Improved Microalgal Carbon Utilization Efficiency via integrated CO_2 Electro-conversion to Formate and Microalgal Sequestration

DE-FE0032186

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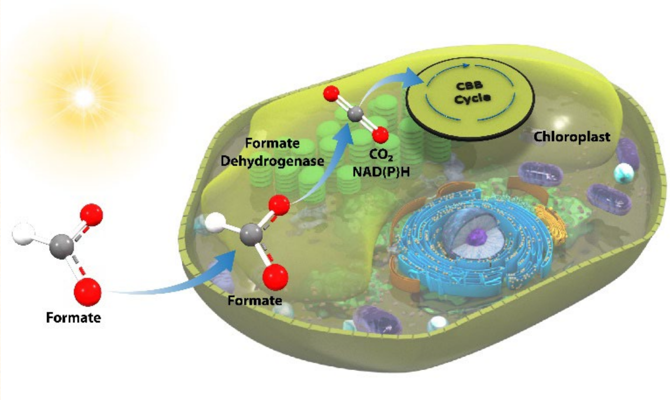
Formate as a carbon source for algae



Properties of formate/formic acid

- Easy to store
- High water solubility
- Enables conversion of electrical energy to cellular energy (i.e., reductant)
- Broadly toxic to many organisms,

Overview

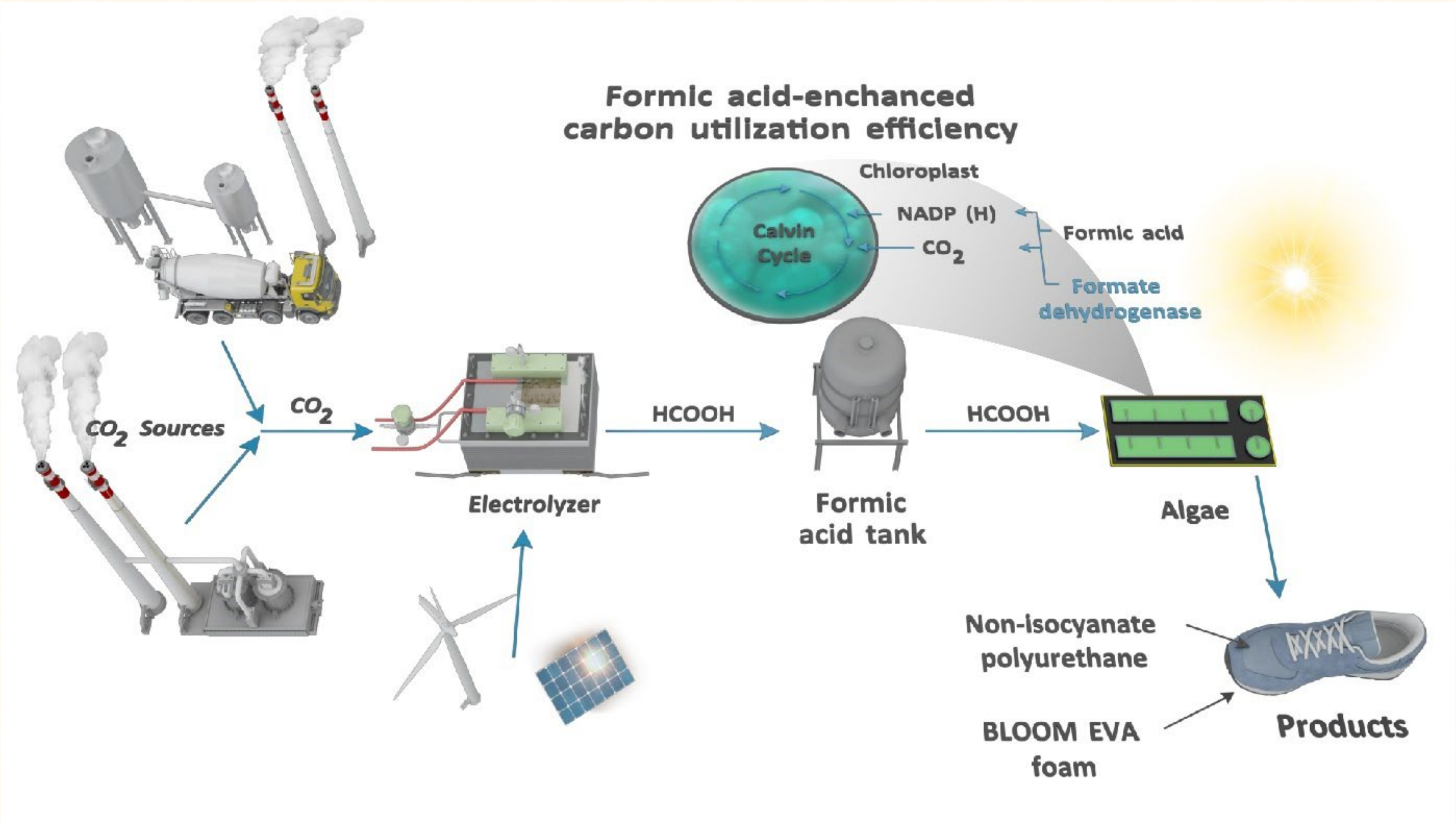
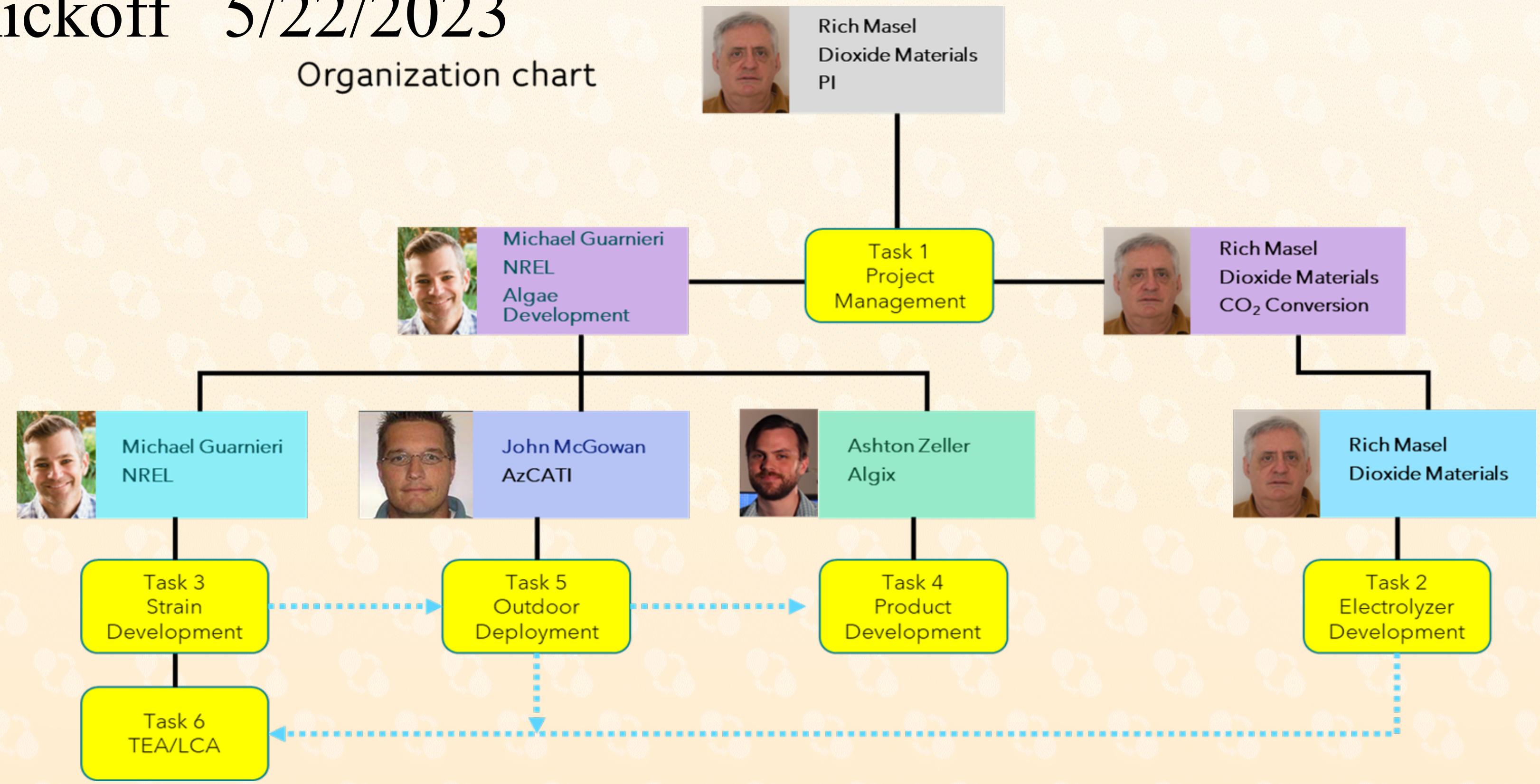


