Tandem Thermochemical and Biological Conversion of Mixed Plastic Waste for Remote Military Operations

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Outline

- Motivation for production of goods at "point-of-need" for soldiers in the US military
- System and process overview
- Chemical deconstruction process descriptions and conditions, chemistry of conversion, and product yields and rates of production
- Pyrolysis process and products
- Natural and engineered microbial consortia and food-nutritional products
- Integration of process units, solar power, and open source control system
- Overall process mass and energy balances
- Conclusions / Future Developments / Acknowledgements

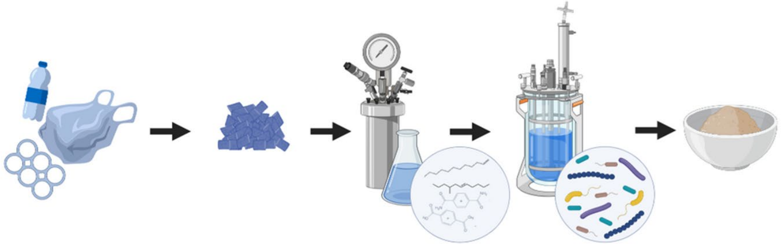
Problems

- Long and expensive supply lines
- Casualties in conflict zones along supply routes
- Burn pits emit toxic compounds

Solutions

- US military seeks solutions for **point-of-need production** of food and fuels
- US military seeks solutions to solid waste mgmt. / avoid burn pits / reduce $ for soldier supply of up to **$10,000/ton** for remote deployments

Avoid Burn Pits



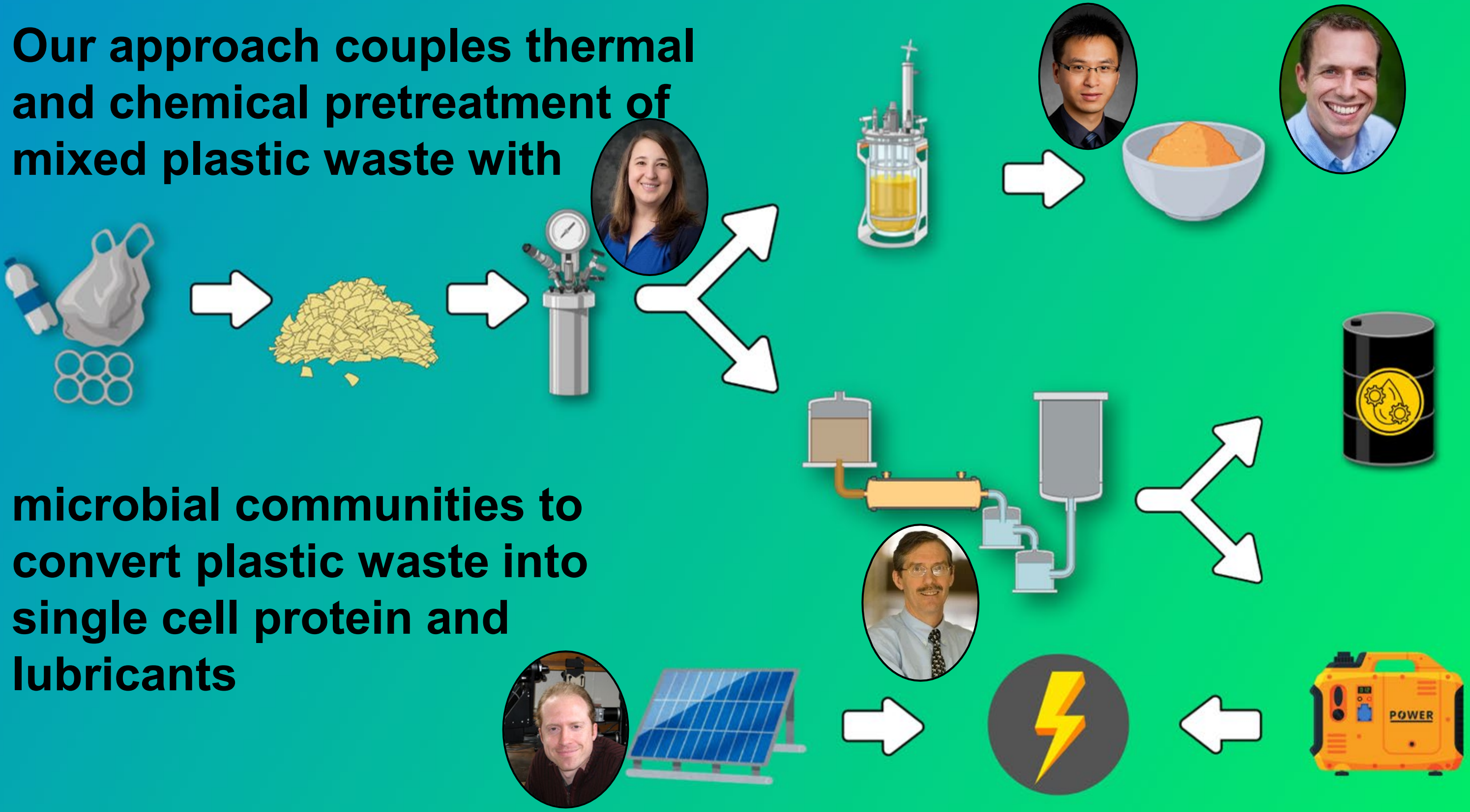
Trash to Treasure

- ➢ Military waste streams are:
  - A **logistical challenge** to handle in forward operating settings
  - Potential resources **if** there are suitable methods for conversion of waste to valuable products

- ➢ **Food, Lubricants, and Fuels** are important resources in field forward settings

