
- *Integrated Prototype Development*
- *Reliability Testing*
- *Field Emissions Testing*

Program Goal: Emissions Reduction

- **Goal**: Tier 4 emissions in a biomass cookstove
  - < 41 mg/MJ of PM 2.5
  - < 8 g/MJ CO
- **Major Approaches**:
  1. Exhaust Gas Recirculation
  2. Air Injection

1.

2.

ENVIROFIT performance matters

Colorado State University

50 YEARS RTI INTERNATIONAL

Measurement Capabilities

- PM 2.5
  - Gravimetric System
  - Isokinetic, isothermal sampling
  - Active control of volumetric flow through cyclone
  - Cumulative PM mass on filter using pressure drop across filter
- CO and CO2 emissions
  - 5 gas analyzer
  - CO and CO2 mass flow rates with 1 second resolution
- Thermal Efficiency
  - Measurements and calculations reflect current GACC procedures

Gravimetric PM Sampling System:

Testing Methodology: Chronological Overview

Time

- Baseline & Effect of Stick Spacing
- Effect of EGR Path Temperature
- EGR Stove Nozzle and Flow Rate Optimization
- Understanding EGR Emissions Reduction
- EGR and Air Injection Comparison
- Air Injection Stove Nozzle and Flow Rate Optimization

Baseline

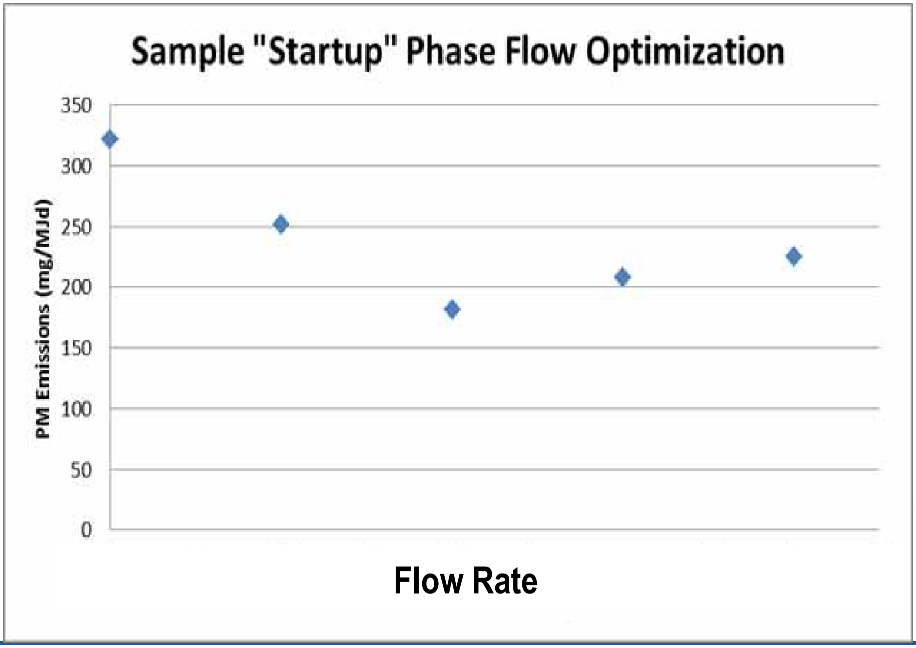
Exhaust Gas Recirculation (EGR)

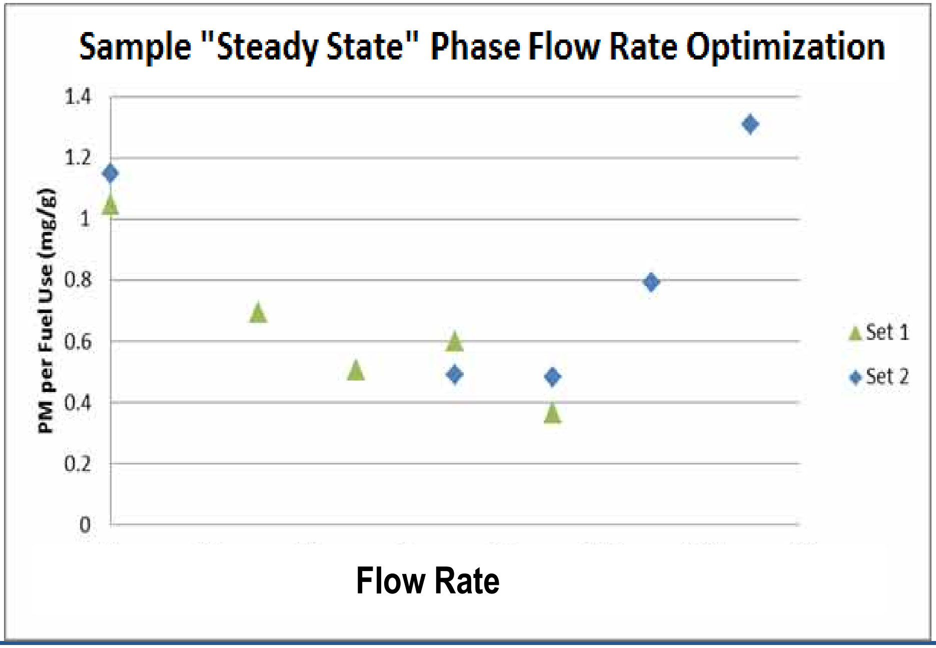
EGR/Air

Air

Testing Methodology: Nozzle/Flow Rate Optimization Procedure

- Developed time efficient Nozzle and Flow Rate Optimization Procedure:
  - Design nozzle (vary injection location, nozzle geometry)
  - Determine optimized flow rates for “startup” and “steady” firepower phases
  - Run cold start water boil tests at optimized flow rates
  - Repeat!