Figure from Josh Bauer and Lukas Dahlin, NREL.

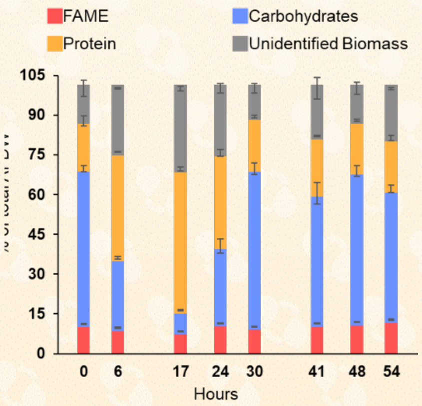
- Funding $2,000,000 (DOE) and ($500,000) Cost Share)
- 2/1/2023-1/31/2026
- Kickoff 5/22/2023

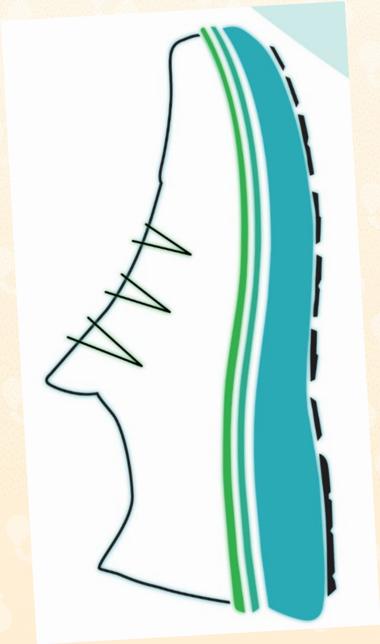
Organization chart



Technology Background

Dioxide Materials	NREL	AzCati	Algix
Formic Acid at a power plant	Algae Strain that can grow in formic acid	Existing Algae Ponds	Incorporate Algae in Polymers



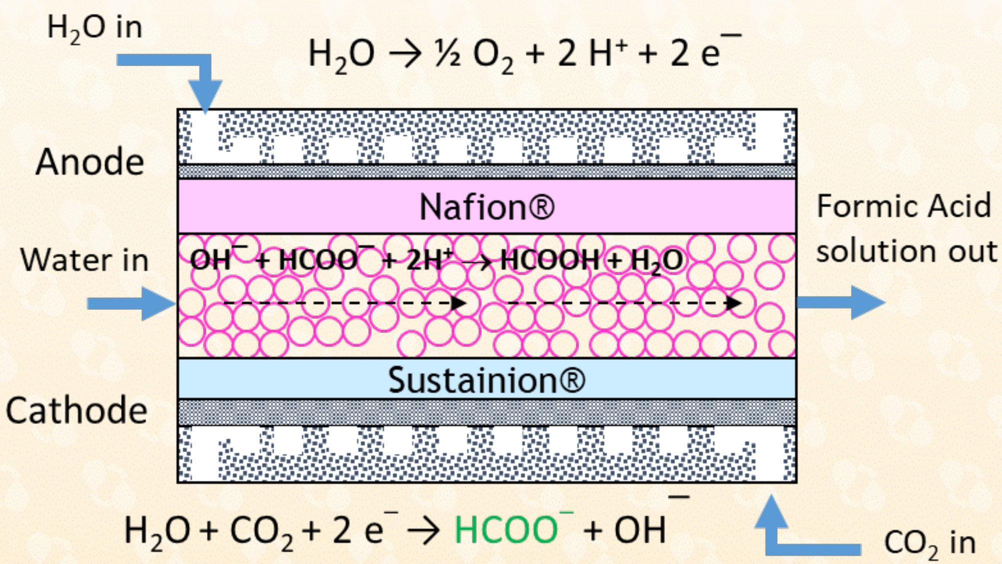


Goals Of The Program

- Electrolyzer 5 cm^2 ⇨ 1000 cm^2
- Productivity on Formate 1-5 $gm/m^2/day$ ⇨ >20 $gm/m^2/day$
- Pond carbon efficiency 30% ⇨ >50%
- Algae growth 250 mL ⇨ 1000 L pond
- Use products in Bloom EVA

