

**DOE Bioenergy Technologies Office (BETO)  
2023 Project Peer Review**

**Fire MAPS - Secure Performance Monitoring and  
User Alerts System**

April 5, 2023

Systems Development and Integration

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MF Fire, Inc.

# Project Overview

*Improper operation of wood stoves leads to massive unreported emissions, producing the majority of wood stove air pollution.*

- **Goals:** *Develop a hardware/software platform that can eliminate user-contributed emissions across all 12 million wood stoves installed in the U.S.*
- **Main idea:** *(1) Monitor wood stove performance data in real-time. (2) Deliver timely and relevant guidance so users can learn to optimally operate their wood stoves, which (3) Eliminates 50-80% of the user-contributed emissions*
- **Today:** *Wood stoves are approved based on lab-tested emissions, but improper or sub-optimal operation by users increase real-world emissions by up to 600%*
- **Importance:** *PM2.5, the primary harmful byproduct of burning wood is a leading cause of respiratory illness and lung disease. Eliminating user-contributed emissions can have the single largest positive impact for wood heat on air quality.*
- **Risks:** *(1) Predictive modeling and guidance may fall short of expectations when applying to wood stove designs across the entire installed base, due to broad differences in design. (2) User behavior may not change significantly, leading to results less than the target goals.*

# 1 – Approach

- Wood stove emissions are only partially reported. Research has shown most emissions generated by imperfect stove operation.
- We examined what creates variability in emissions at the user level and discovered large sensitivity in emission results from user behavior. Preliminary testing showed the potential to reduce real-world emissions by 50-80%.
- To eliminate user emissions, MF Fire developed a solution that provides users with real-time information and guidance that allows them to operate wood stoves in a cleaner way
- Challenges:
  - Create a full test matrix of potential user behavior and measure emissions impact from changing each behavior
  - Create an adaptive algorithm that can automatically map to any stove in operation so that valid guidance can be delivered to users.
  - Create guidance system that motivates people to use the system to make positive changes in operating behavior.
- We previously created an integrated real-time system to monitor and automate wood stove operation; but no automation retrofits are allowed for existing wood stoves. We transitioned to real-time operator guidance to improve user behavior and operation.
- Completed all go/no-go decision points and conducted in-home trials with wood stove owners. We continue to monitor users and collect trial data. The last remaining project elements are a complete analysis of the database and impact assessment.
- Progress metrics: analyze reduction in user emissions and increase in efficiency from control test matrix and user baseline data. Users were interviewed throughout the project to confirm data and guidance accuracy and timing. 50+ field test units were deployed with test users for in-home trials.

## 2 – Impact

- Big pressures from all parts of society and government to make wood heat cleaner.
- Fire MAPS has the potential to dramatically reduce real-world emissions across all 12 million stoves in the US and 100 million stoves worldwide while delivering sub year ROI for users
- Once we analyze data, we will publish peer-reviewed articles in the academic and scientific communities while promoting the innovation through popular news outlets. We will actively seek large support from domestic and international governments to accelerate wide deployment.
- A typical wood stove is owned for 20 years or more. This innovation has the chance to make a generational change without the need to wait 20 years to percolate through users.

