DOE Bioenergy Technologies Office (BETO)
2021 Project Peer Review

Swirl Stove: Swirling combustion for efficient wood burning

Date
Technology Area Session

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Project Overview

Wood stoves are a widely used heat source in US homes, which produce air pollution and create health issues.

- ***Goals**: reduce particulate emissions production to below 0.5 g/hr, a 75% reduction, and increase efficiency to 85%, a 15% increase over control stove*
- ***Main idea**: leverage swirling combustion (mixing combustion air with gasified wood) to achieve a more complete burn, thereby reducing emissions and increasing efficiency*
- ***Today**: Traditional wood stove geometries and air introduction systems leave many pockets of incomplete air/gas fuel mixture leading to incomplete combustion, higher emissions and lower efficiency*
- ***Importance**: Wood heat produces 40% of PM2.5 particulate matter in the US, a leading cause of respiratory illness and lung disease.*
- ***Risks**: 1)Swirling combustion is a technique used in predictable, consistent combustion environments. Wood combustion is inherently inconsistent and swirling combustion has not been achieved in a repeatable consistent way. Project success requires developing a method that can repeatably and consistently achieve sustainable swirling combustion. 2) Creating swirling combustion with wood fuel may not deliver the emission reduction sought.*

1 – Management

- Team centers around a Ph.D. combustion expert, mechanical engineer 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.

2 – Approach

- MF Fire started with a hypothesis based on scientific principle and experienced/observed by its lead scientist in other, more consistent fuel combustion environments.
- We modeled the wood combustion process, focused on creating conditions that achieve swirling combustion, and then leveraged CFD modeling to evaluate a broad array of potential solutions. In all we tried 14 configurations in an isothermal simulation and 2 in a combustion configuration, before transitioning to real-world prototyping of the most promising configurations.
- Challenges:
  - CFD modeling has limits for modeling the complexities of wood combustion. Favorable simulations do not always translate into real world solutions
  - Swirling combustion, such as a fire tornado, is rarely seen in nature due to the need for multiple conditions to align. It may be that successfully creating a swirling combustion does not lead to a sustainable swirl.
  - Once created, a swirling combustion device may not achieve the targeted goals for emissions reduction.
- The team has high confidence through experience that we can achieve swirling combustion. The emissions testing of the prototype – the first major go/no-go decision point – is important as it will provide confidence in the potential for emissions reduction at project completion.
- Progress metrics: CFD modeling yields multiple potential swirl configurations, prototype testing results in actual sustained swirling combustion, early lab testing confirms emissions reduction scale, design can be made at scale for under $5,000.

3 – Impact

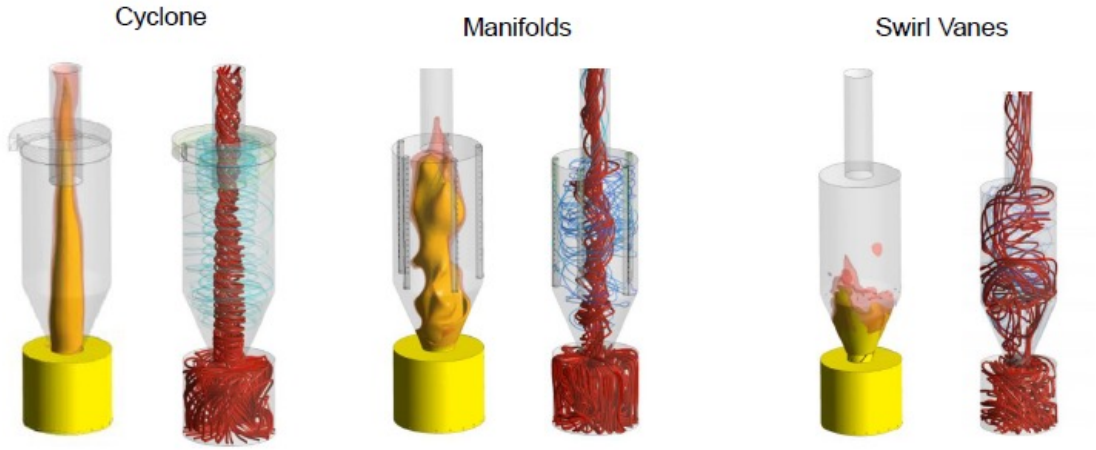
- The biggest challenges facing the industry are the external pressures and regulatory drivers to convert wood heat into a cleaner heat alternative.
- A successful swirl combustion stove has the potential to simplify wood stove design, thus lowering manufacturing costs and making it more affordable, while transforming wood heat into clean energy.
- Once results are known, we will publish peer-reviewed articles in the academic and scientific communities while promoting the innovation through popular news outlets.
- The company's patented technology will be made available to the hearth industry to help accelerate the rate of adoption.
- Early customer focus groups have shown very strong consumer interest for both aesthetic and practical reasons.