System Overview

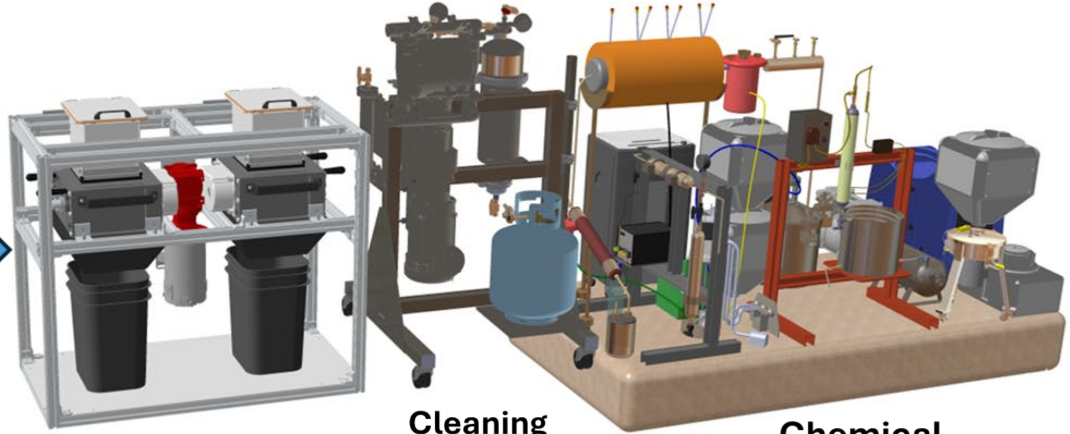
Our approach couples thermal and chemical pretreatment of mixed plastic waste with



microbial communities to convert plastic waste into single cell protein and lubricants

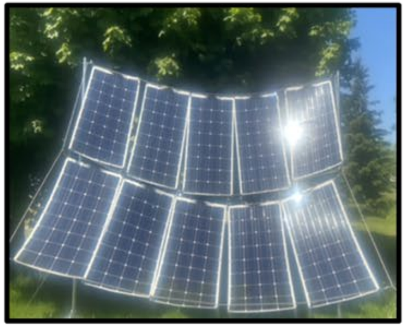
Process Overview

1 kg/hr capacity for remote deployment of 100 soldiers.
500 kg, 8 m^3, all solar powered, open source control



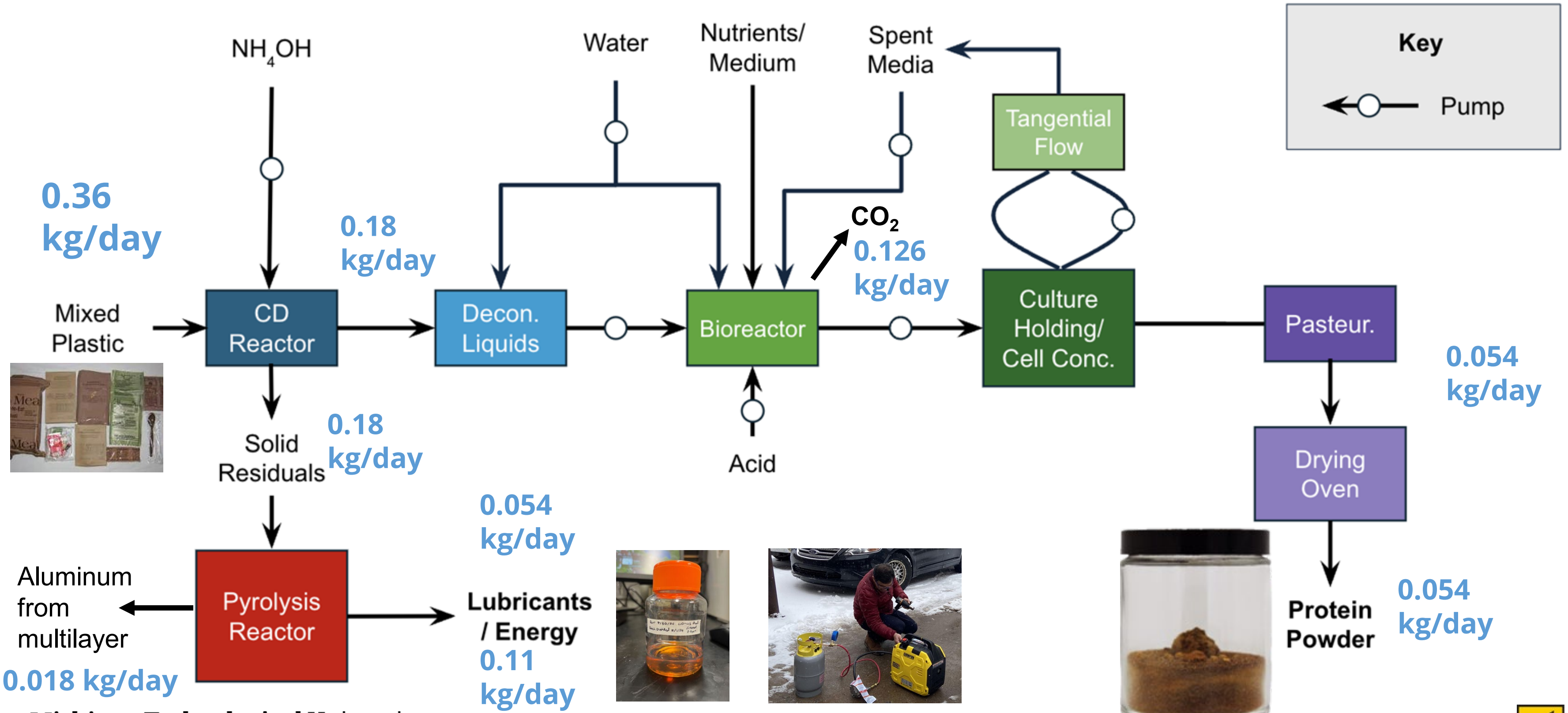
Shredder **Cleaning** **Chemical Deconstruction, Bio-Manufacturing, Pyrolysis**

