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Optical Diagnostics of Simple Biogas Flames

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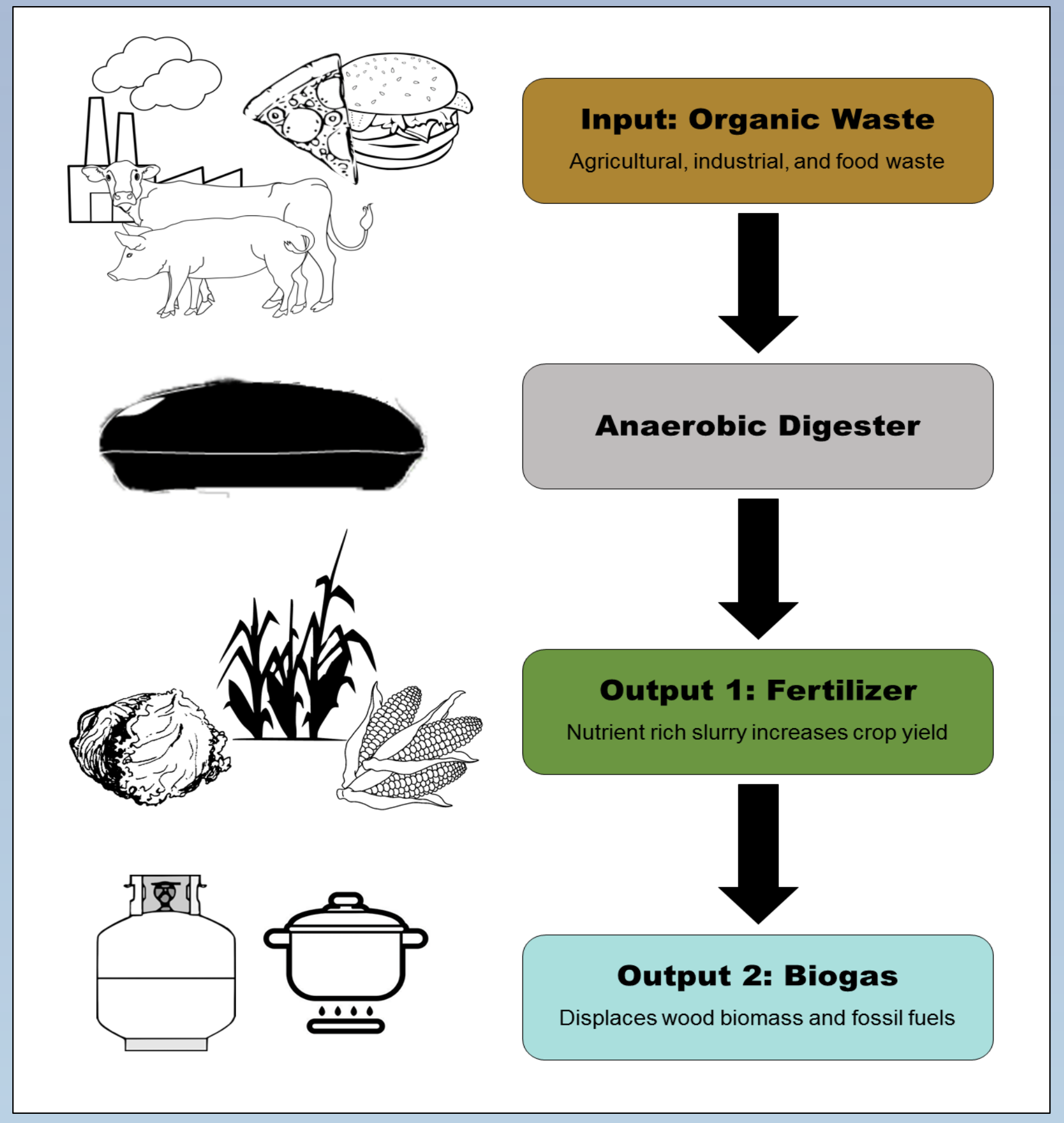
Background

The environmental and monetary impacts from disposing of organic waste streams from agricultural, animal, and industrial sources represent a significant cost as well as a potent health hazard, specifically, in developing world countries[1]. Processing these organic waste streams to create a combustible gas (e.g. biogas) is a promising alternative to traditional means of disposal in that the resulting biogas provides a renewable energy source as well as a nutrient rich slurry stream that can be used as an effective fertilizer[2]. Moreover, for the approximately two billion people who still rely on biomass as cooking fuel, the use of biogas could play a vital role in mitigating the significant negative health effects of cooking with traditional fuel supplies [3], [4]. A chief challenge in biogas research is the limited knowledge of how the combustion process is affected by components in the biogas mixture[5] – components such as H2S, organic compounds, and high amounts of CO2, which are not present in traditional hydrocarbon fuels.