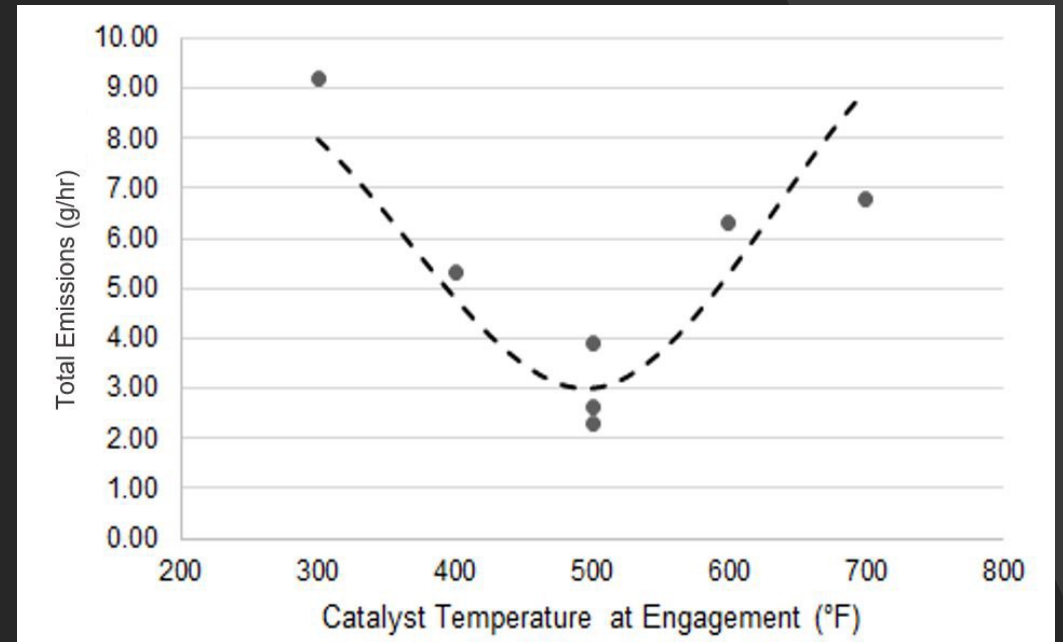
# 3 – Progress and Outcomes

- **Completed system development**, as well as alpha and beta field trials. Analyzing the very large data set is the major remaining milestone
  - Fire MAPS is a complete and fully functioning system producing a constant stream of stove and user data from which to validate the core project hypothesis.
  - User app is fully functional and multiple versions have been downloaded on both iOS and Android stores
  - Burn database live
  - Data analytics tool live
  - 50+ test units built and deployed in consumers' homes
  - Extensive live burn data since early 2021
- **Learned**
  - Stove operators successfully used the system as a source of real-time guidance that was more accurate than visual or mechanical means (simple thermostat)
  - We can successfully change user behavior, both learned best practices and stove operation precision.
  - Long tail use. A to-be-determined percentage of the test group has incorporated ongoing use of the device in daily stove operation
- **What we don't know yet**
  - Can we quickly train the system on stoves of different designs (cat vs non-cat, single burn rate vs multi-burn rate), enabling mass adoption (outside project scope)
  - What are the achieved gains against emissions and efficiency goals (TBD during data analysis)

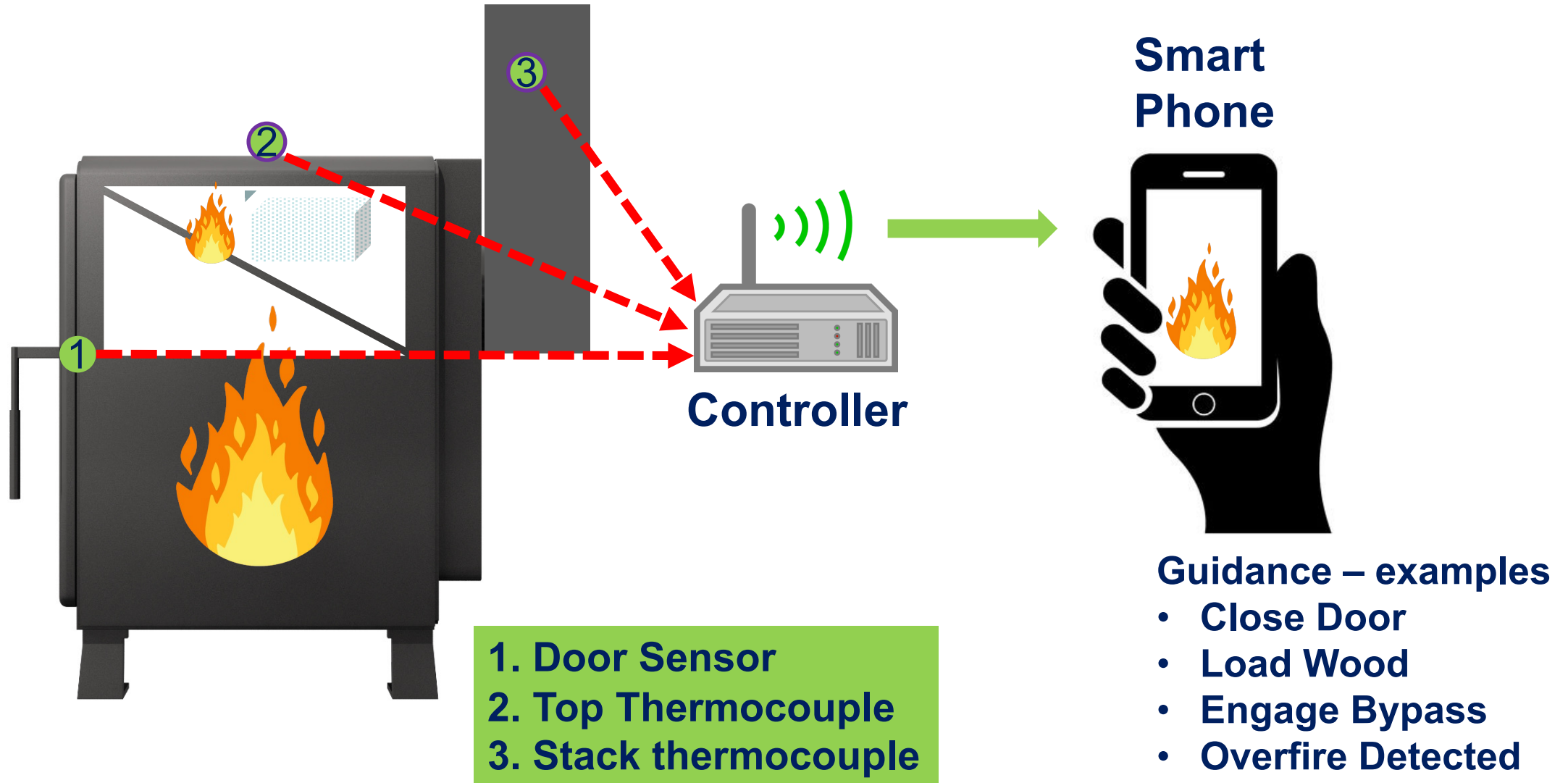
# Connecting User Behavior to the Reduction of PM and Increased Efficiency

- Poor wood stove user behavior and choices substantially increase total emissions while lowering efficiency
- Wood stoves are very sensitive to timing and temperature of actions.
  - Shutting the door
  - Engaging the bypass
  - Reloading
- Imperfect timing results in emission spikes or efficiency reductions.
- Related learnable behaviors also impact emissions and efficiency
  - Choice of wood (moisture, size), pre-heating to induce good draft, learning to build a fast-starting fire

*Changing user behavior – retraining through real-time data-driven guidance – eliminates unnecessary emissions*