Results: EGR Stove Nozzle/Flow Rate Optimization

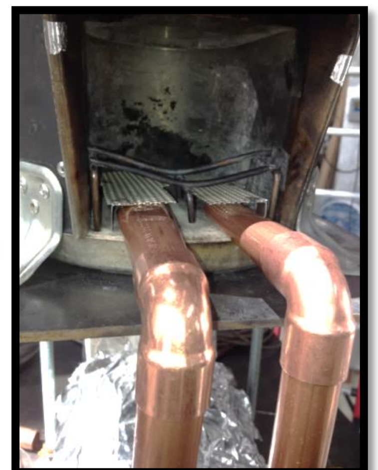
EGR Stove Nozzle/Flow Rate Optimization:

- 4 nozzle configurations optimized
- PM emissions reduced from 275 mg/MJd (baseline M-5000) to **153 mg/MJd** (with EGR) (44% reduction)

Air Curtain

Side Injection Nozzles V1

Diffusion Nozzle



Chimney Ring

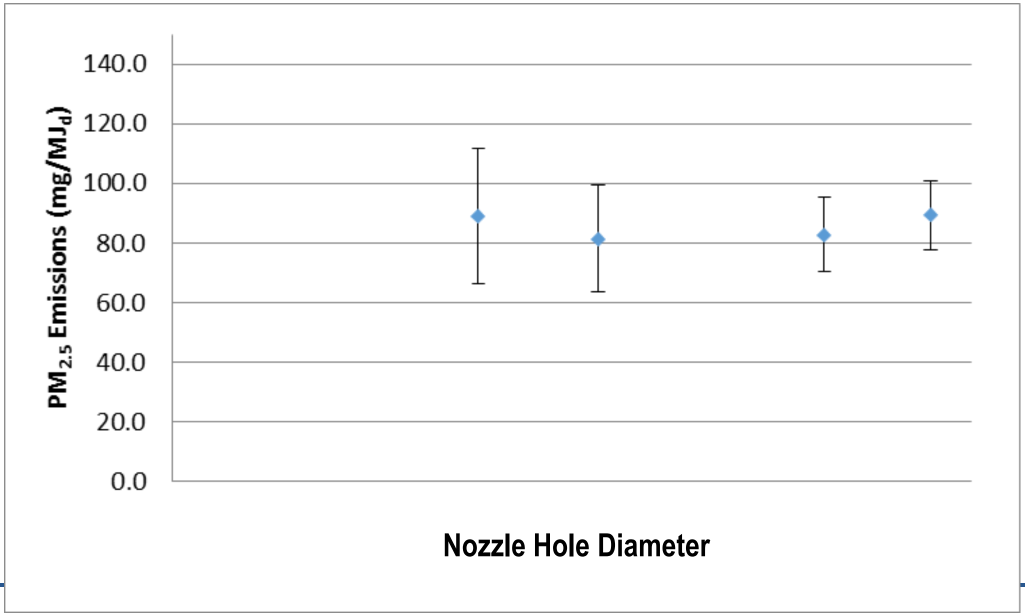
Results: EGR and Air Stove Comparison

- **Testing Methodology:**
  - Direct comparison between optimized PM emissions EGR and forced air using the same nozzle configuration
  - Completed flow rate optimization for both EGR and Air

- **PM Emissions Results**
  - M-5000 stove baseline PM emissions = 275 mg/MJd
  - EGR reduced PM to **153 mg/MJd** (44% reduction)
  - Air reduced PM to **82 mg/MJd** (70% reduction)
  - Air stove outperformed EGR stove of the same configuration

Results: Air Stove Nozzle/Flow Rate Optimization

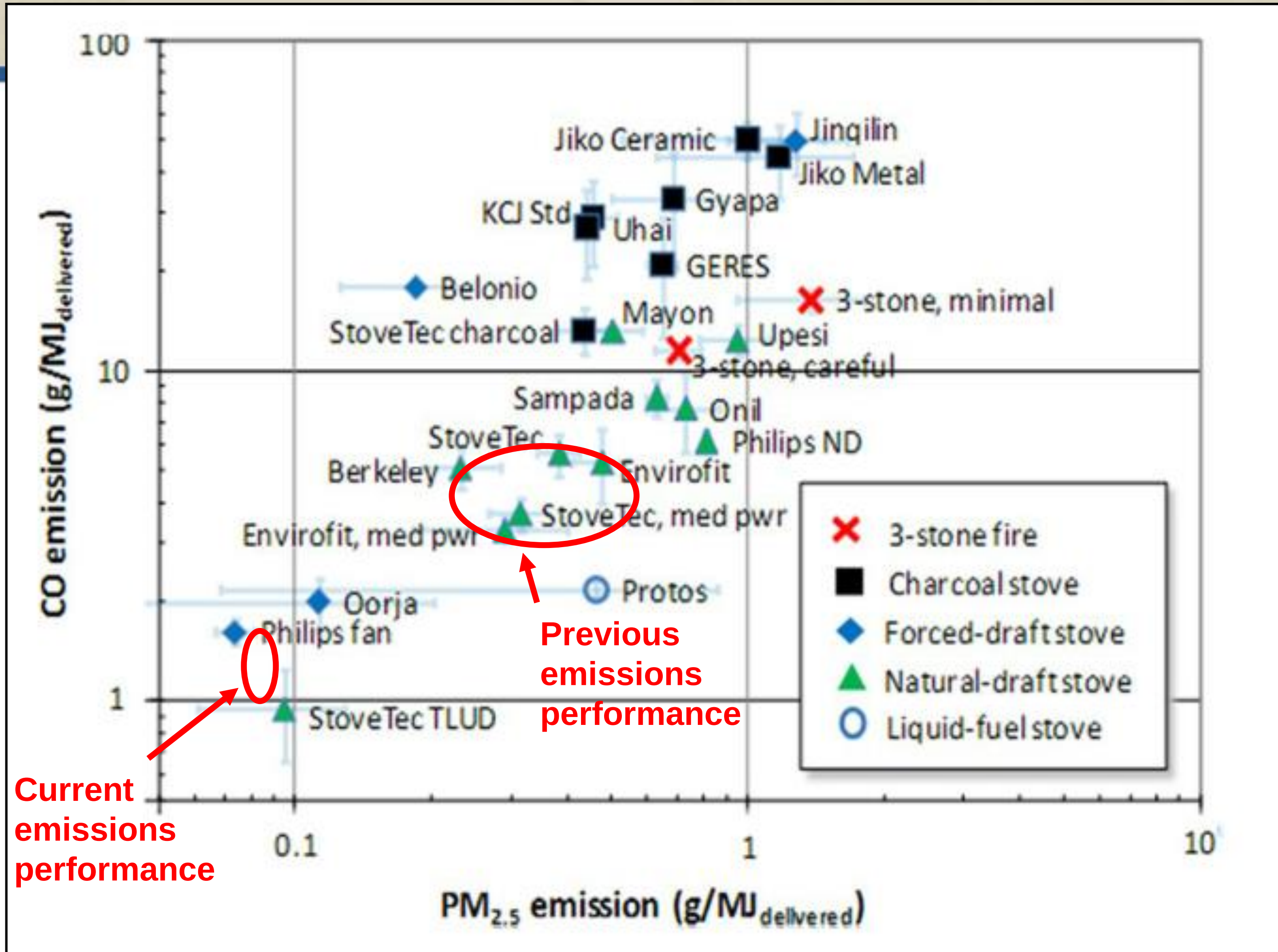
- 4 nozzle configurations optimized
- Focused on isolating the effect of forced draft velocity on PM emissions
- Evaluated performance with varied hole diameters
  - Emissions at optimized flow rates are not strong function of diameter
  - Emissions at less-than optimized flow rates are better for smaller diameters
- Optimized emissions = **82 mg/MJd** (70% reduction from baseline, 92% reduction from Traditional Stoves)