The experiments preformed herein are aimed at improving our understanding of the combustion of biogas mixtures, thus allowing for more efficient use of these promising bio-fuels. Applications of biogas usage spans from renewable energy use in industrial applications[2], [6] to improved cookstoves used in the developing world[3], [7]–[9]. In short, if we better understand the combustion of biogas then we can create cleaner burning combustion systems which rely on this promising, renewable fuel source.



Input: Organic Waste
Agricultural, industrial, and food waste

Anaerobic Digester

Output 1: Fertilizer
Nutrient rich slurry increases crop yield

Output 2: Biogas
Displaces wood biomass and fossil fuels

Experimental Overview

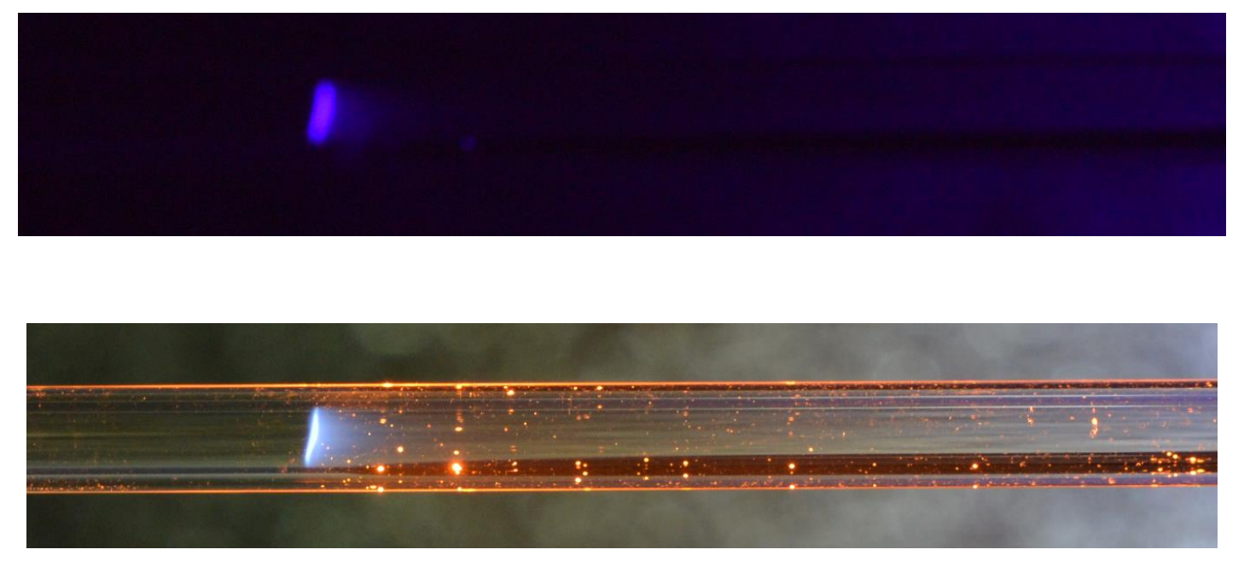
In the present work, simulated biogas fuels are combusted in various "simple flames." The term "simple flames" refers to flames of simple geometry. Optical diagnostics of these flames allows for comparison against detailed chemical kinetic simulations so as to examine both the reaction chemistries within the flames as well as resulting emissions from the flames. Two primary experiments are currently being investigated, a micro-reactor experiment and an LED absorption experiment. The micro-reactor experiment isolates the chemical kinetics from the macro-scale flame effects, due to the fact that the micro-reactor diameter is smaller than the normal quenching distance of the flames. The goal of the LED absorption experiment is to develop small, portable systems that could be used on "real-world" combustion engines and burners to measure the concentration of desired product species. The current experiment is a first step in developing such a system. It utilizes a line-of-sight absorption technique wherein a beam of light is passed through a biogas flame. Additionally, this experiment uses LEDs as a light source for this technique, which are significantly smaller, cheaper, and less complex than lasers, which have been the light source traditionally used for this technique.