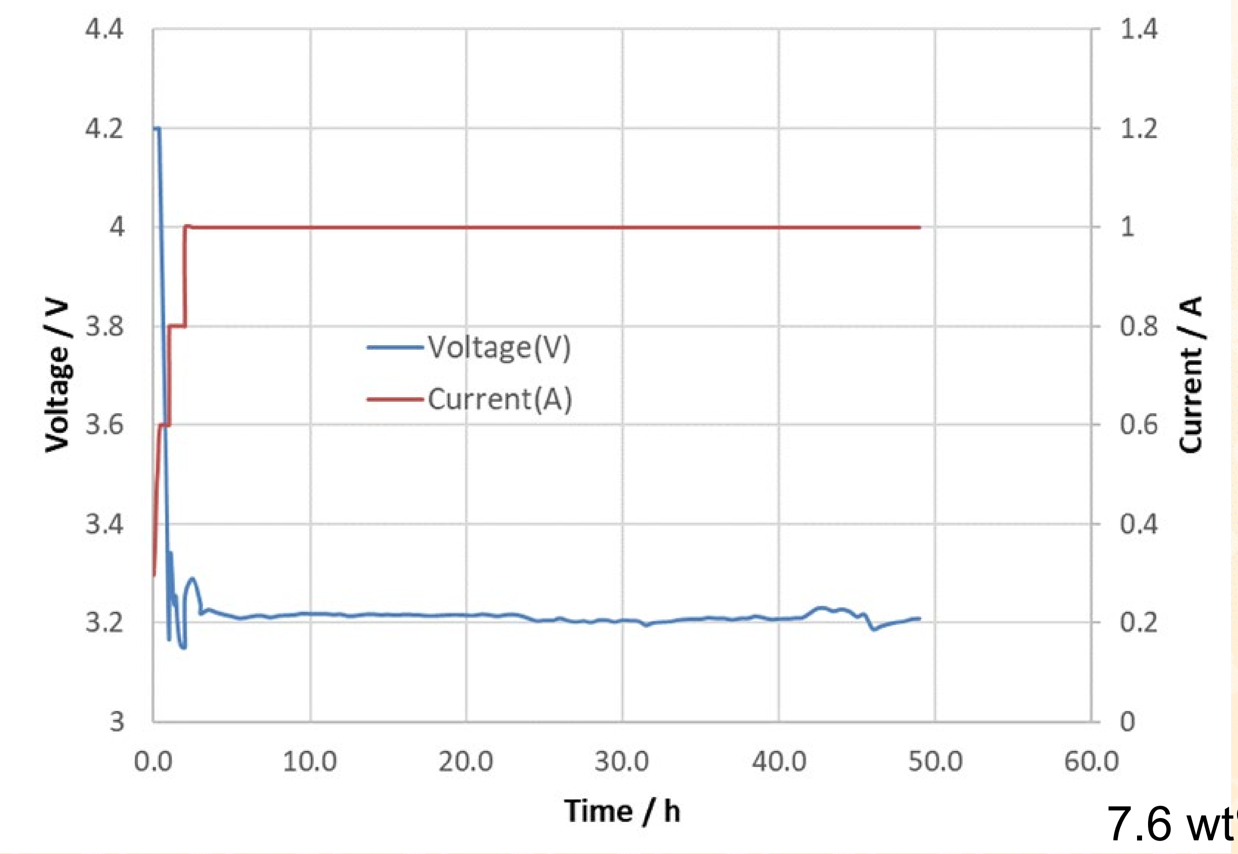
Technical Approach

- Formic acid electrolyzer scaling
  - New materials
  - Oxygen control
- Engineer *P. renovo*
  - Incorporate Formate Dehydrogenases
  - Adaptive lab evolution
- Test in indoor photoreactors (BP1) open ponds (BP2)