Stove Emissions Comparison

Current lab emissions:

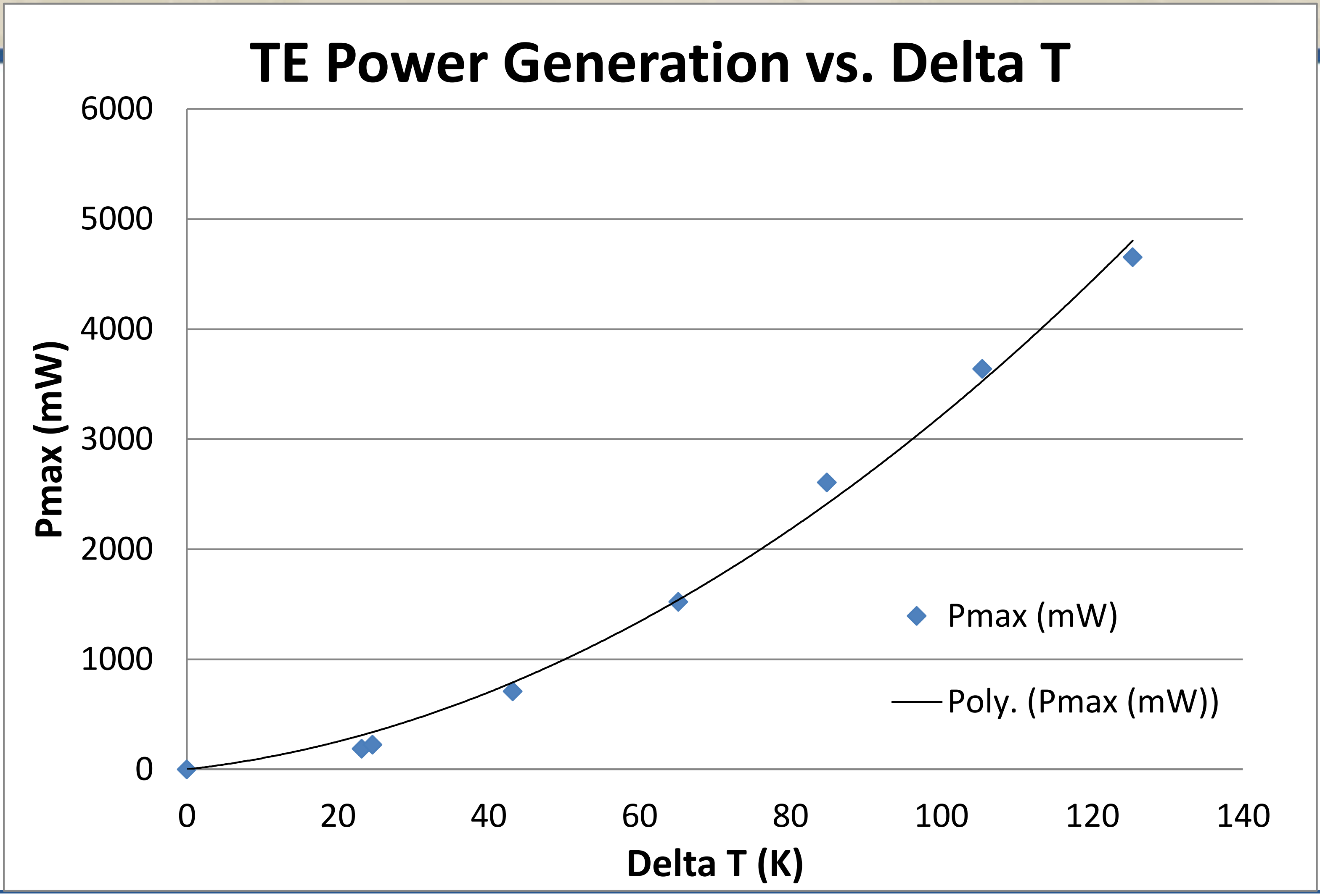
- CO
  - 1.5-2 g/MJd
  - Tier 4
- PM
  - 82 mg/MJd
  - Tier 3.7