Research Questions

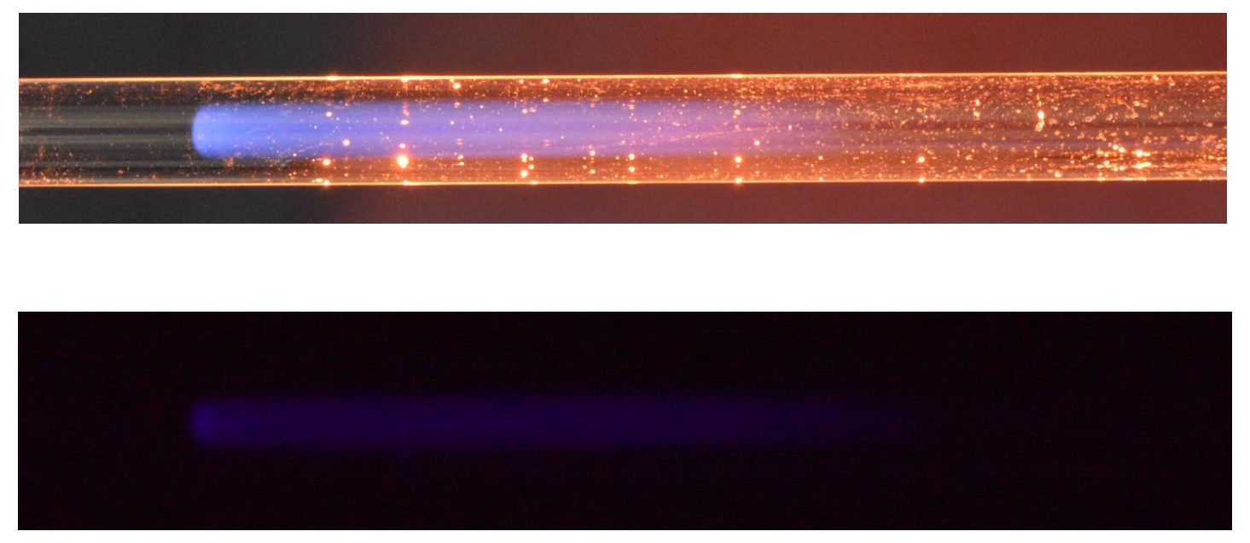
1) How do the various biogas species affect combustion in ways that differ from traditional hydrocarbons such as methane and natural gas? Specifically what are the effects on: a) flame properties such as flame speed, flame temperature, extinction limits, etc., and b) flame-out emissions such as NOx, CO2, soot, etc.?
2) How might we design end-use combustion systems such as cookstoves, burners, and engines specifically for biogas fuels?
3) A secondary research interest is to design robust, low-cost, and easily deployable experiments for field measurements of combusting systems.

Micro Reactor

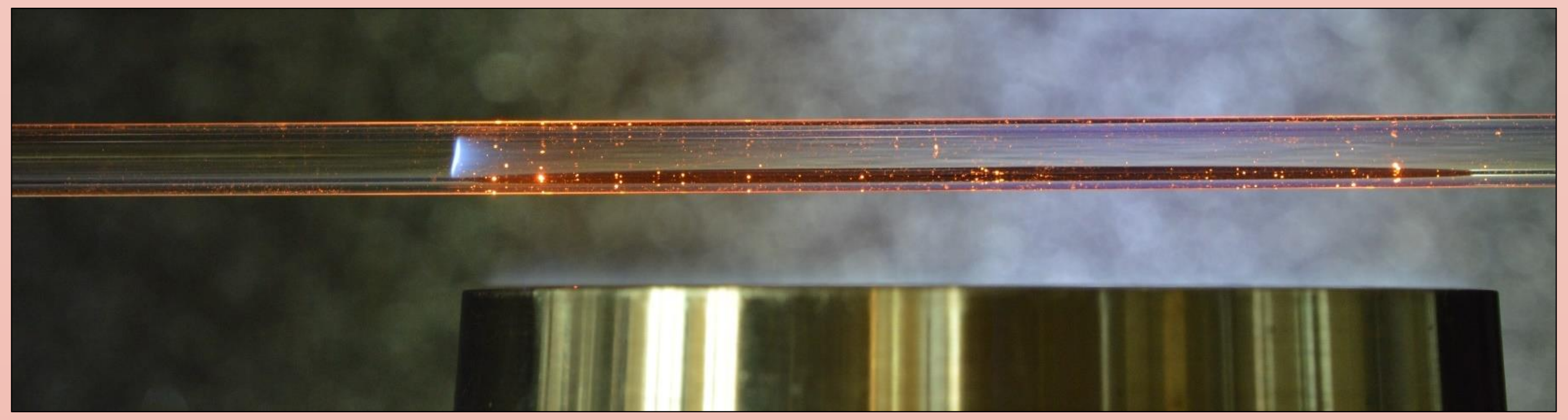
Micro-reactor experiments have been previously used to investigate micro-scale combustion applications such as power sources in MEMS devices, miniature chemical reactors, or even small scale satellite propulsion units[10], [11] However, recent studies have begun to use them more as a tool for fundamental combustion research[12], [13]. More specifically, a micro-reactor with a controlled temperature profile allows for the separation of macro-scale flame effects from the chemical kinetics within the reaction zone. Thus, heat production in the reaction zone is small enough that it does not significantly affect the experimental temperature profile. In these experiments the reaction zone (a luminescent flame-like region) can be stabilized at a given location and observed via the chemiluminescence of the CH and OH radicals within the flame. Lastly, since the geometry of the system is quasi-1-dimensional, the reaction physics can be greatly simplified when modeling a given experiment, thus allowing for more detailed simulation of the chemistry involved.