# Fire MAPS Physical System



# Fire MAPS Hardware

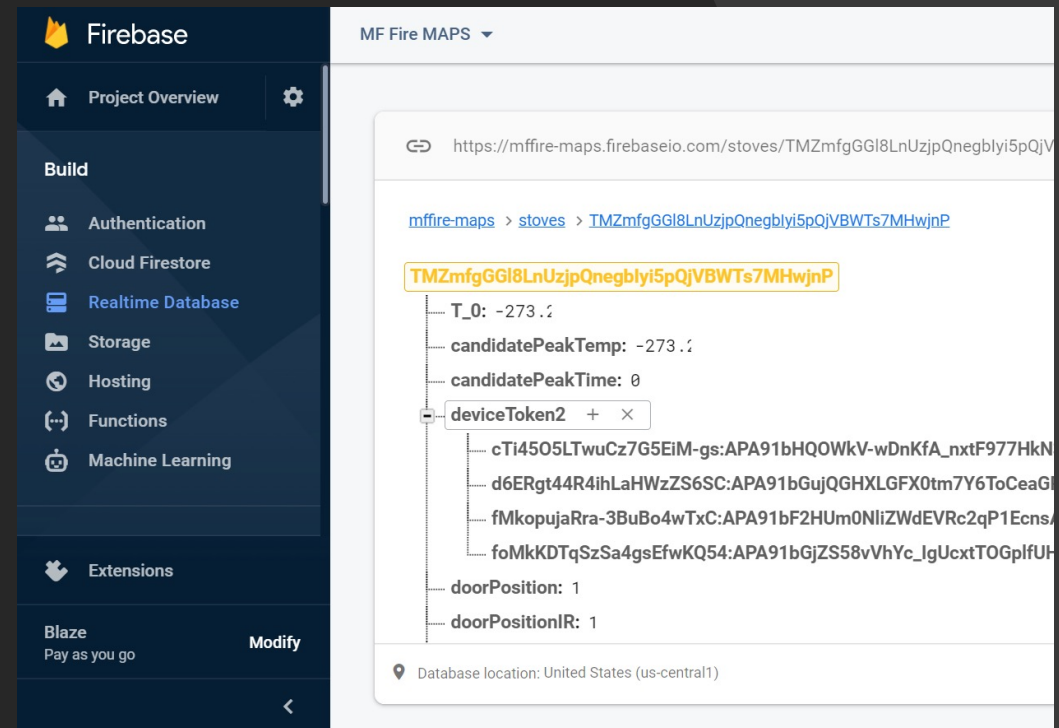
- Sensors
  - Door sensor (mechanical, IR, laser)
  - Thermocouples (2)
- Hardware
  - Printed circuit board
  - Sensor modules
  - Case





# Cloud Database

- Captures and continuously logs data from the sensors
- Performs a backend analysis of the data
- Communicates to users registered to a particular stove.



The screenshot displays the Firebase console interface. On the left, the 'Build' menu is visible, with 'Realtime Database' selected. The main area shows the 'MF Fire MAPS' project with a URL: `https://mffire-maps.firebaseio.com/stoves/TMZmfgGGI8LnUzjpQnegblyi5pQjVBWts7MHwjnP`. The database entry for this key is expanded, showing the following data:

```
{
  "T_0": -273.15,
  "candidatePeakTemp": -273.15,
  "candidatePeakTime": 0,
  "deviceToken2": [
    "cTi4505LTwuCz7G5EiM-gs:APA91bHQOWkV-wDnKfA_nxtF977HkN",
    "d6ERgt44R4ihLaHWzZS6SC:APA91bGujQGHXLGFX0tm7Y6ToCeaG",
    "fMkopujaRra-3BuBo4wTxC:APA91bF2HU0NliZWdEVRc2qP1Ecns",
    "foMkKDTqSzSa4gsEfwKQ54:APA91bGjZS58vVhYc_lgUcxtTOGplfUH"
  ],
  "doorPosition": 1,
  "doorPositionIR": 1
}
```

At the bottom, the database location is noted as 'United States (us-central1)'.

# Mobile App

# FireMAPS

MF Fire

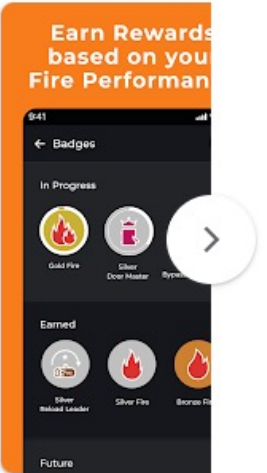
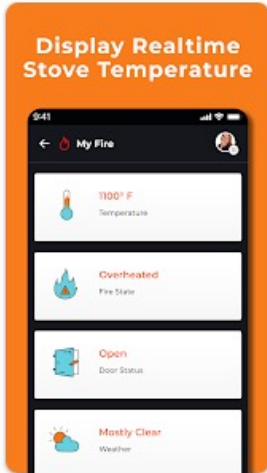
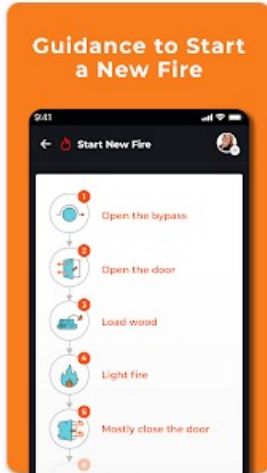
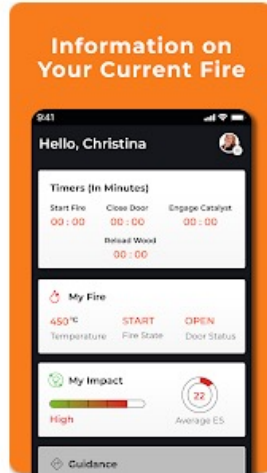
100+ Downloads