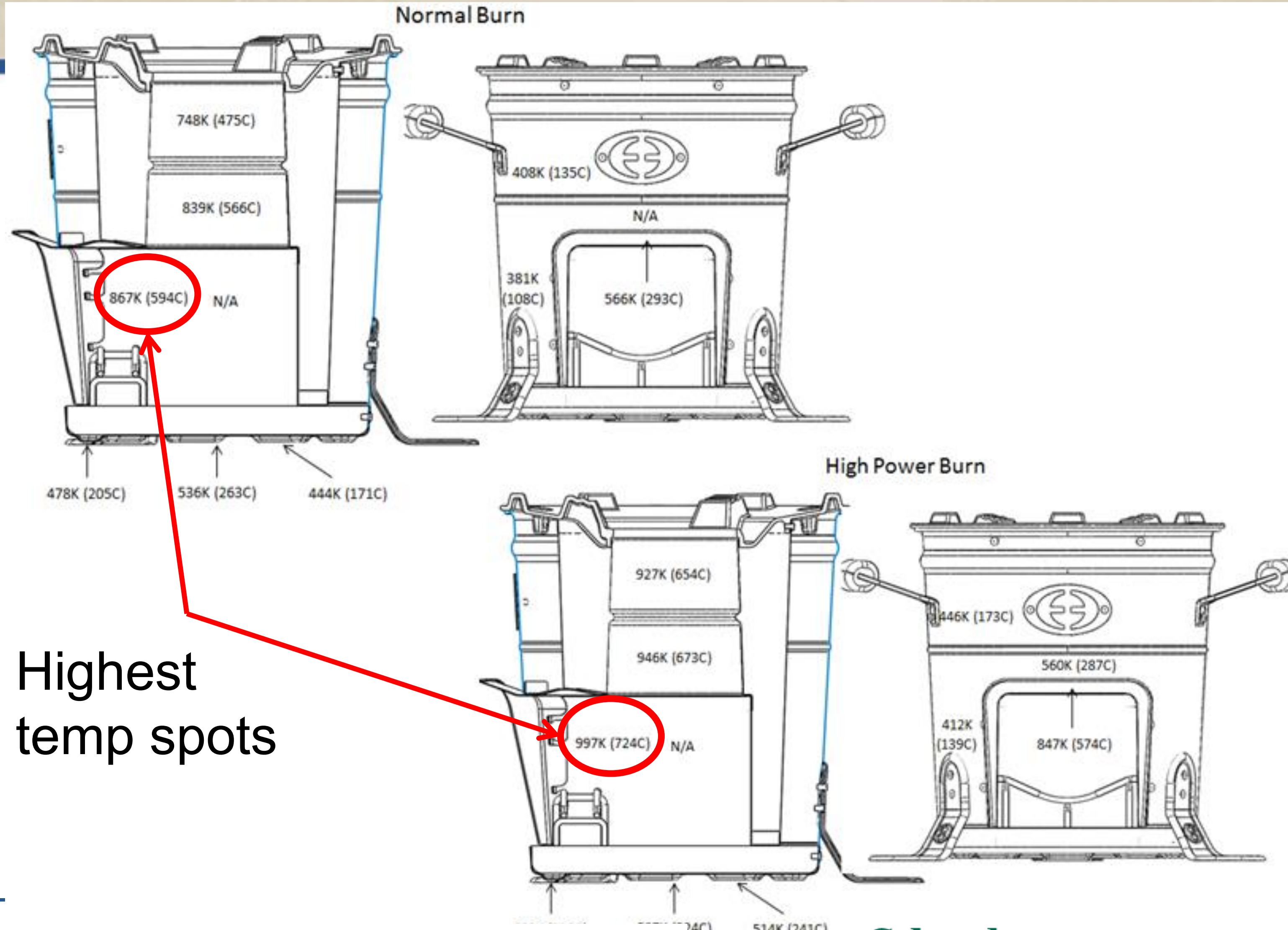
PM Emission Reduction Lessons Learned

- Mechanisms that reduce PM:
  - Chemical effect of injecting optimized O2 concentration
  - Increased residence time of particles via recirculation
  - Enhanced Mixing
- Parameter optimization:
  - Air injection location
  - Air flow rate
  - Velocity