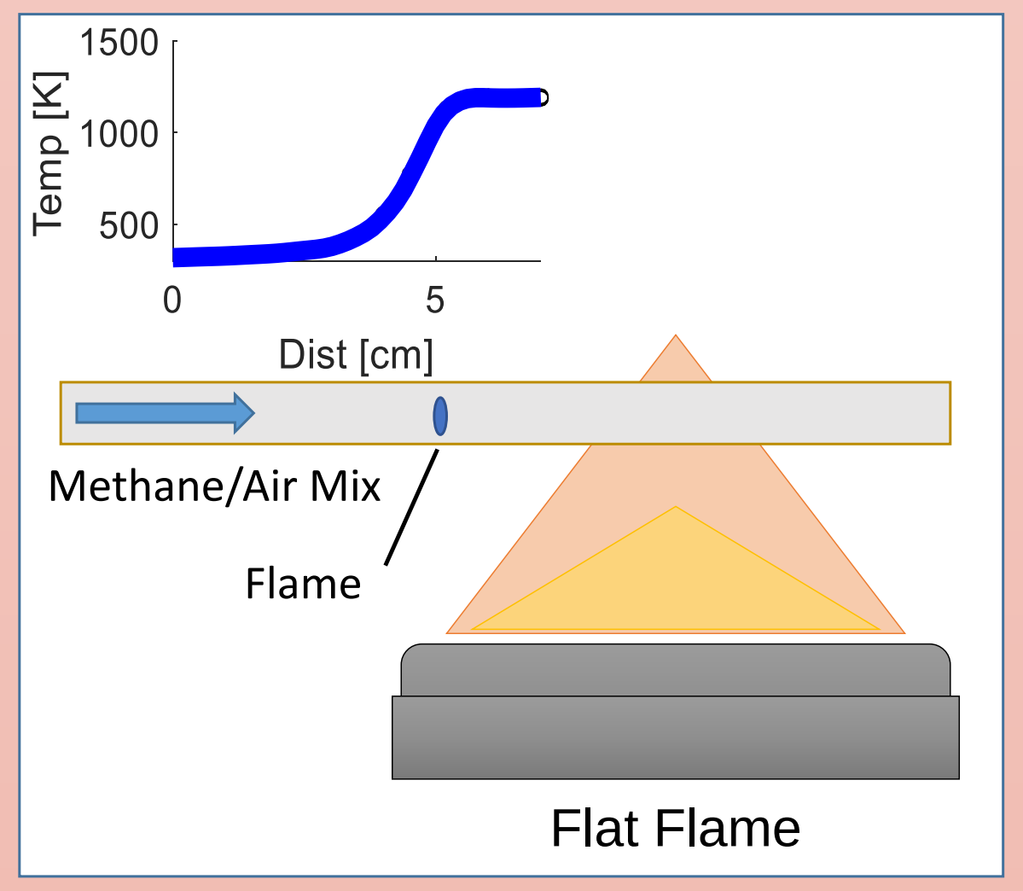


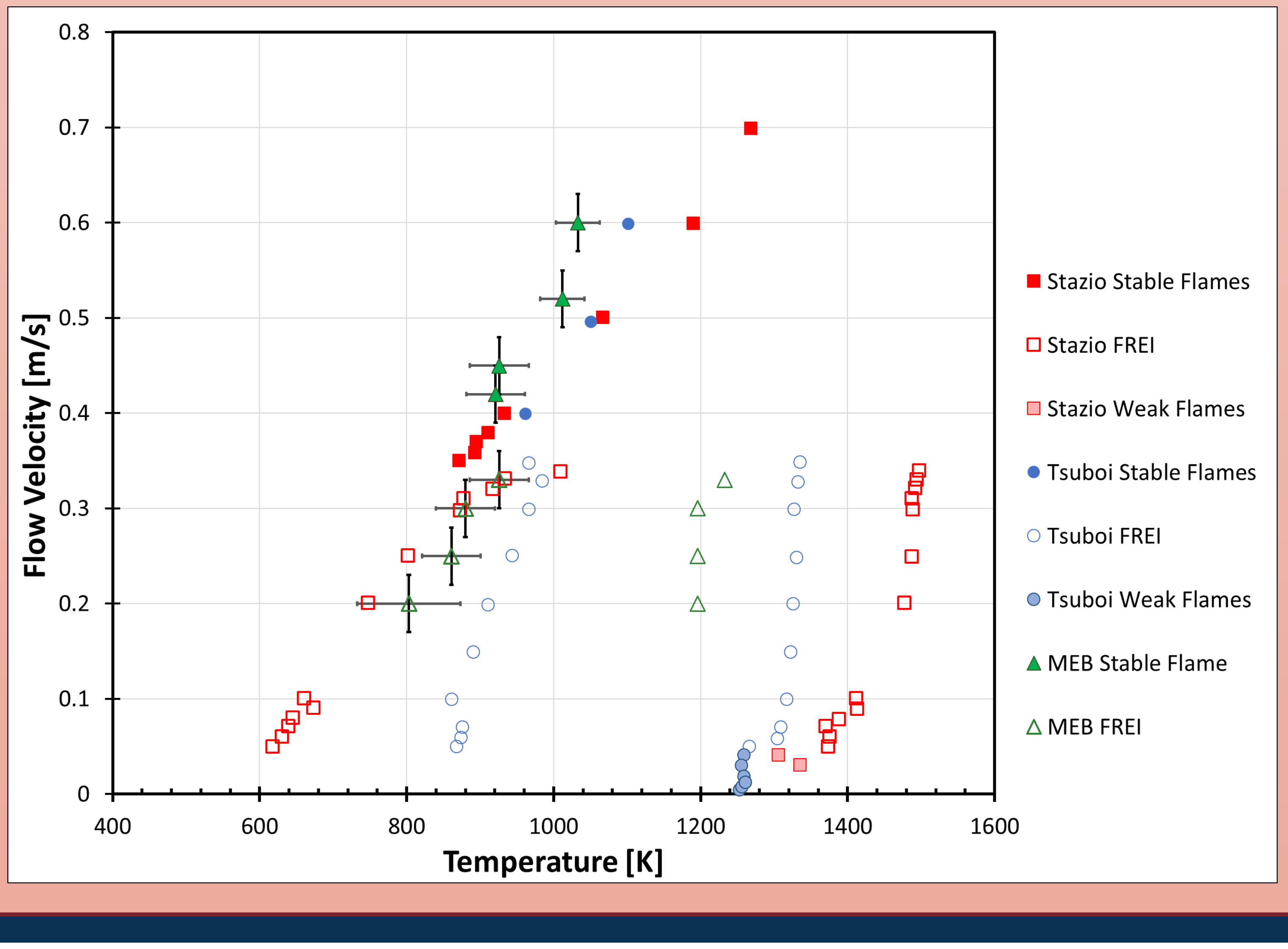
Stable Flame (U=60 cm/s)