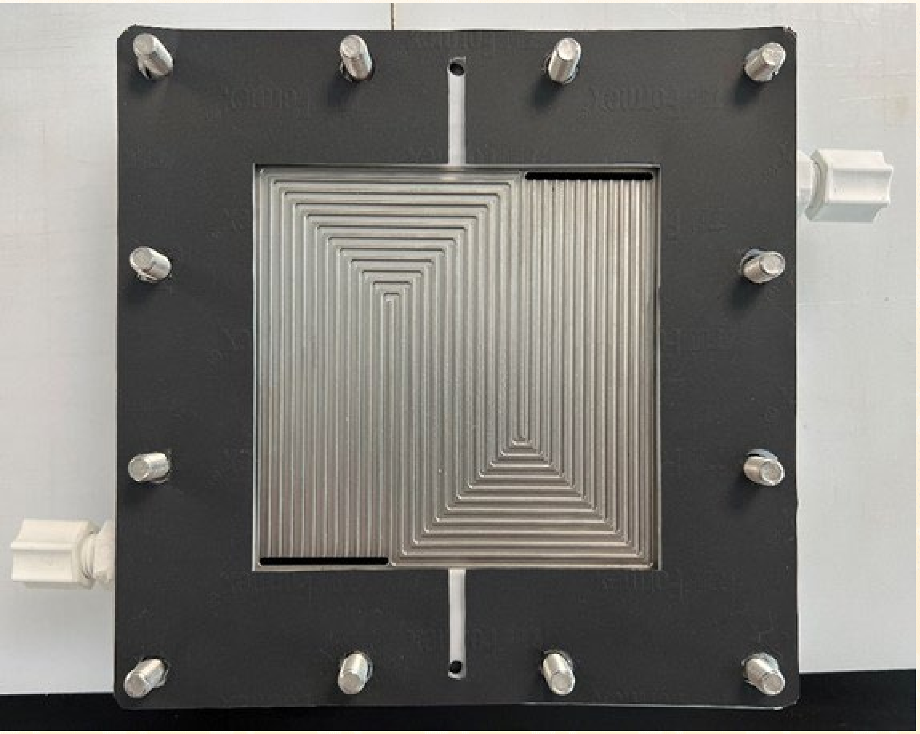
H2O in
H2O → ½ O2 + 2 H+ + 2 e–
Anode
Nafion®
Formic Acid solution out
Water in
OH– + HCOO– + 2H+ → HCOOH + H2O
Sustainion®
Cathode
H2O + CO2 + 2 e– → HCOO– + OH–
CO2 in

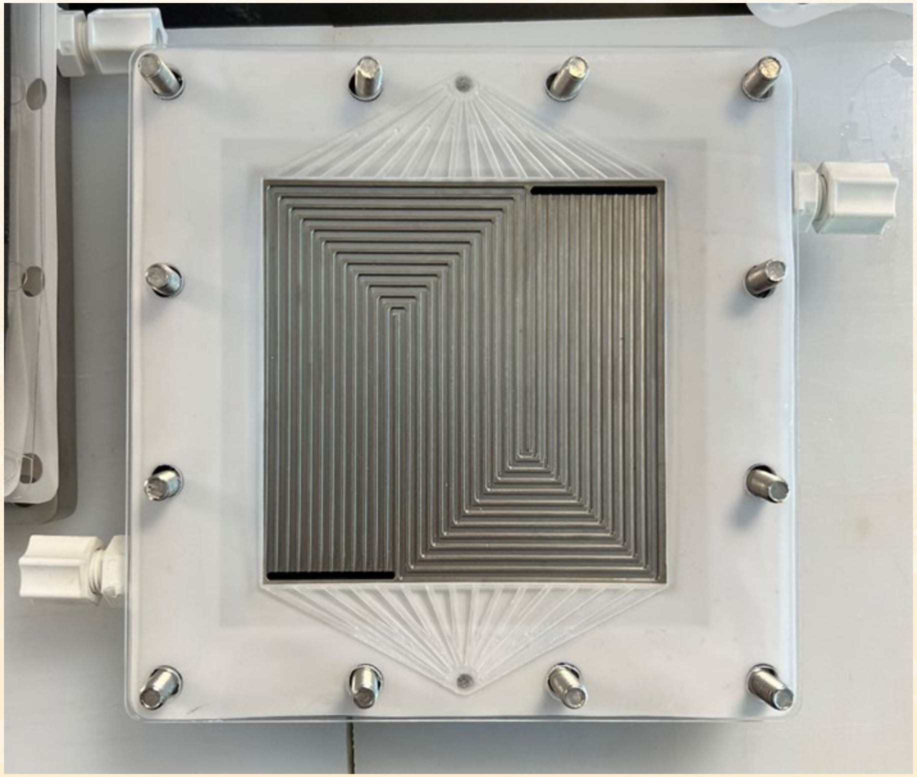
Task 2.1.1: Replace beads with solid structure & test in 5 cm² cell