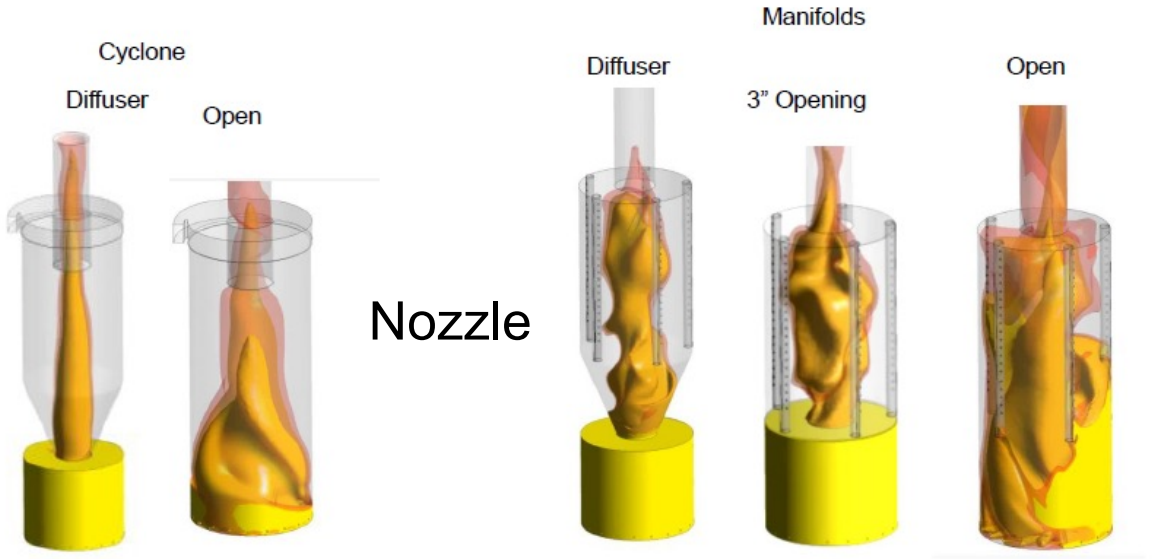
4 – Progress and Outcomes

- Met every milestone and on budget. We have completed the major R&D elements leading up to real-world prototype development, the next critical step.
  - Initial design specifications and extensive CFD modeling complete, initial prototype created and tested
  - Formal prototypes are in development and expected to be available for testing soon
- The company leveraged domain expertise to provide an initial framework to define the project and steps necessary to achieve success.
  - Modeled swirling combustion to identify attributes needed to achieve a theoretic sustained swirl.
  - Built complex CFD models to predict and help visualize outcomes of possible design approaches. 14 configurations in an isothermal simulation and 2 in a combustion configuration.
  - Hand built a prototype to provide early testing of promising approaches
- Learned:
  - Which methods are most effective and necessary for tornado coherence.
  - Ratio of primary to secondary are required to maintain swirl coherence.
- What we don’t know yet
  - Can we sustain combustion, how its look in real world environment, and is it clean

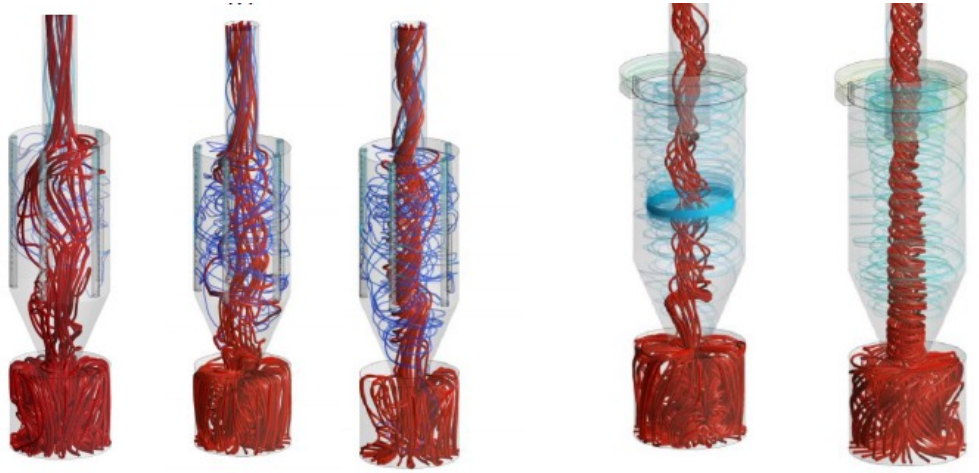
4 – Progress and Outcomes

Cyclone, Manifolds, or Swirl Vanes





Secondary Air



Summary

- Swirling combustion in other (non-wood) fuel sources results in a more complete combustion, which results in fewer byproducts and emissions.
- Sustainable swirling combustion of wood fuel shows potential to be achieved
- Swirling combustion designs in wood stoves have the potential to advance the state of the art for wood heat emissions and allow for continued improvement to achieve ever-tighter emission targets.

Quad Chart Overview

Timeline

- Oct 1, 2019
- Anticipated June 2022

	FY20 Costed	Total Award
DOE Funding	$460,425	$998,937
Project Cost Share	$115,230	$250,810

Project Partners

- N/A

Project Goal

The goals and objectives for this project are to create a system that:

1. Achieves stable swirling combustion
2. Reduces or eliminates the 50-75% of emissions
3. Improves the realized efficiency by 10 to 15%
4. Is affordable and can be incorporated into a commercially viable product.

End of Project Milestone

The expected outcomes of this project are:

1. A commercially viable, low emitting wood stove, ready for affordable mass adoption.
2. Passage of UL Safety Tests and EPA Method 28 Emissions Testing with a swirl combustion stove meeting particulate emissions goals of less than 0.5 g/hr
3. A peer reviewed journal article describing the utility of swirling combustion applied to batch loaded wood.

Funding Mechanism

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