MRE (meals ready-to-eat) packaging



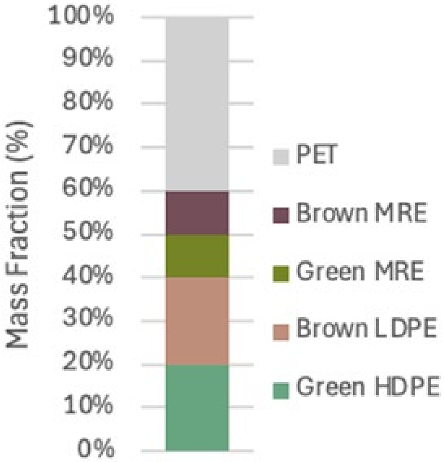
Low-carbon auxiliary power

Process Overview: Final Demonstration Capacity

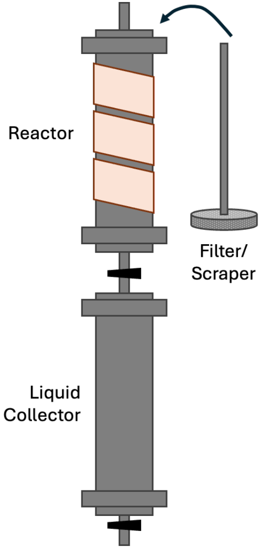


Chemical Deconstruction

Mixed Plastics



Chemical Deconstruction



- **Solids Loading:** 0.25 g mixed plastic per mL 10 (v/v)% NH_4OH
- **Temperature:** 220 °C
- **Residence Time:** 20 min
- **Plastic Loading:** 350 g per reactor

Liquid Product to Bioreactors

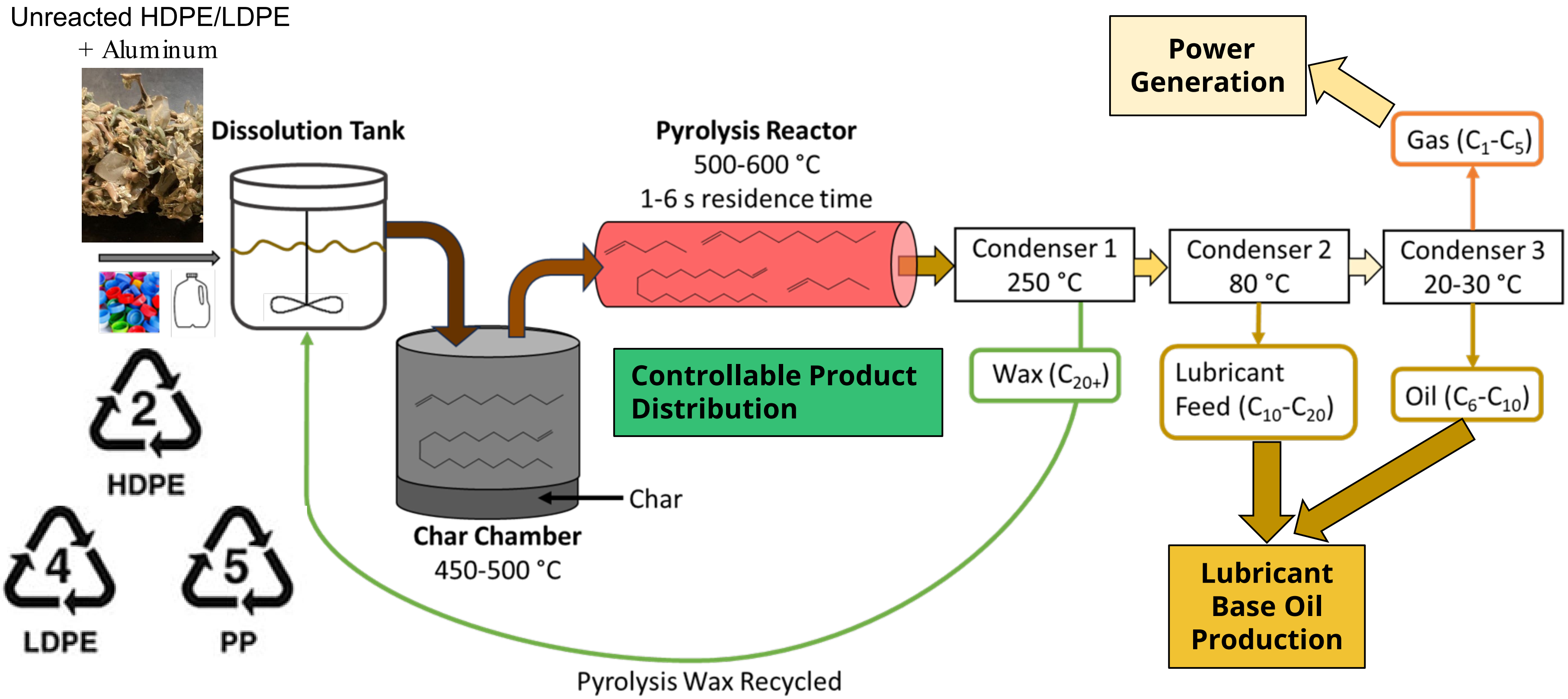
Experimental Solubilization:
39.0% ± 2.5%