Thermoelectric Device Characterization

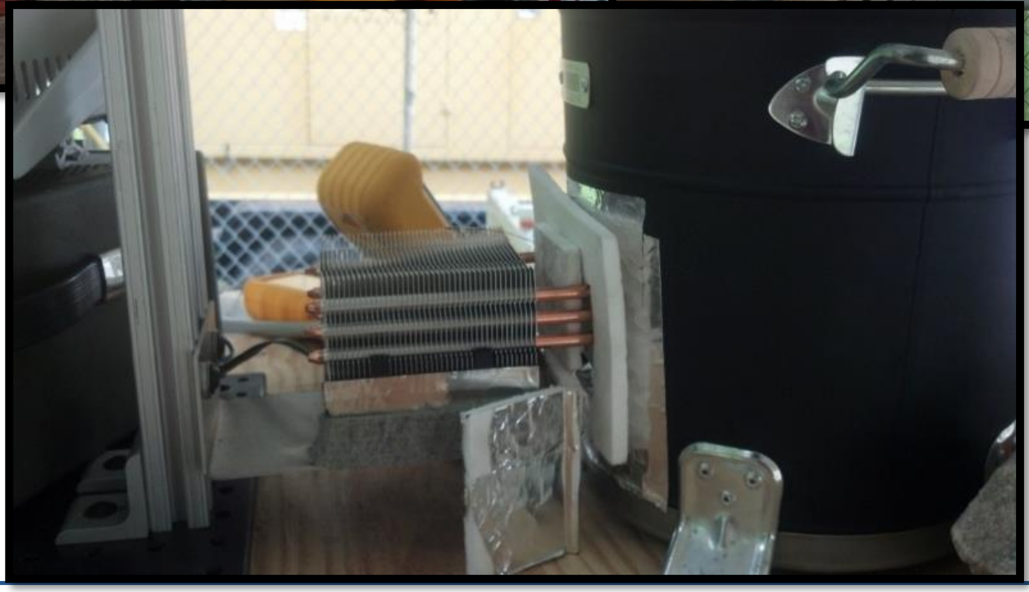


Envirofit M-5000 Temperature Profile

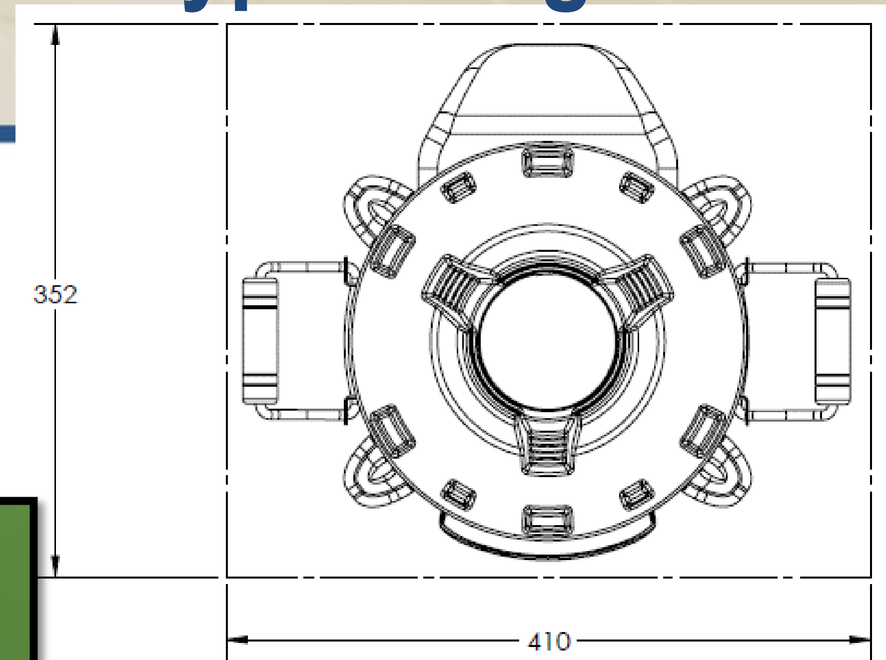


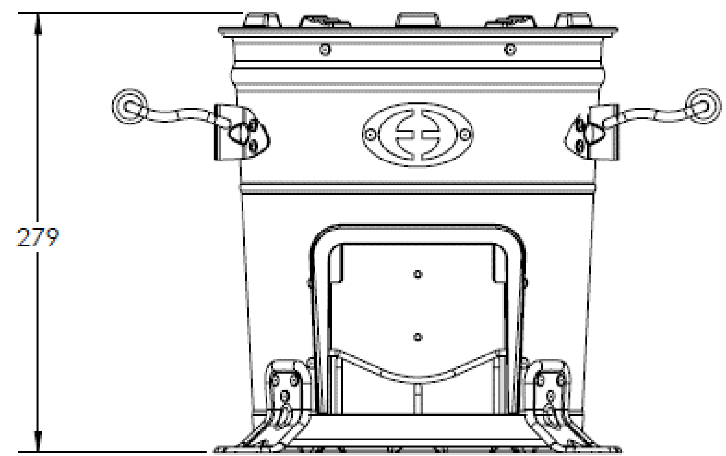
Side Heat Capture Test

Rear Heat Capture Test

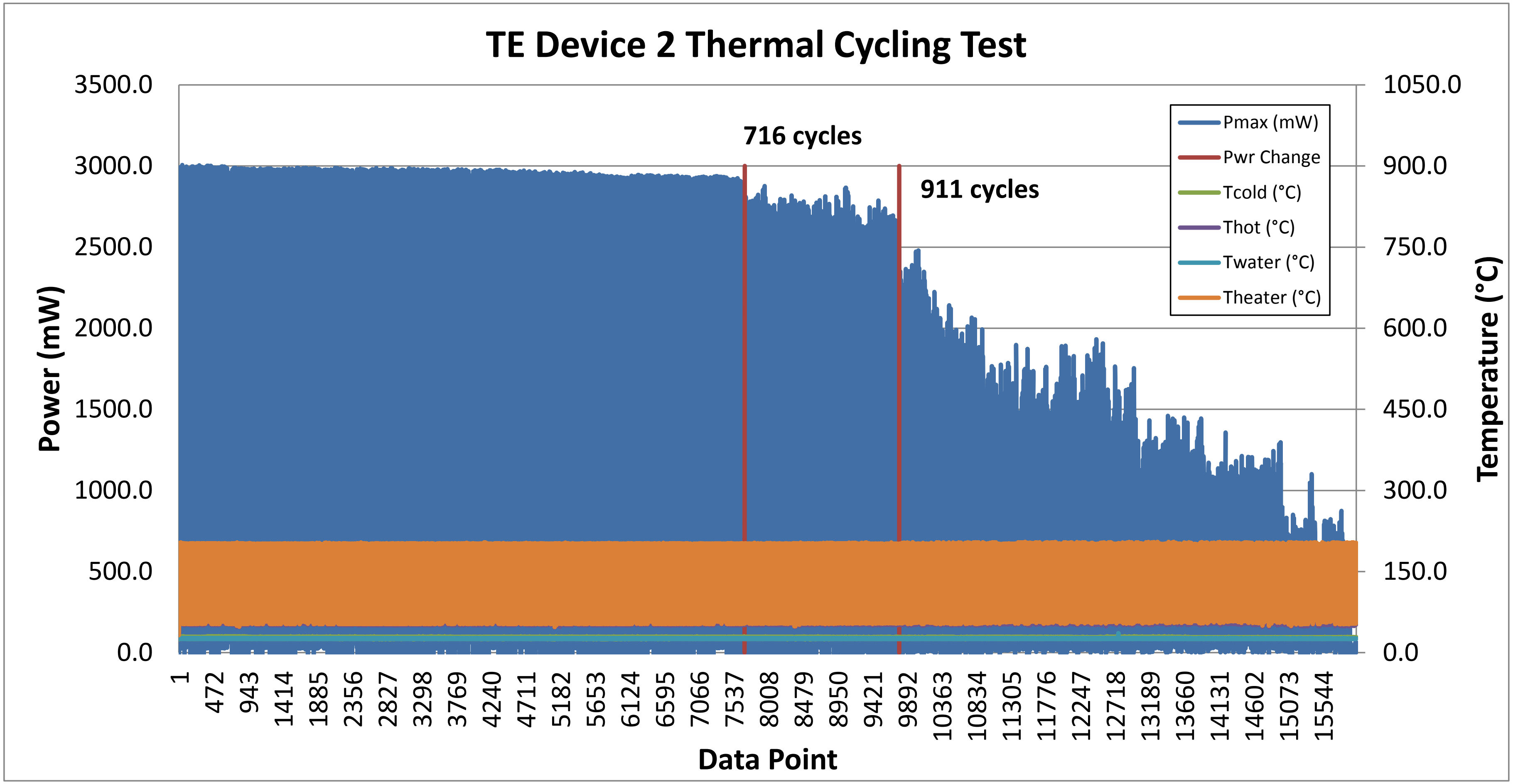


Fully Integrated Prototype Design



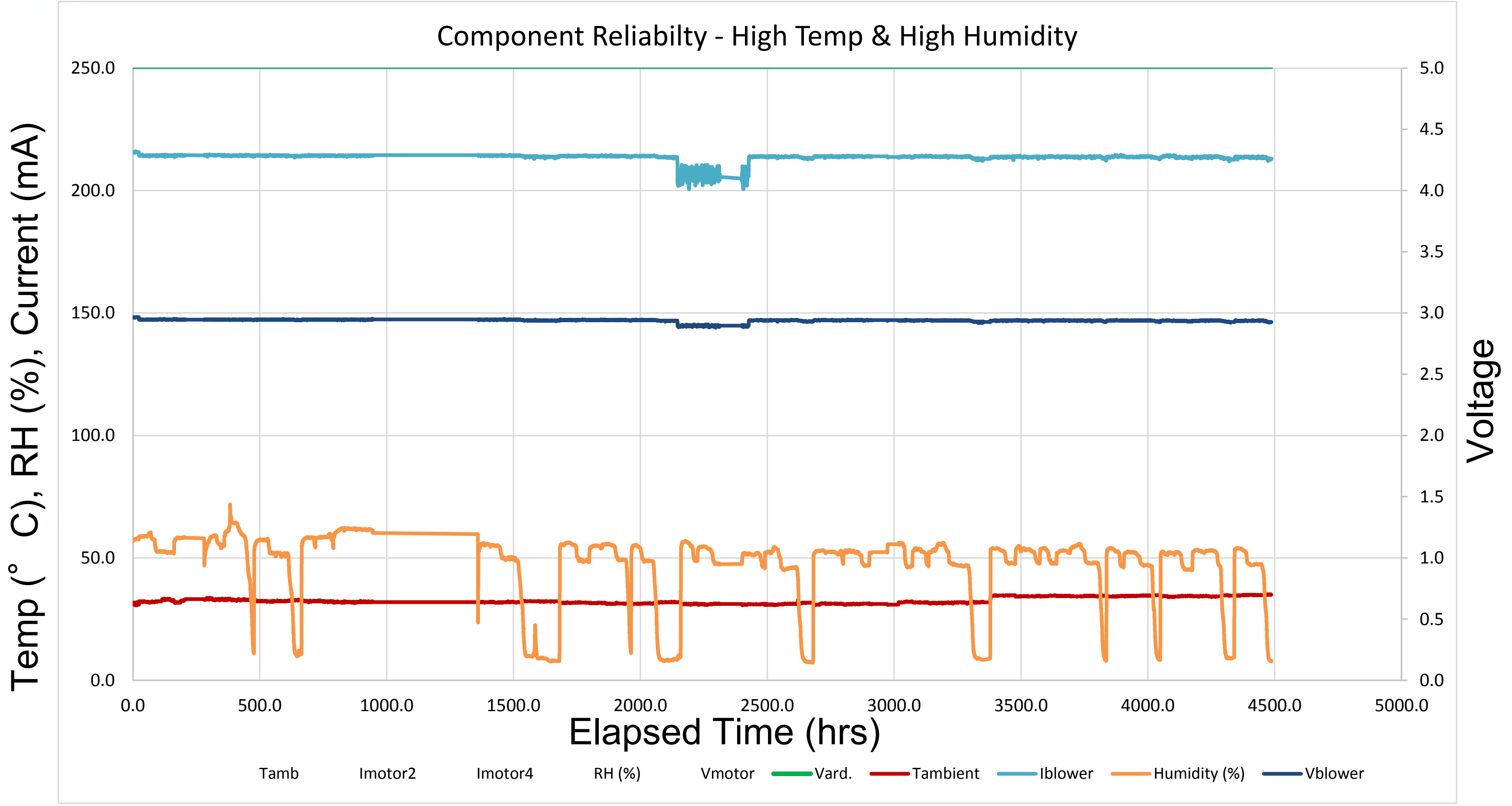


TE Device Thermal Cycling Results



Component Level Reliability Testing