Everyone

Install

Add to wishlist

This app is available for your device

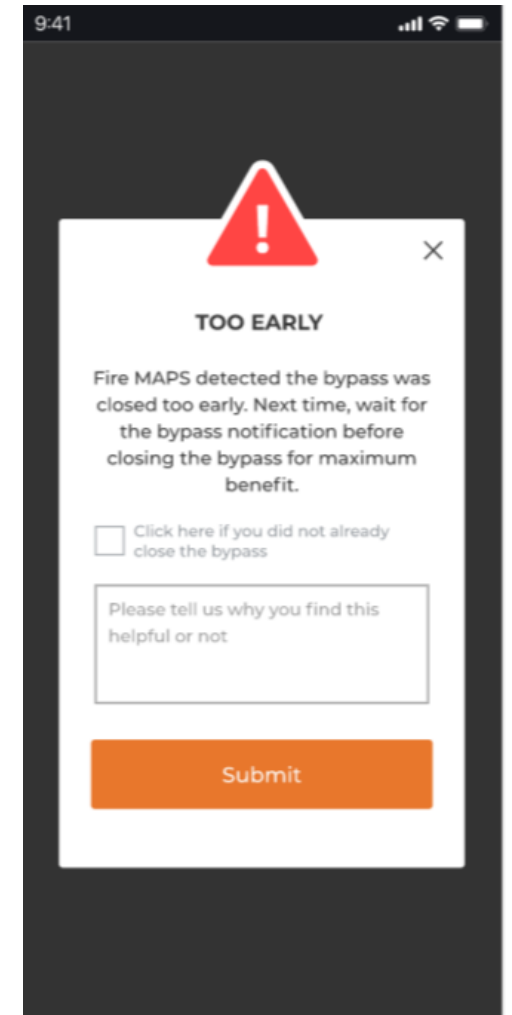
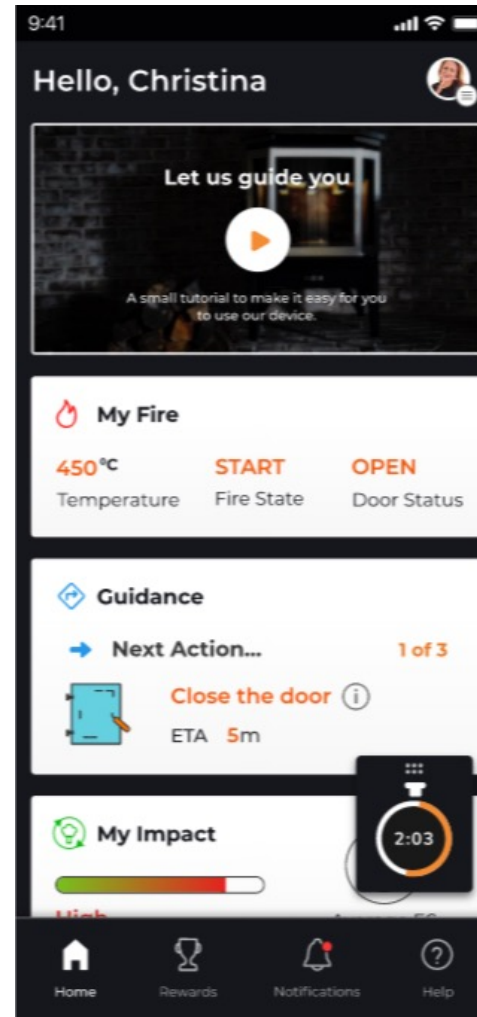