Theoretical Max:
42.7%

Solid Product to Pyrolysis

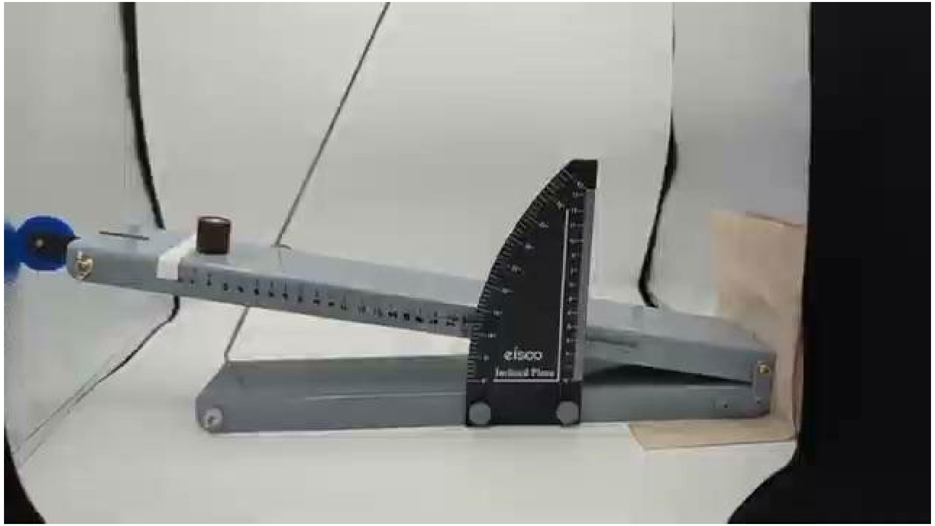
Unreacted HDPE/LDPE + Aluminum

Polyolefin Pyrolysis



Novel Pyrolysis Products - Synthetic Lubricant

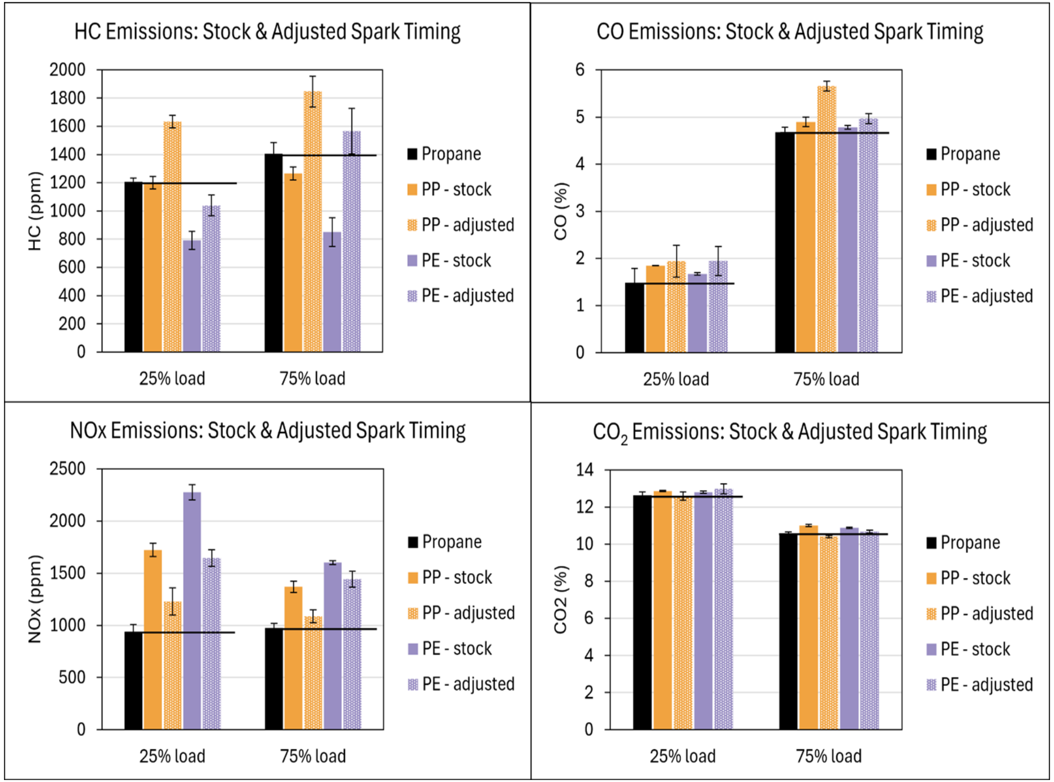
Video of Synthetic PyOil Lubricant



Novel Pyrolysis Products - Py Gas

Py-gas works as a drop-in fuel replacement for propane applications

- Requires increased fuel pressure for higher loads to maintain correct fuel mixture ratio
- Py-gas shifts combustion phasing earlier in the engine cycle due to a faster initial burn rate
  - Adjusting spark timing can compensate
- Py-gas has a high knock tolerance, and no knocking was observed during testing
  - Opportunity for performance and efficiency gains with system optimization
- Py-gas produced slightly higher overall emissions than the propane reference, however, polyethylene-based fuel exhibited uniquely low HC emissions (right)