Environmental chamber settings: 32° C & 60% RH

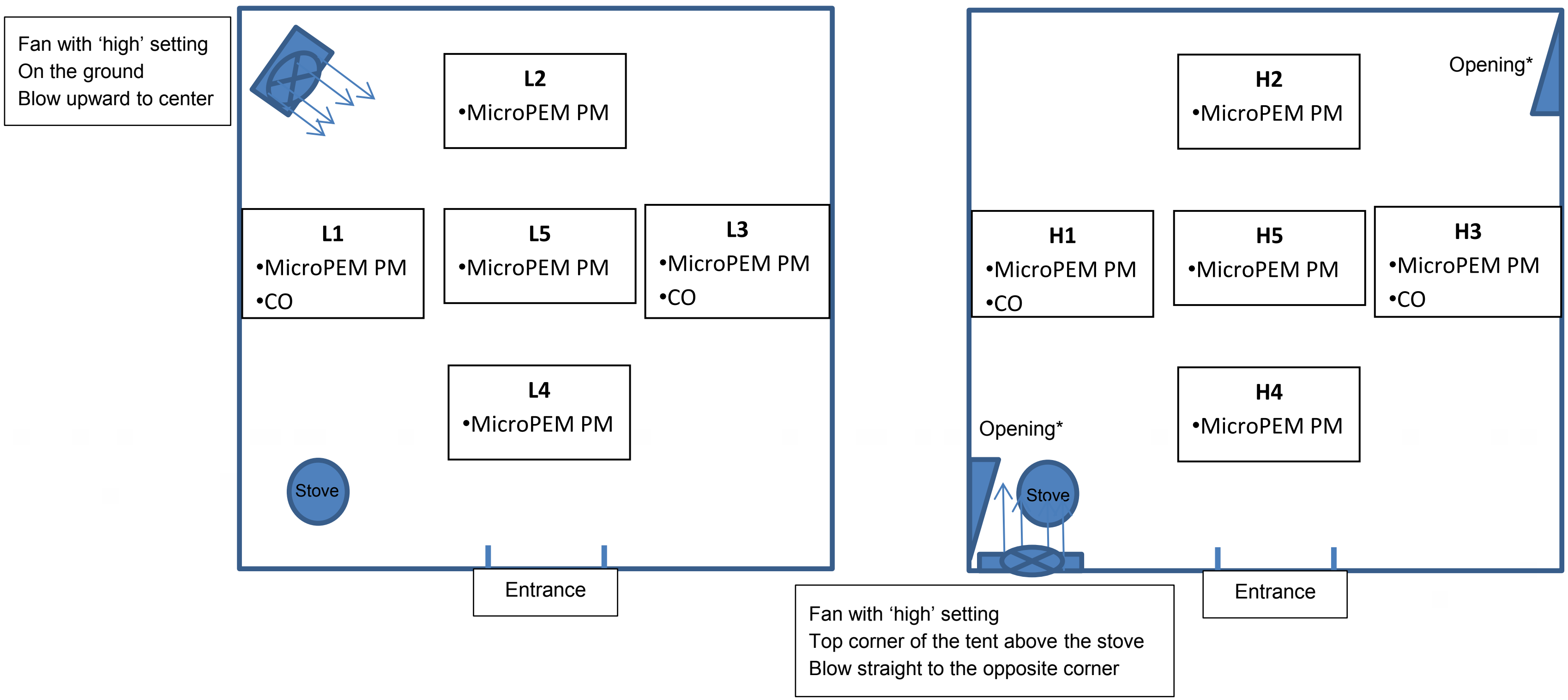


Field Durability Testing

- 24/7 Durability lab in India
- 1 hour cycle – 45 minute burn/15 minute cool down
- Data Acquisition System will be used
  - Monitor TEG Performance
  - Monitor motor current and temperatures of key components
- Data recorded on a dedicated laptop with an uninterruptible power supply