Developer contact

About this app

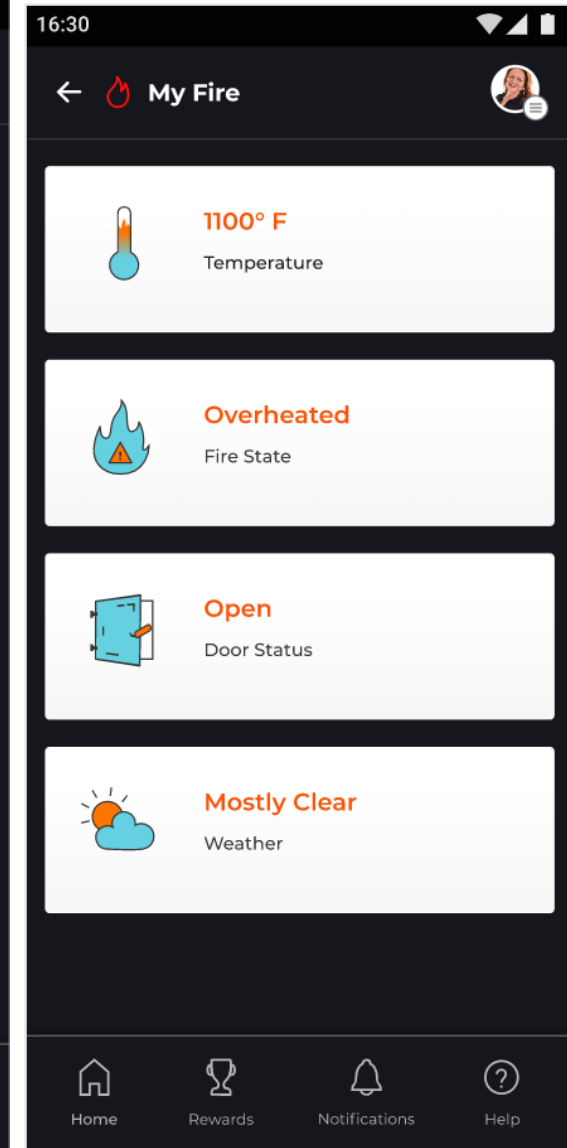
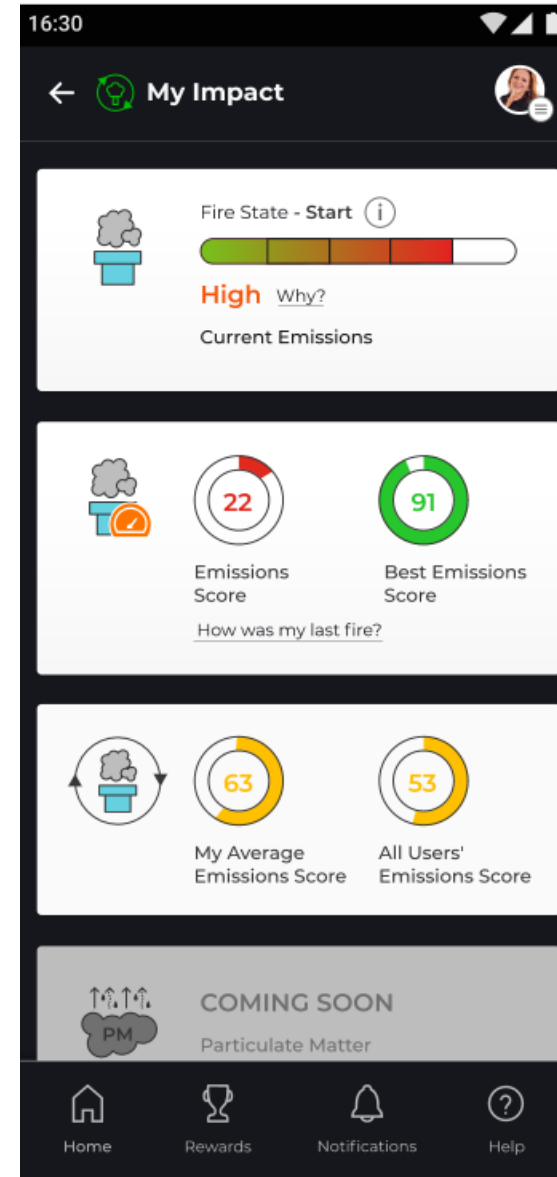
# Mobile App

- Communicates with stove and database
- Receives and displays data from the smart controller
- Provides automatic and manual user notifications
- Collects user contributed information to improve system