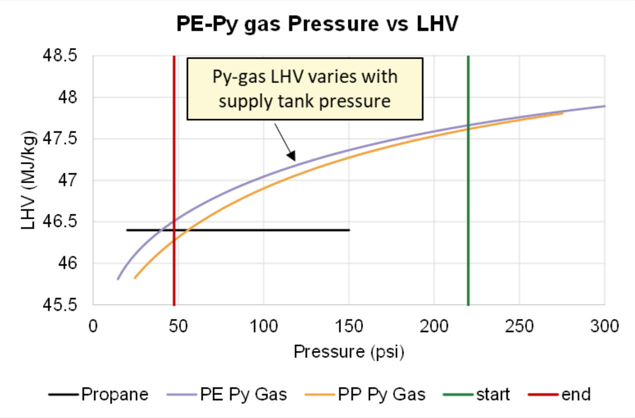
Novel Pyrolysis Products - Py Gas

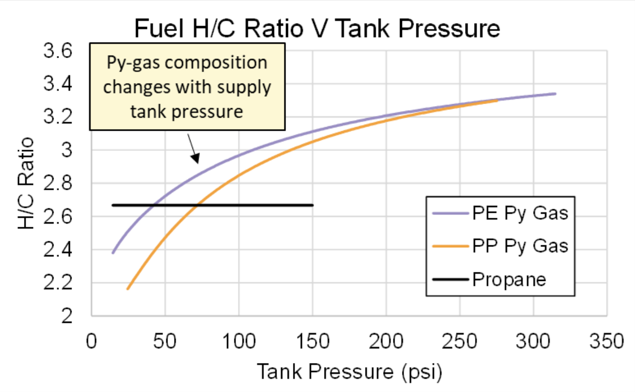
Extended steady state runs were performed at 75% load to measure fuel efficiency

- Py-gas tests used the modified timing that was adjusted to match propane CA50
- The average Py-gas lower heating value (LHV) was calculated and used

Fuel	LHV (MJ/kg)	Load	Lambda	Spark Timing (ATDC)	CA50 (ATDC)	BSFC (g/kW-hr)	Efficiency
Propane	46.4	75% (1249W)	0.86	-31.4	5.4	**420**	**18.5%**
PP py-gas	47.0	75% (1249W)	0.86	-28.9	4.1	**416**	**18.4%**
PE py-gas	47.2	75% (1249W)	0.86	-27.7	4.3	**465**	**16.4%**

- Polypropylene Py-gas achieved similar overall efficiency to the reference fuel
- Polyethylene Py-gas was about 2% lower
    - Further investigation of timing could close this gap

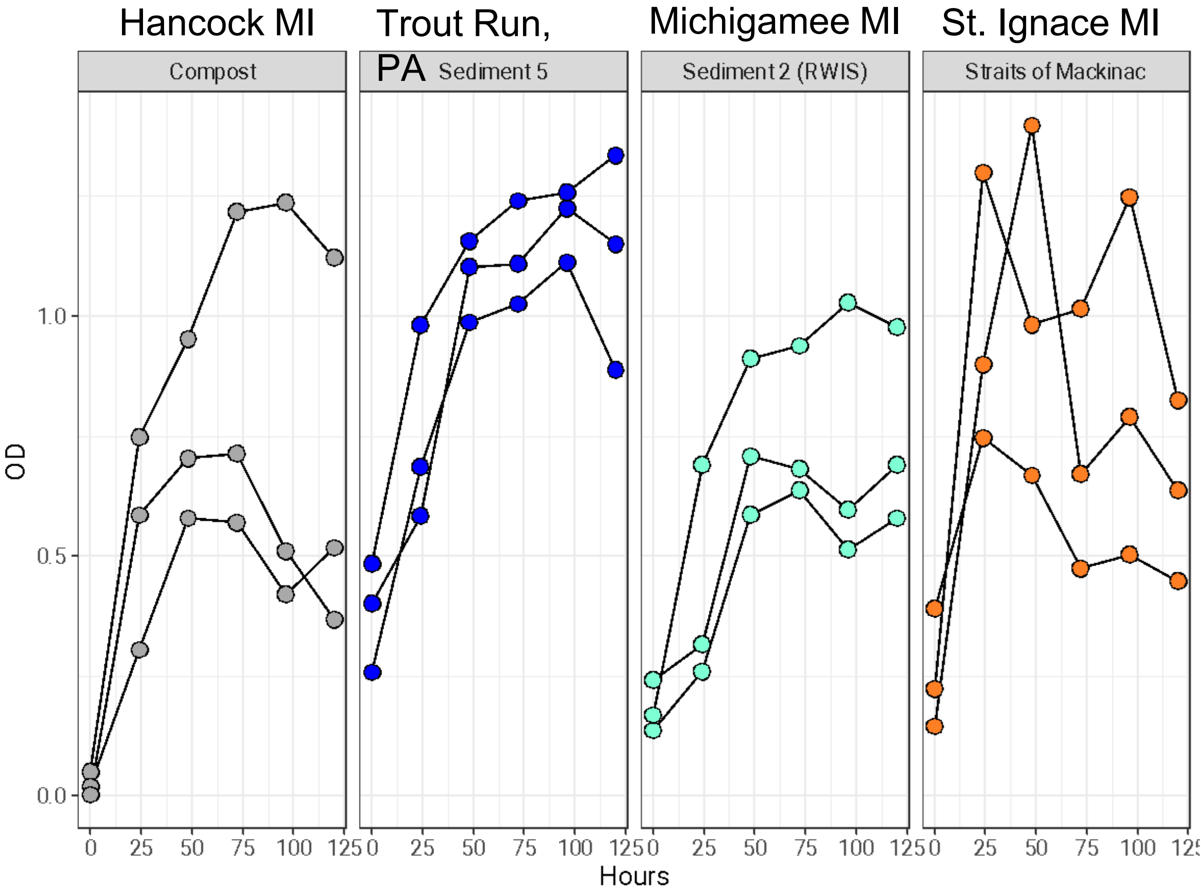




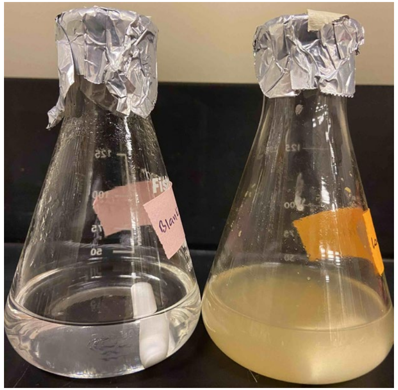
Microorganisms as Food

- Bacterial cells are contain many of the nutrients needed in a food source (proteins, carbohydrates, fats, vitamins, etc.).
- The use microbial cells as food has been common and is often used as a nutritional supplement (Nutritional Yeasts, Spirulina, Vegemite)
- Single Cell Protein (SCP) are microbial cells used as a food or food supplement.