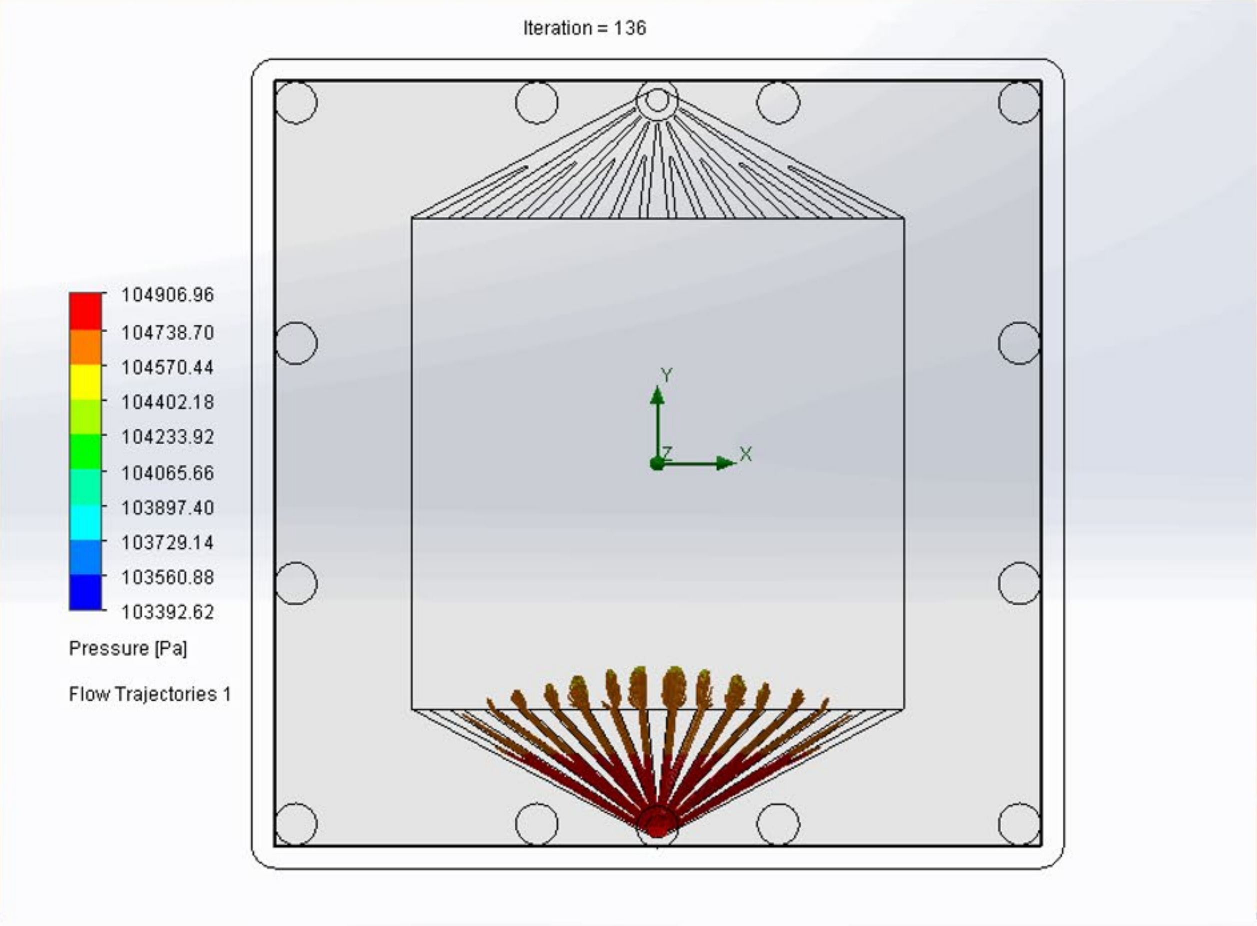
7.6 wt% FA with 64% FE