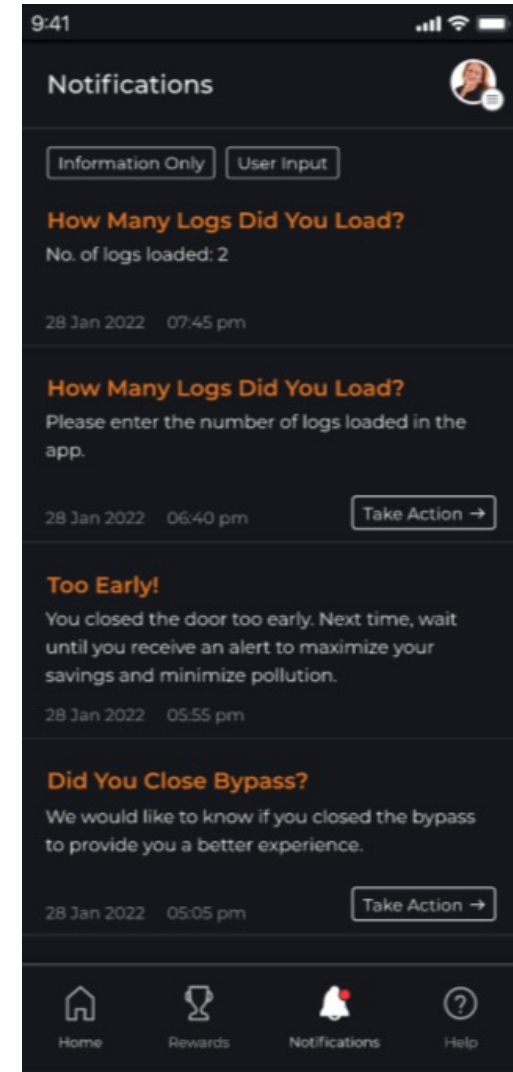
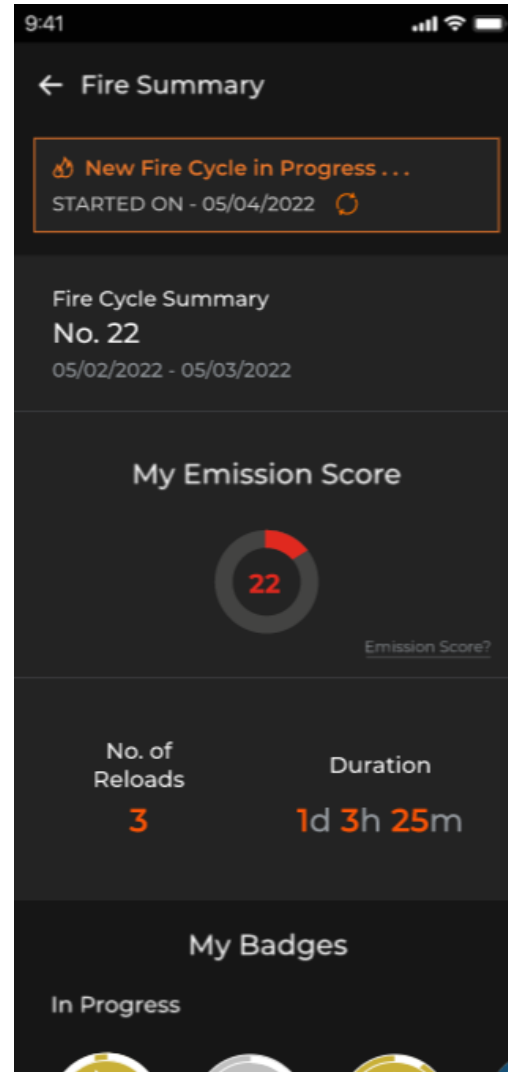
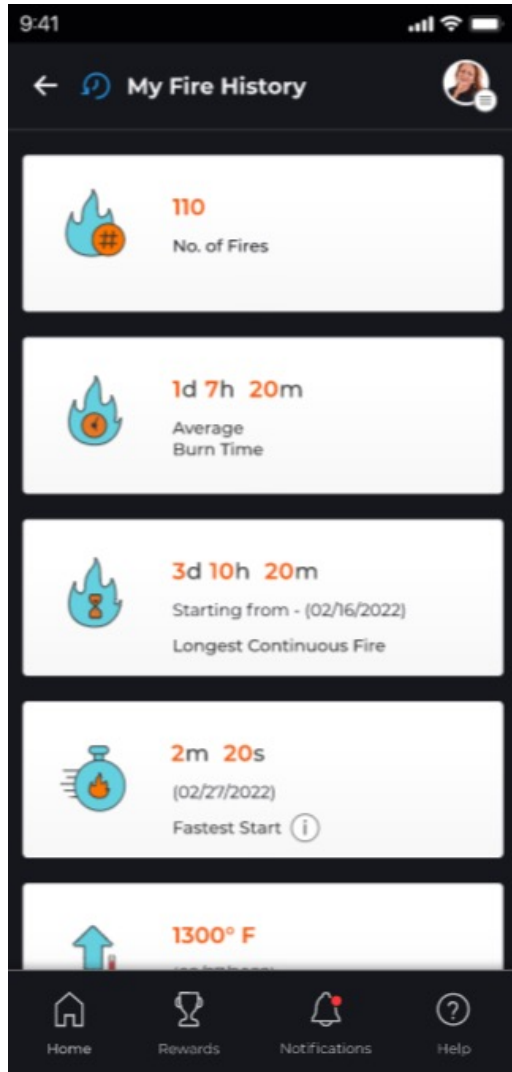