Conversion: Natural consortia grow rapidly to high biomass



- Rapid growth was observed using deconstructed plastics product as the carbon source.
- Consortia can grow to high biomass densities on chemical breakdown products of PET in 24 – 48 hours.



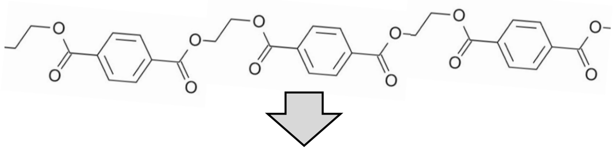
Food Product

Nutritional Analysis

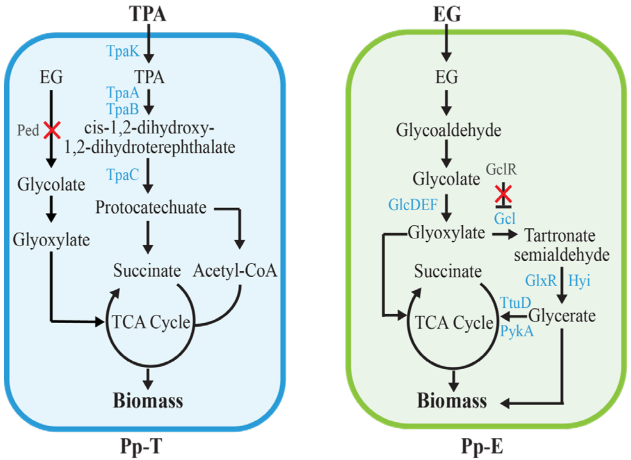
Analysis	Biomass
Calories	442 Cal/100 g
Calories from Fat	137 Cal/100 g
Fat by Acid Hydrolysis	15.20%
Carbohydrates	44.40%
Total Dietary Fiber	35.90%
Protein	31.90%
Ash	7.07%
Moisture	1.35%

Conversion: Engineered microbial consortia

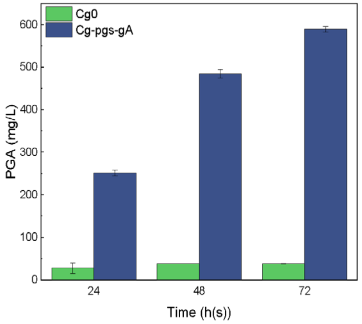
Engineered consortia produce additional nutrients

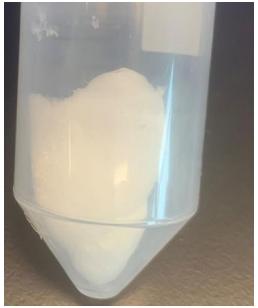


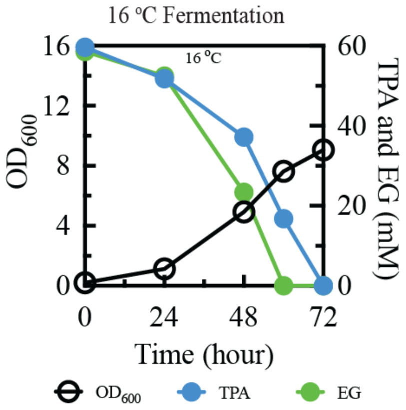
Terephthalic acid (TPA)　　Ethylene glycol (EG)