- Laptop will be connected to the internet and data will be automatically uploaded to a shared Dropbox folder
- This allows near real time monitoring of performance from the U.S.

PM and CO monitor placement (Test #1 and #2)

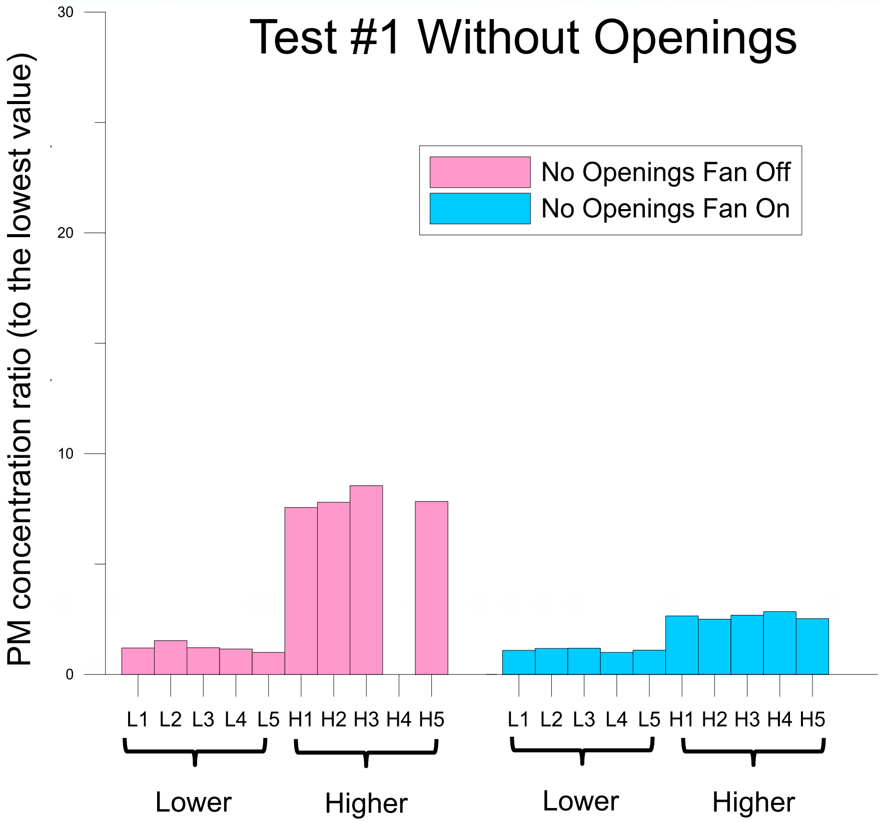
Lower layer (30 cm above the ground) Higher layer (1.5 m above the ground)

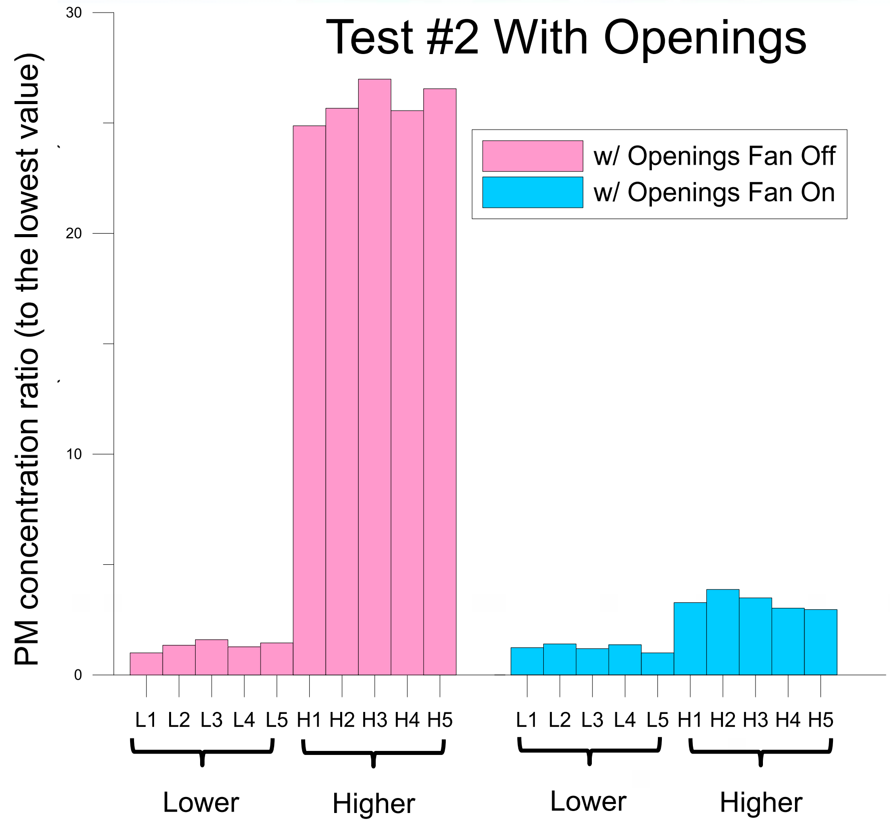


*Openings made only for the Test #2

PM and CO monitor placement (Test #1 and #2)