# Mobile App

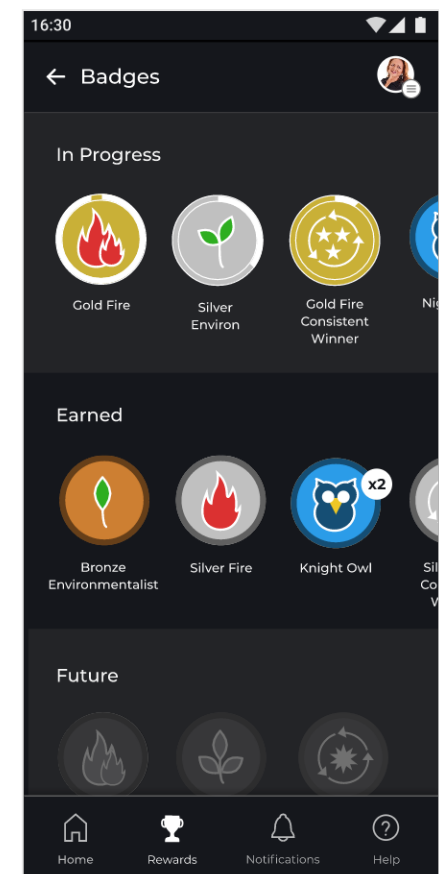
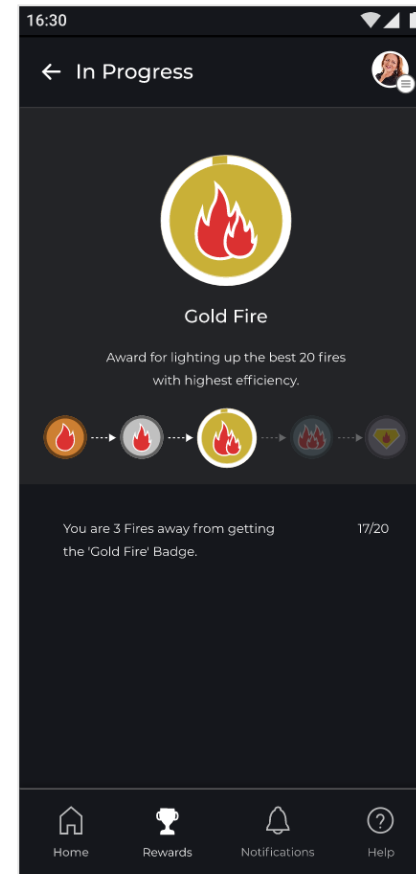
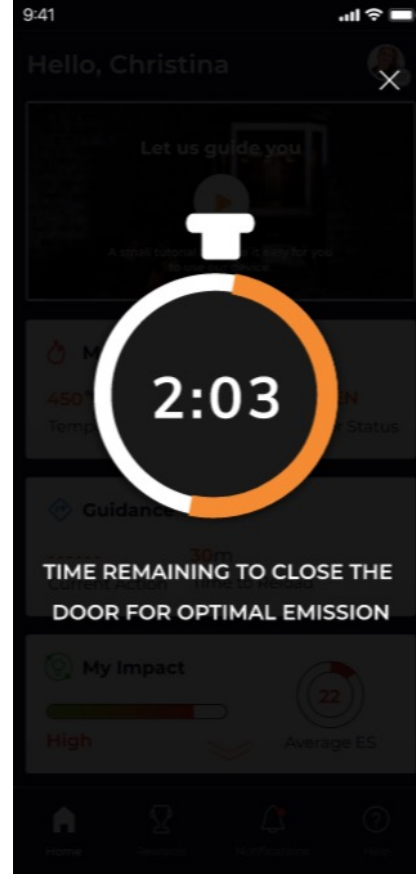
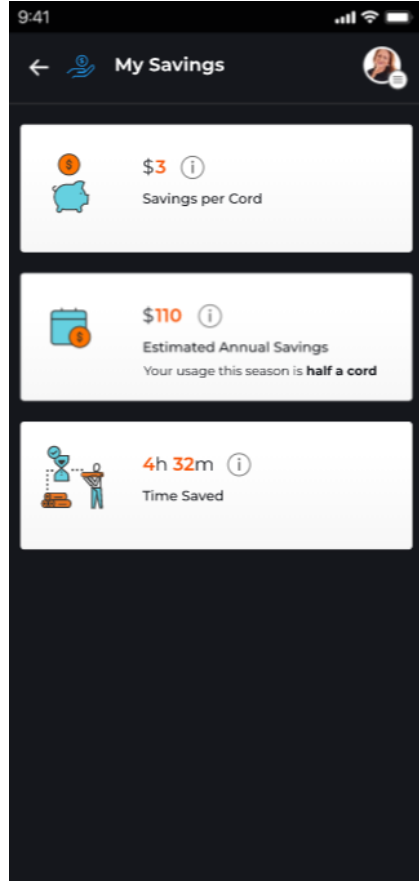
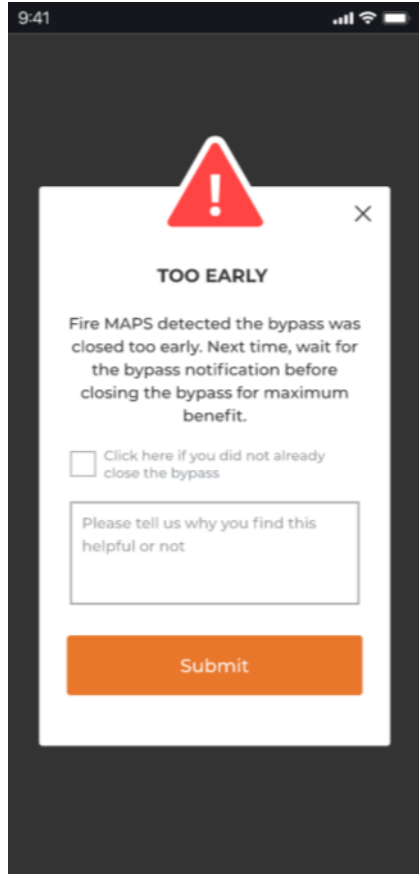
- Top level tiles with at-a-glance information
- Select any tile takes you to more detailed information about that topic
- Sections include
  - Fire
  - Fire History
  - Impact
  - Saving
  - Guidance
  - Achievements



# Mobile App



# Mobile App



# Customer Support and Research Tool

Generate FireMaps Report

Hide/Show Input Fields

User Profile Data

User Action Color

Logout

Stove ID

Beta055



Firecycles Filters ( Select any Fire Cycle to generate graph for that Date Time )

FireCycle162

--Select Reload FireCycle--



DateTime  
02/21/2023 11:24:09  
Tc1 Filtered  
104.97  
User Action  
ONTIMEFIDETECTED