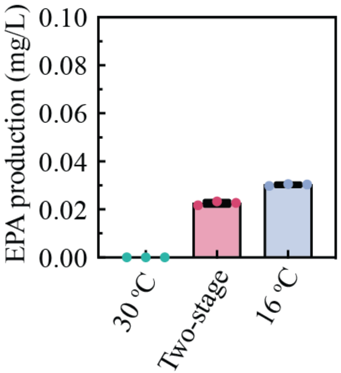


polyglutamic acid production





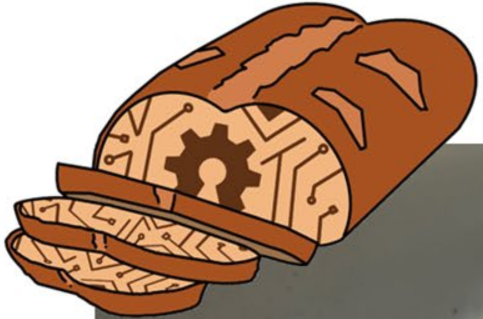




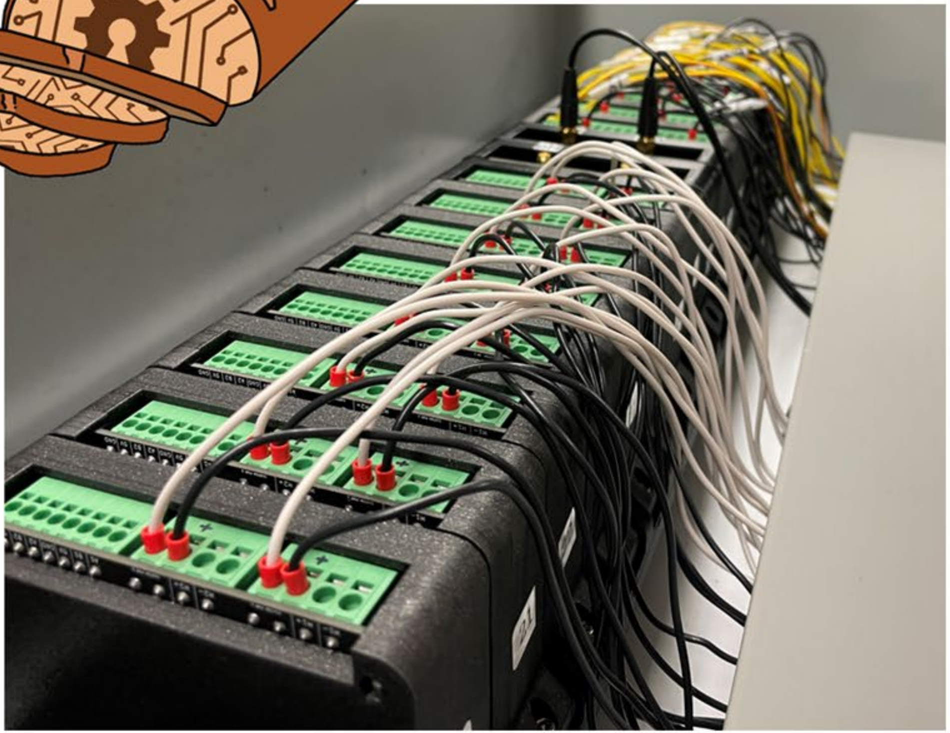
polyunsaturated fatty acid production

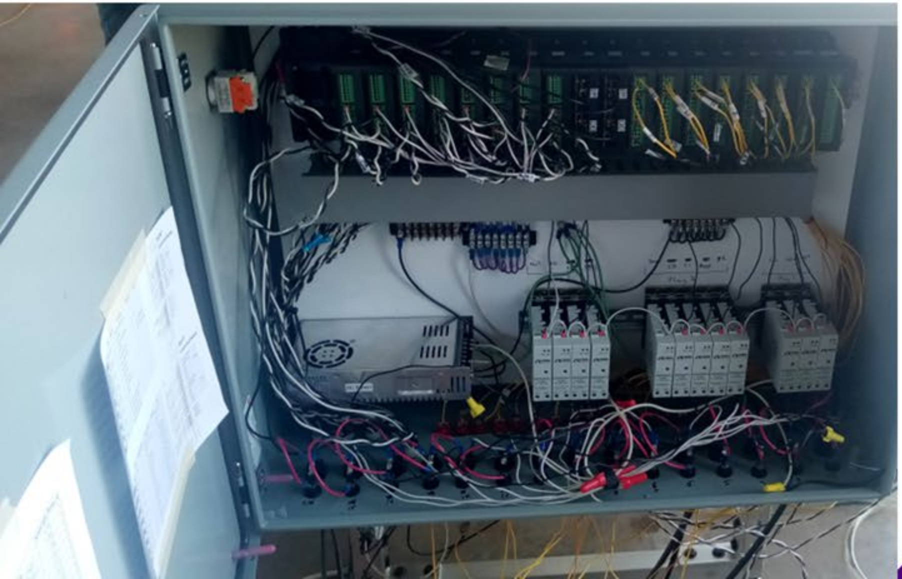
Integration with BREAD

- Broadly Reconfigurable and Expandable Automation Device (BREAD)

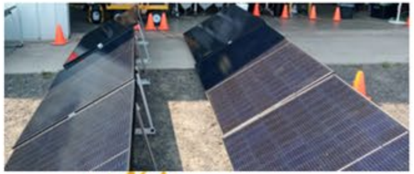


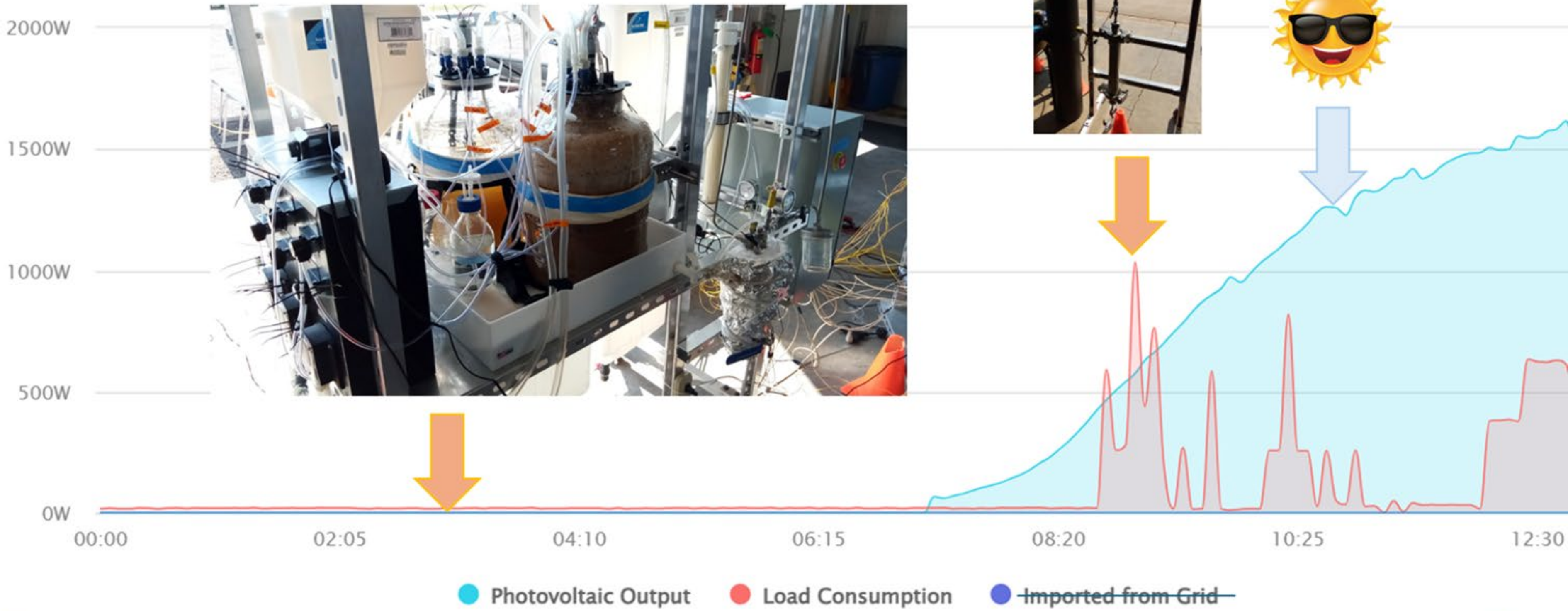
BREAD V1 (MTU) Open Source Hardware Enterprise
BREAD V2 (Western)
Inexpensive process control using open-source, plug-and-play electronics and 3D printed enclosures