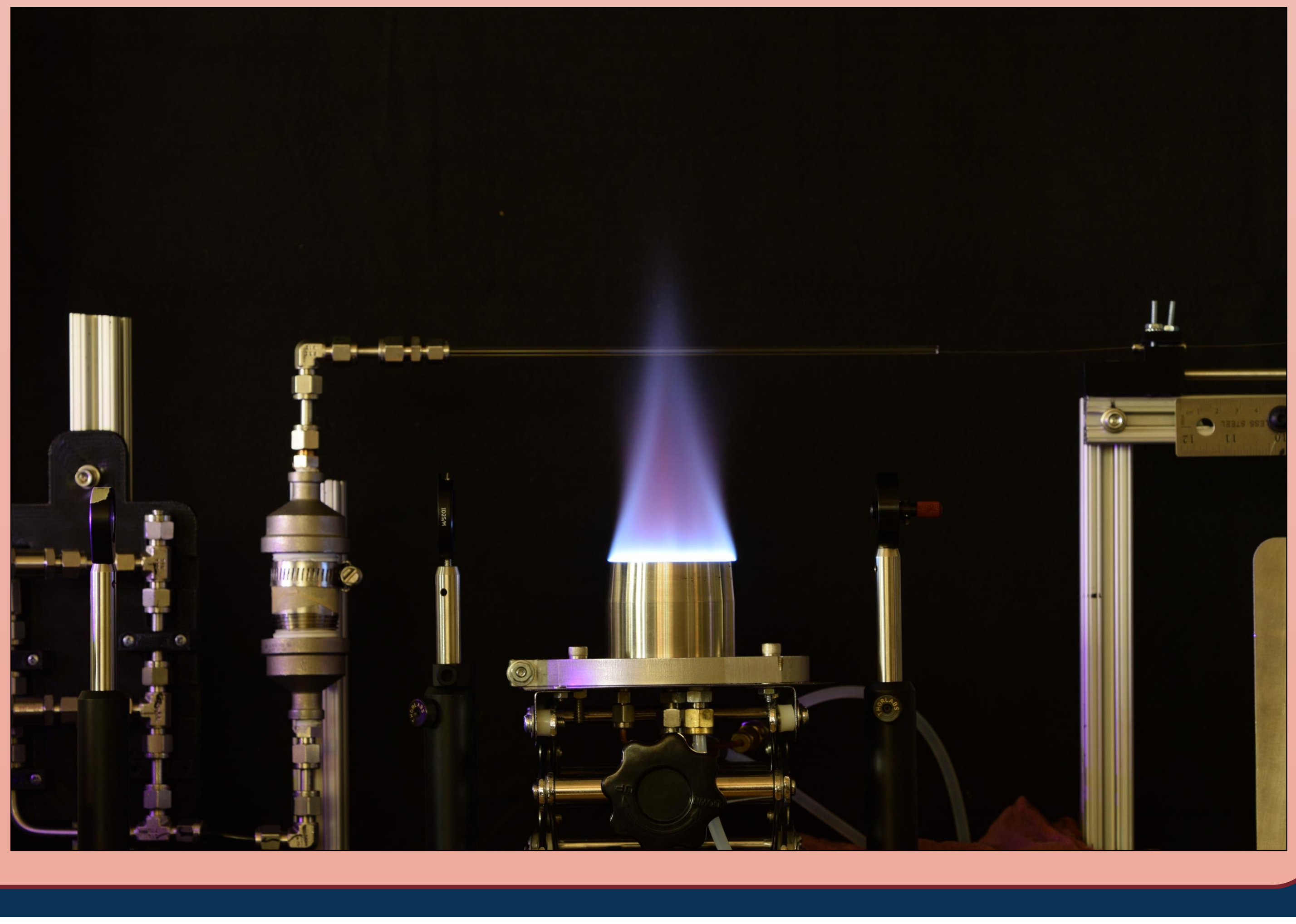


FREI (U=30 cm/s)