Task 2.1.2 Design 100 cm² cell

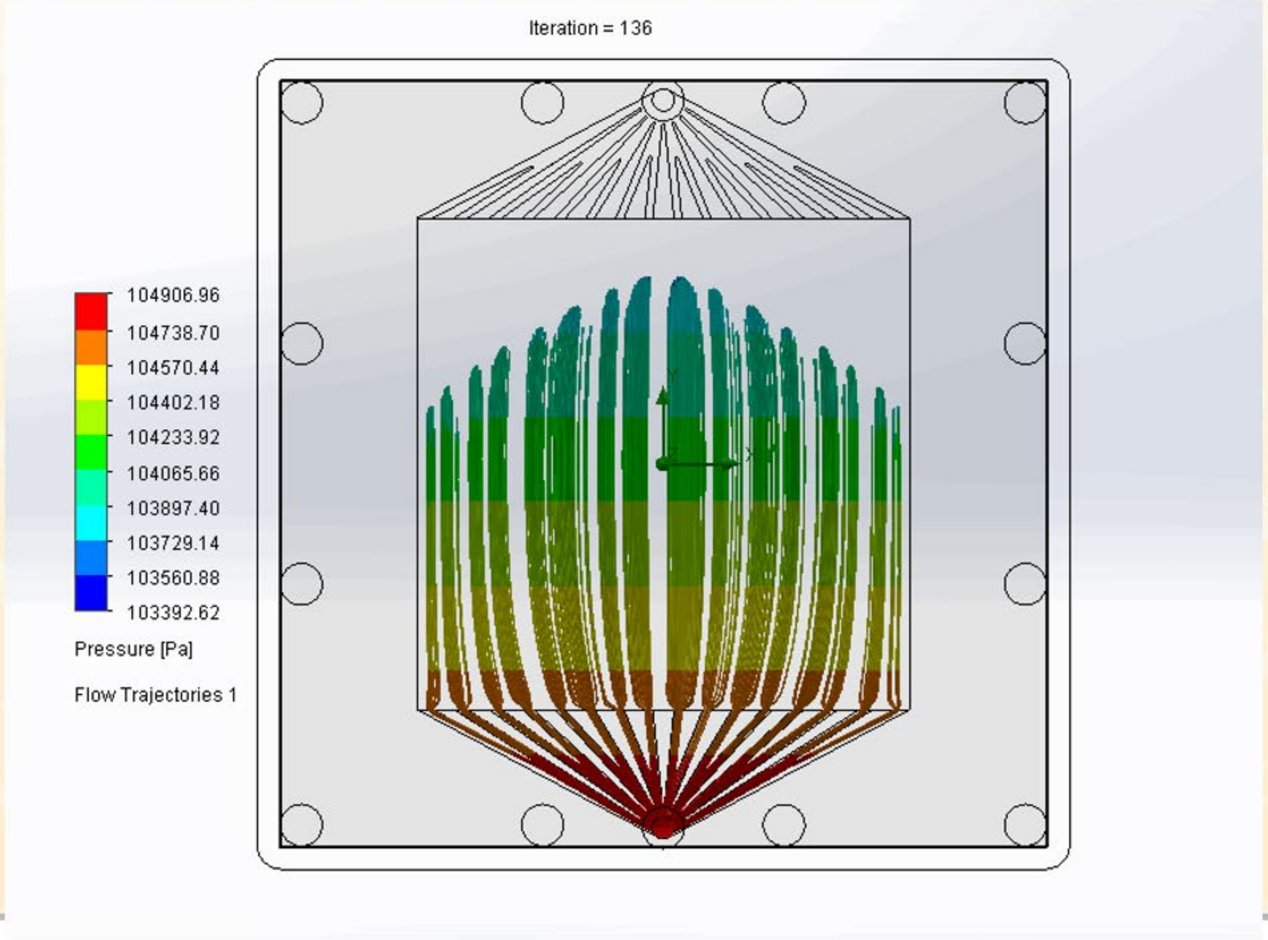