PM spatial concentration gradient

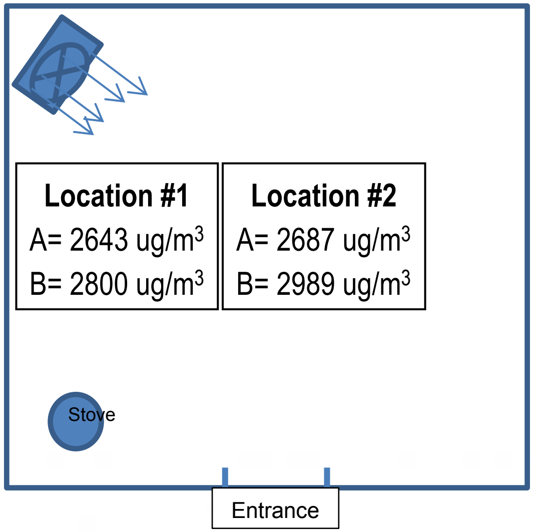




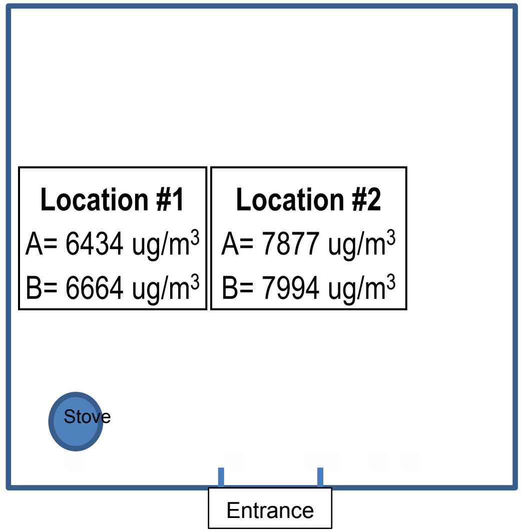
- Use of two fans significantly improved vertical mixing of PM in the simulated kitchen
- Fan's mixing effect was greater in the kitchen with openings (typical condition in the field)
- CO data Test #1 was higher than sensor max measurement; Test #2 data showed similar trend with PM

PM and CO monitors placement (Test #3)

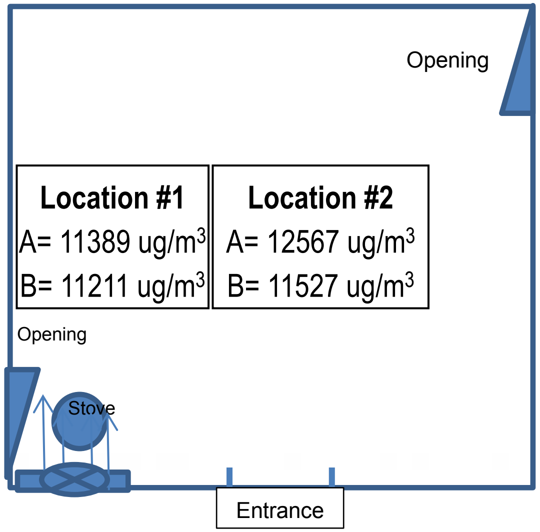
Lower layer (30 cm)



Middle layer (1 m)



Higher layer (1.5 m)



- Further characterized PM special profile to narrow down the technique for field testing
- Measurements at three heights to confirm the vertical gradient of PM observed during Test #1 and 2
- Fan arrangement was identical to previous tests

4 – Relevance

- *This work addresses the key challenges in developing a biomass cookstove for the developing world that is:*
  - *Clean burning – low PM emissions to provide a substantial health benefit*
  - *Reliable – can last for 5 years*
  - *Adoptable – provides value to the end user and promises to make a difference in their lives*
- *We expect that the cookstove technology developed in this program can help other cookstove developers in the following ways:*
  - *Simplified approach developed to optimize cookstove emissions*
  - *Greater understanding of the mechanisms for emission reduction with forced draft*
  - *Platform for deployment in other stoves (including indigenous ones)*
  - *Approach for bring lab and field emissions measurements closer together*
- *The success of this project can provide a solution for getting a large number of clean cookstoves in operation in the field by leveraging those stoves that are already being used and enhancing their performance.*

5 – Future Work

- Field reliability and safety testing:
  - Test prototype in the Envirofit 24/7 burn lab in India
  - 5,000 burn cycles to simulate 5 years of operation
- Field emissions testing:
  - Perform emissions test in US in portable tent
  - Perform emissions tests in India
  - Evaluate agreement between lab and field measurements
- Develop commercialization plan:
  - Manufacturing and scale-up plan
  - Marketing approach and analysis
  - Leverage RTI's and Envirofit's facilities in India and Kenya.

Milestone	Projected Date
Component reliability testing complete	Nov. 2014
TECA prototype complete	Dec. 2014
Lab testing complete	Dec. 2014
Field testing complete	May 2015
Field reliability testing complete	Nov. 2015

Summary

- Goal: Develop an affordable add-on device to enhance biomass cookstove performance to approach Tier 4 standards (41 mg/MJd)
- Approach:
  - Forced draft add-on device for an existing biomass rocket stove
  - Thermoelectric power generation for self-sufficient operation (and excess power)
  - Partnership between RTI, Envirofit International, and Colorado State University
- Results:
  - PM emissions at **82 mg/MJd** (70% reduction compared to baseline, 92% reduction from Traditional Stoves)
  - Developed stove optimization approach that reduces experiments
- Relevance: Provides a solution for clean cooking in the developing world
- Future Work:
  - Field reliability and safety testing – in India
  - Field emissions testing – in India
  - Commercialization & scale-up

Additional Slides

Publications, Patents, Presentations, Awards, and Commercialization

- Patents – provisional filed on air injection approach
- Publications
  - EGR stove optimization paper - written
  - Air stove optimization paper - written
- Commercialization efforts
  - We are just beginning the commercialization task of this program
  - Partnership with RTI's commercialization group and Envirofit International's product development team