Net Zero (Net Negative Electric Power)



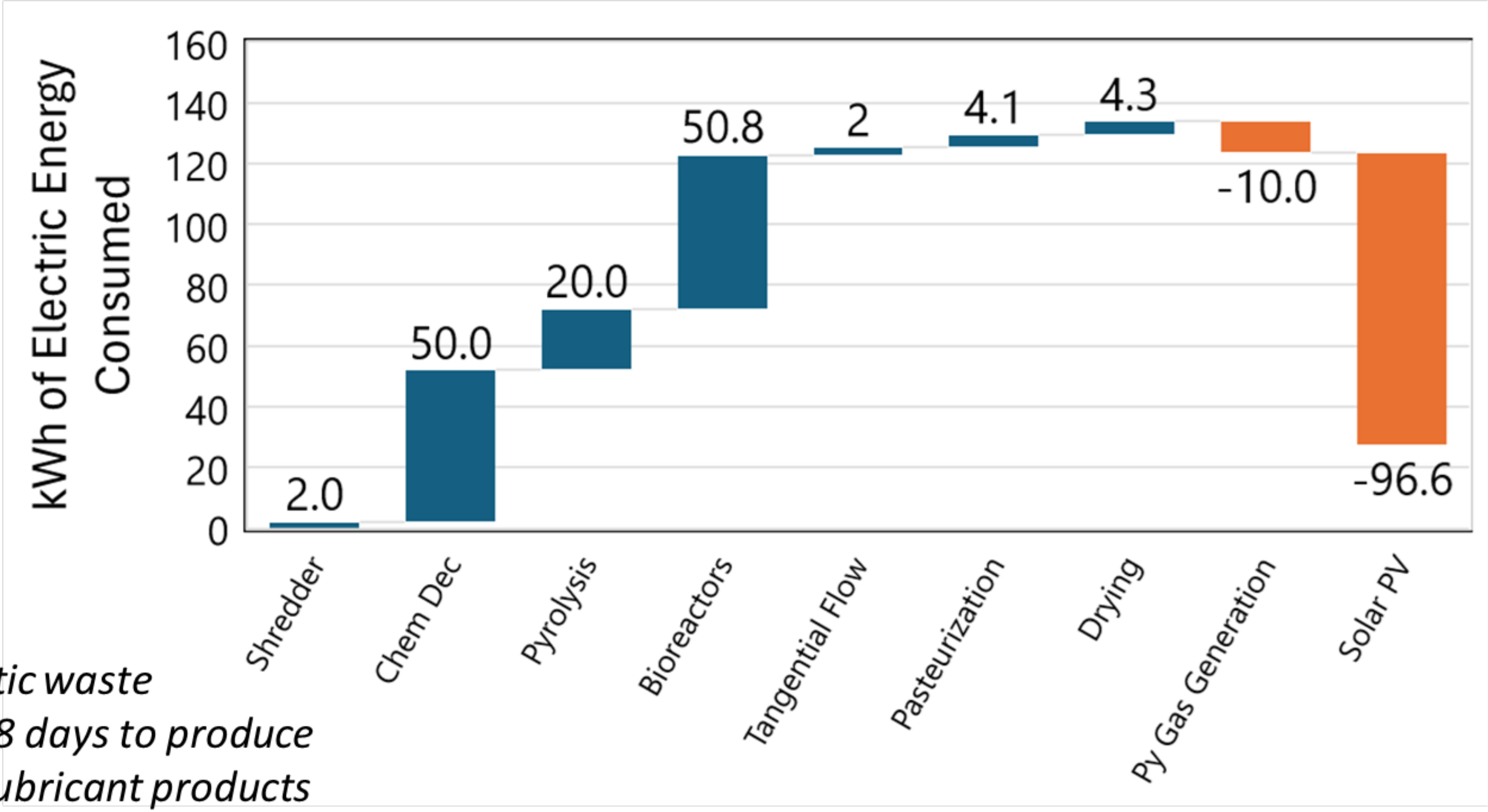


Western Engineering

Energy Balances

Net 27.1 kWh external power over 28 days,

0.97 kWh/day



10 kg mixed plastic waste processed over 28 days to produce 2.5 kg food and lubricant products

Summary / Conclusions / Future Developments

- Mobile process has been developed coupling thermochemical and biological conversions to process military mixed plastic waste

- Production of food, lubricants, and py gas for power displaces essential goods at **point-of-need** in remote settings.

- End of project performance metrics have been met for material capacity and energy consumption. Space and weight limits were exceeded.

- Future development of the technology should include safety testing of food product, scale up and demonstration at military installations.

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