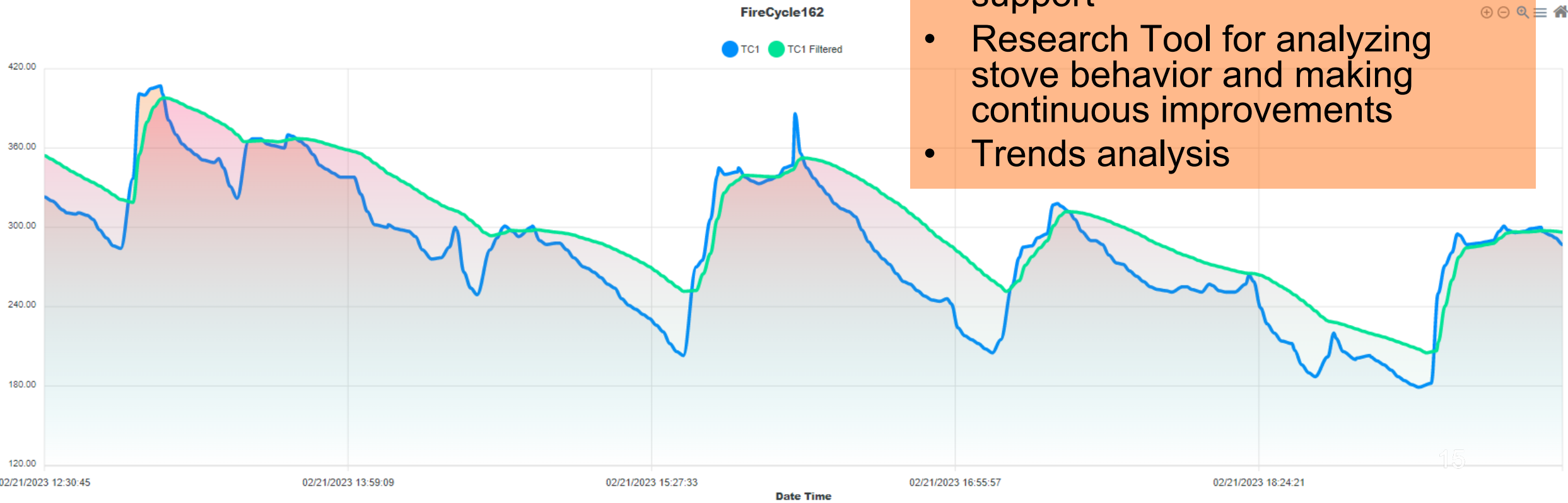
DateTime  
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CLOSEDOOREARLY

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TEMPERATURE\_RISING

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Tc1 Filtered  
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EARLYENGAGECATALYST

DateTime  
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Tc1 Filtered  
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User Action  
DOOR\_OPEN\_CATALYST\_DISENGAGED

DateTime  
02/21/2023 18:32:27  
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User Action  
DOOR\_CLOSED



- Tool for user administration and support
- Research Tool for analyzing stove behavior and making continuous improvements
- Trends analysis

# Summary

- Wood stove users contribute up to 600% of a wood stove's lab-tested emissions rating
- Most of the user created emissions is attributable to improper or sub-optimal stove operation
  - Lack of real-time data about the fire or fuel, i.e. -
    - Is fire well established enough to close the door
    - Is the stove hot enough to engage the bypass
    - Why is the wood not burning this time (wood is too wet)
  - Lack of understanding of how to properly operate a given wood stove for best performance, i.e. -
    - When is the best time to reload
    - Does it matter when I engage the bypass
    - Putting stove in low burn mode at the wrong time
- Fire MAPS is a solution that educates and trains wood stove users to lower emissions and get more efficiency from their stoves



# Quad Chart Overview

## Timeline

- Oct 1, 2019
- Anticipated September 2022

	FY22 Costed	Total Award
DOE Funding	\$293,993	\$989,644
Project Cost Share	\$75,903	\$255,500

## Project Partners

- N/A

## Project Goals

Create a system that:

1. Reduce/eliminate user-contributed emissions
2. Monitors wood stove use and performance data in real-time.
3. Delivers timely and relevant guidance to users so that they can optimally operate their wood stoves.
4. Changes wood stove user behavior
5. Creates first ever industry and government burn database.

## End of Project Milestones

1. Validated system that monitors and provides real-time guidance to users as conditions change throughout the fire.
2. A test matrix that captures and reports on the real-world, user-contributed emissions.
3. A commercially viable product that is ready for affordable mass adoption.
4. A national burn database for research and policy decisions.

## Funding Mechanism

DE-FOA-0002029  
FY19 BIOENERGY TECHNOLOGIES OFFICE MULTI-TOPIC,  
AOI 3: Efficient Wood Heaters

# Additional Slides

(Not a template slide – for information purposes only)

- *The following slides are to be included in your submission for evaluation purposes, but will not be part of your oral presentation –*
- *You may refer to them during the Q&A period if they are helpful to you in explaining certain points.*

# Management

- Team centers around a Ph.D. combustion expert, IoT product development expertise and project manager.
- The project is managed using best practices as defined by Project Management Institute.
- Team utilizes weekly formal status meetings as well as daily scrum session to manages progress and key decisions. A separate weekly finance meeting ensures the product adheres to the overall schedule and budget.
- An integrated set of management tools are used to track the project and preserve a record of communication and decisions, such as Slack, Asana, and Google Drive
- The team has successfully worked together on other patented and commercial wood stove technologies for over 6 years.
- Strong collaboration and communication enable the team to keep sight of progress and spot issues early. We utilize a proven, formalized process for product development, which enables the team to work through challenges and test core hypothesis.

# Responses to Previous Reviewers' Comments

## Previous Comments

- **Will this influence user behavior?** The initial trial scope was 30-90 days. 30 days of use appears sufficient to alter user performance and stove operation. Continuing use profiles show many users come to rely on the device for optimum operation, and many users continue to use the device well into the second year. When interviewed, those users express confidence in use and improved attention to timing. Both short term and long term users demonstrate overall improvement in stove operation and corresponding emissions and efficiency outcomes.
- **Concerns about technical setup** – Fire MAPS is extremely simple to setup and use. It requires no specific knowledge or tools and takes users less than 10 minutes to setup. During the in-home user trials, we were able to remotely support all self-installing stove owners with a minimum of effort.
- **Who will use this?** We solicited a broad applicant pool for trials and focused on a diversity of use cases and personas. Our feedback shows newer stove operators (<10 years), younger owners (<50), parents of any age, and users who are planning to or recently changed stoves and want to learn differences in operation.

# Publications, Patents, Presentations, Awards, and Commercialization

- Patent filed 2021-03-18
- Application number: 17/019,654