Hydrogen Generation, Storage, and Stove Technology to Mitigate Indoor Air Pollution

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Introduction

Acute lower-respiratory infections (ALRI's) are the #1 cause of death in children under five.[1]

- 3 billion — of the world's poorest rely on biomass-fueled stoves (left)
- 3.8 million — people die annually from exposure to household air pollutants
- 50% — of pneumonia deaths in children under five linked to indoor air pollution

From World Health Organization, 2018

Our Bass Connections team began by researching the current trends and history of biomass as a fuel source for cooking. We based our work on the previous project team, who focused specifically on India. We gained an understanding of the cultural motivations for using biomass, indoor air pollution problems resulting from burning biomass, restrictions in accessibility to cleaner resources, and the implications of government incentives to convert to other cooking fuels. We worked off of the previous project team's idea for an alternative, renewable fuel source that would eliminate the need for a supply chain and be cheaper than a battery.

Project Goals

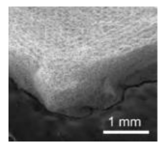
- **Generate** hydrogen locally with an alkaline water electrolyzer
- **Combust** hydrogen gas safely as a cooking fuel with a hydrogen stove
- **Compress** hydrogen gas in an ultra-high pressure vessel system
- **Conduct** case study in India to examine cultural context of target population

Hydrogen Generation

Purpose: Generate H_2 locally with an Alkaline Water Electrolyzer for use with hydrogen cook stove.

Objective: Achieve current densities for a scaled-up system similar to small-scale results with high efficiency.

Alkaline Water Electrolyzer System Set-Up:



2 porous Ni microfiber electrodes

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Gas impermeable PES membrane

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Electrolyte (30% wt. KOH)

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Power Supply

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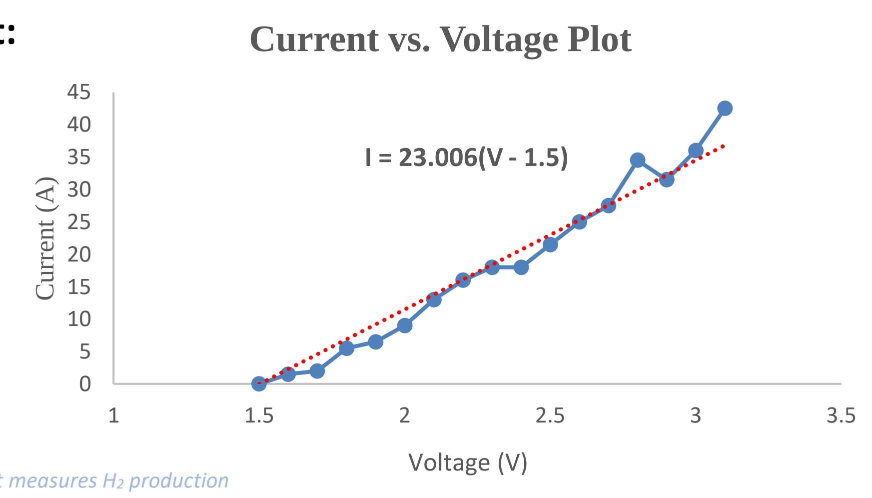
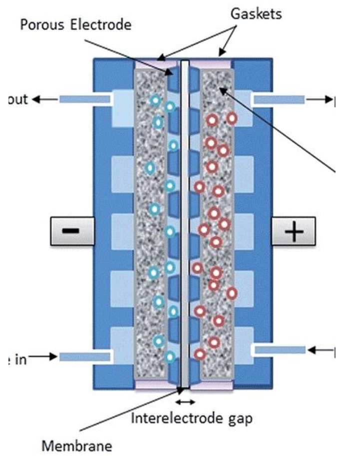
Pressure Vessel

Result:



**Current measures H_2 production*



Hydrogen Compression

Purpose:

Hydrogen has very low density, so it must be compressed to ultra-high pressures to maximize energy density.

Target Pressure: 5000 psig

Pressure Vessel Set-Up:

Sealed interior chamber contains water and gas bladder pumped to high pressure using bike pump + Additional water is pumped into the vessel to reach ultra-high pressures inside the vessel

Result:

0.4 L of air @150 psig → Compression → 13 mL of air at 5000 psig → Release → 4.6 L of air at ambient

Combustion

Purpose:

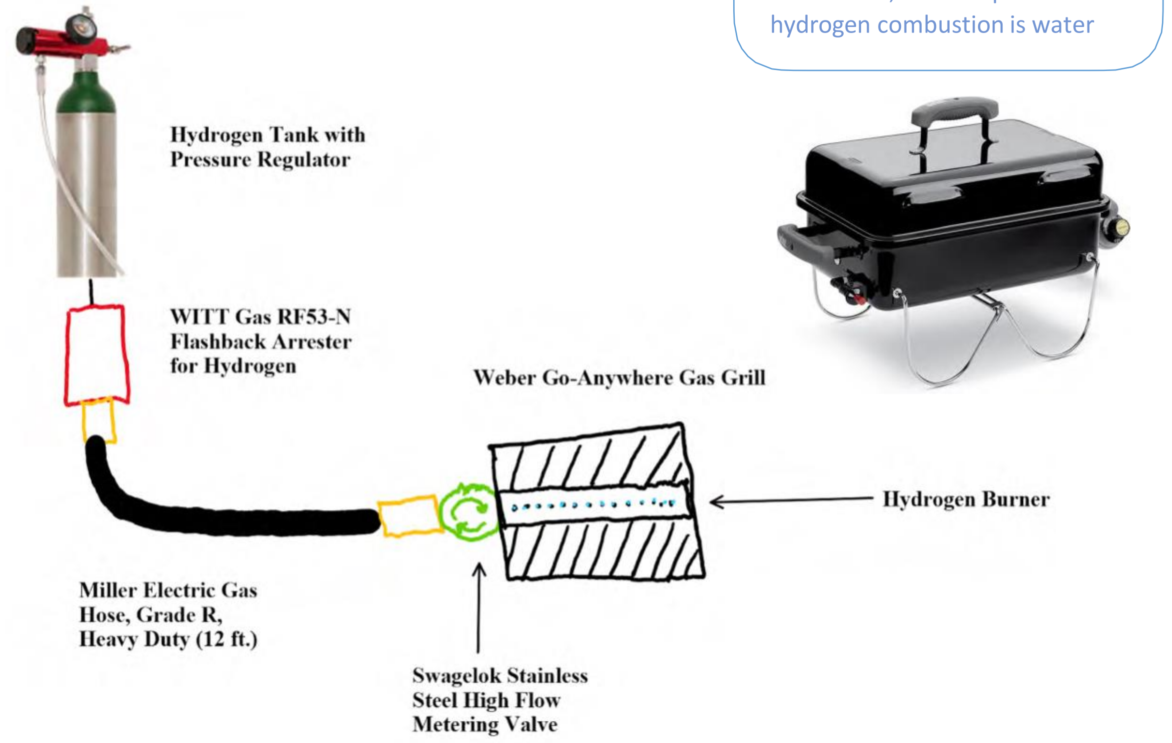
Construct a safe, efficient hydrogen stove that can utilize 40 L of H_2 at 300 bar for 10 hours of cooking.

Combustion Reaction

$$2H_2 + O_2 \xrightarrow{\Delta} 2H_2O$$

Ideally, hydrogen combustion in air does not generate harmful substances; the sole product of hydrogen combustion is water

Hydrogen Stove System Set-Up:



A Weber 1141001 Go-Anywhere [Propane] Gas Grill (right) was modified to combust hydrogen with the assistance of the Duke Physics Instrument Shop and Dr. Walter Pyle, director of research at H-Ion Solar Inc.

Additional Modifications:

- Aluminum griddle top
- Variable-area flowmeter

Safety & Efficiency:

- Tightly sealed connectivities and flashback arrestor to maximize safety
- Burner crafted from stainless steel to minimize NOx formation
- Variable-area flowmeter permits for efficiency testing in the future

Result:

The previous team tested the modified grill under a fume hood, successfully cooking a patty.

Implementation

Developing a clean cookstove solution is one challenge, but implementing it requires new considerations. While working on building the cookstove, the previous team simultaneously researched policy implications of a clean cookstove intervention.

The most critical findings were:

- **Cost** is the **largest barrier** to cookstove adoption
- **Women and children** are disproportionately impacted by pollutants from traditional cookstoves
- Households in which **women** have **less bargaining power** are **less likely to adopt** novel cookstove solutions
- Consumer cookstove **preferences vary significantly** from each individual household. Thus, consumer preference should guide cookstove design

Independent Duke Engage Project: Piloting Improved Cookstoves In India

As a continuation of this project, the previous team worked with an NGO in Gujarat, India to help them pilot their improved cookstoves. The purpose of this was to fully understand what it takes to implement a cookstove intervention and understand the workings of a village and the numerous actors necessary for an intervention to be a success. This project was later cancelled due to the COVID-19 crisis. **However, the framework of the plan once arriving in India was:**

- **Phase 1:** Familiarization with the NGO and the scope of their work. Finalizing which employees will aid in this project specifically.
- **Phase 2:** Immersion in the community to understand consumers' daily lives and preferences.
- **Phase 3:** Creating awareness and developing interest in the community through demonstrations, flyers, door-to-door discussion, etc.
- **Phase 4:** Developing the pilot program through working with community members, NGO employees, and local actors (especially cookstove manufacturers).

Summary of Progress

Generation

- Produced and scaled AWE electrolyzer
- Optimized required power input and electrolyte flow rate to maximize current density
- Developed consistent electrode fabrication process

Compression

- Achieved compress-and-release cycles for air in ultra-high pressure liquid vessel
- Arranged system setup to allow for more efficient compression with minimal manual input

Combustion

- Constructed H_2 stove from commercial grill
- Modified cooking surface to accommodate Indian cuisines
- Conducted multiple leak checks to verify and improve safety of apparatus

Next Steps

- Seamlessly integrate these three components
- Scale electrolyzer and compression unit to serve an entire village
- Analyze costs
- Field-test the efficacy of the unified system in a village in India
- Refine system components as needed
- Distribute cookstoves on a household basis

Technology alone is not enough to address global problems. In light of this, an exhaustive literature review of the social, economic, and theoretical requirements and obstacles associated with our project has been written.

References

1. Household Air Pollution and Health. https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health (accessed Nov 6, 2019).
2. Wiley, B. J., Burning Hydrogen to Prevent Pneumonia. Duke University: 2019; p 2.
3. Hydrogen production by alkaline water electrolysis - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Basic-scheme-of-a-water-electrolysis-system_fig3_262617097 [accessed 6 Nov, 2019]

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