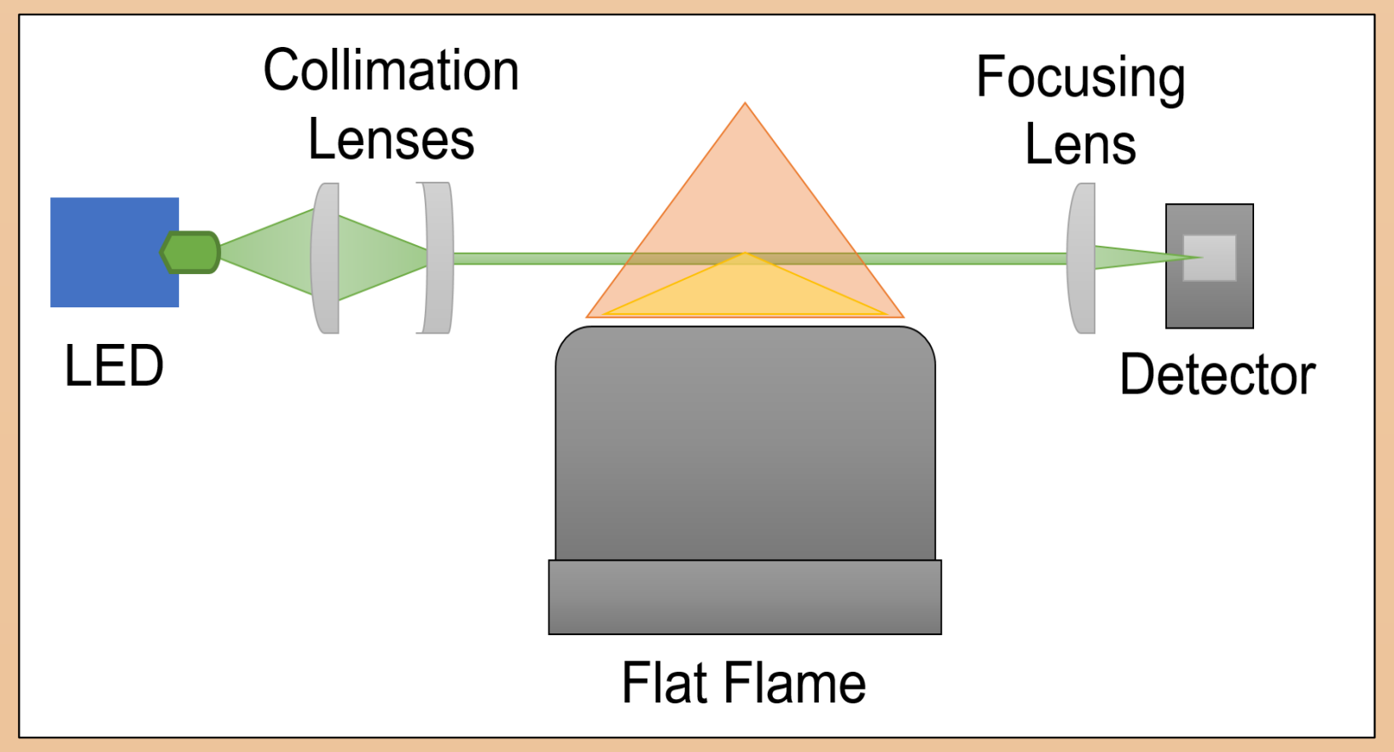


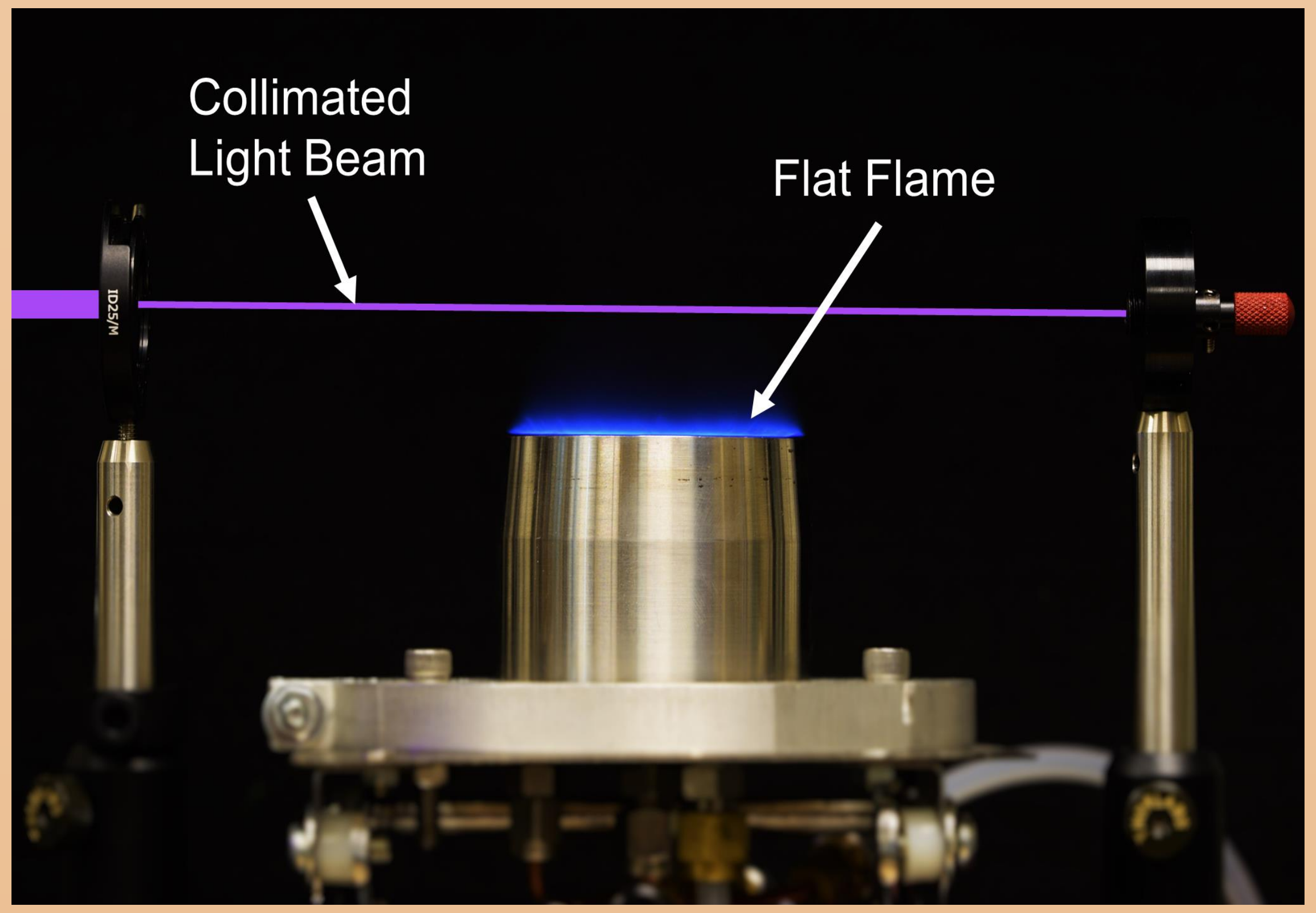


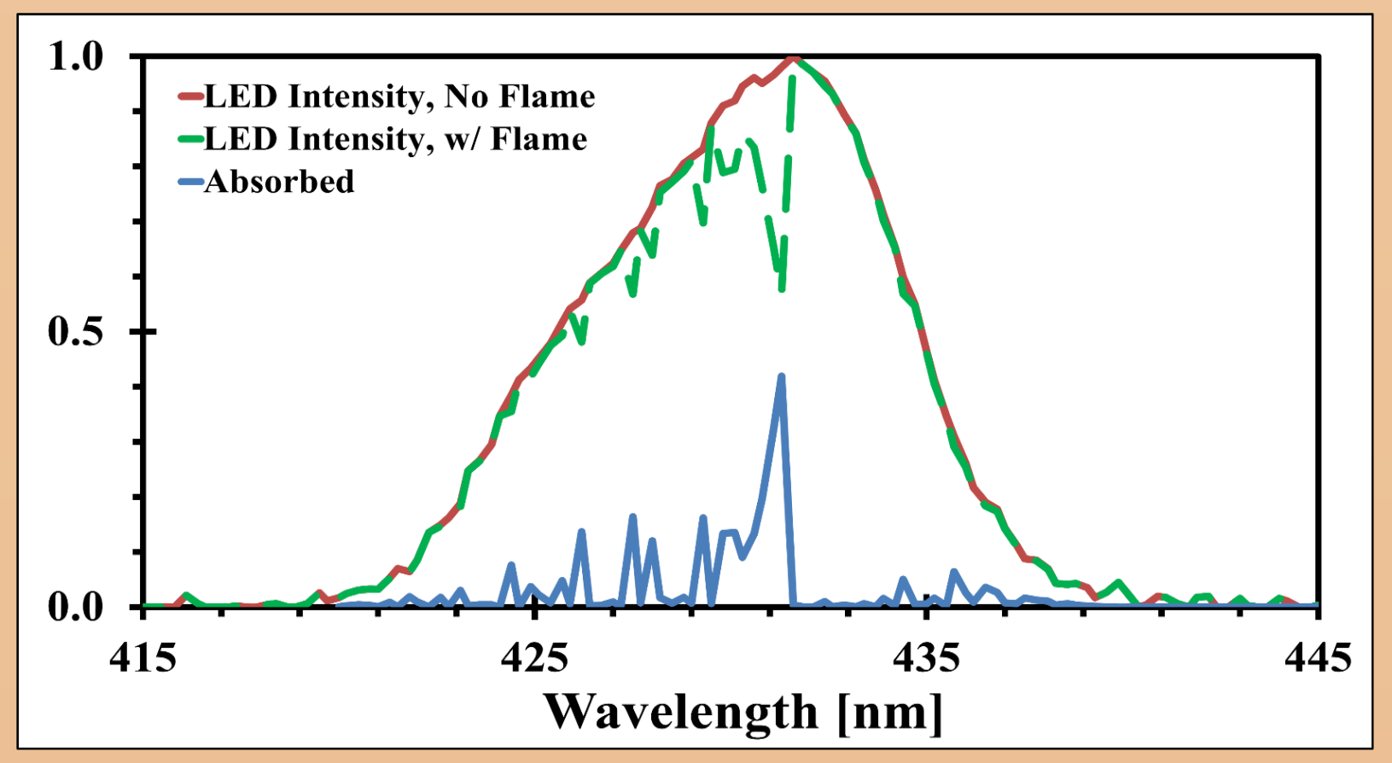


LED Absorption

In this experiment, the amount of light absorbed as it passes through a biogas flame relates to the concentration of a desired species within the flame itself. The light wavelength is chosen a priori to be coincident to the wavelength of absorption/fluorescence of a desired species (ex. CH, OH, or NO). Lasers have been used for many years as a light source for this technique[14], [15] since they can be tuned to a very specific optical transition of a target species However, lasers are costly, complex, and are often ill-suited as onboard diagnostics vs. other light sources. Light-emitting diodes (LEDs) are small, inexpensive, consume very little power, and have recently become available with high enough power ratings in narrow enough wavelength ranges that make it possible for them to be used in absorption and fluorescence techniques in much the same way that lasers are currently[16]. LEDs have been used for a number of years in bio and atmospheric sciences in a similar manner as proposed herein, but at wavelengths in the infra-red and not in combusting systems. Alternatively, herein we use deep-UV and near-UV LEDs as a diagnostic tool in simple biogas flames.







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