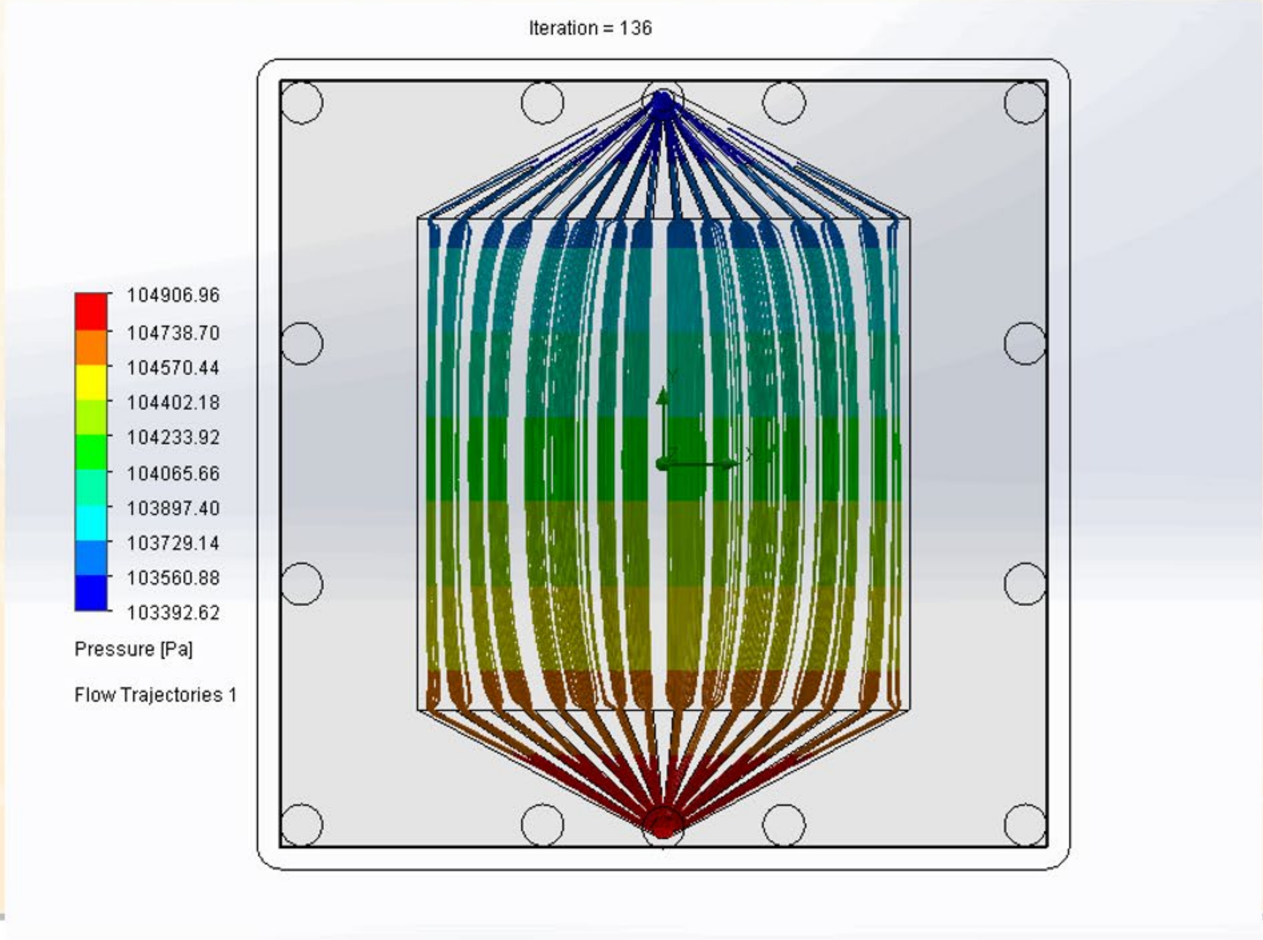
Simulate Flow Distribution



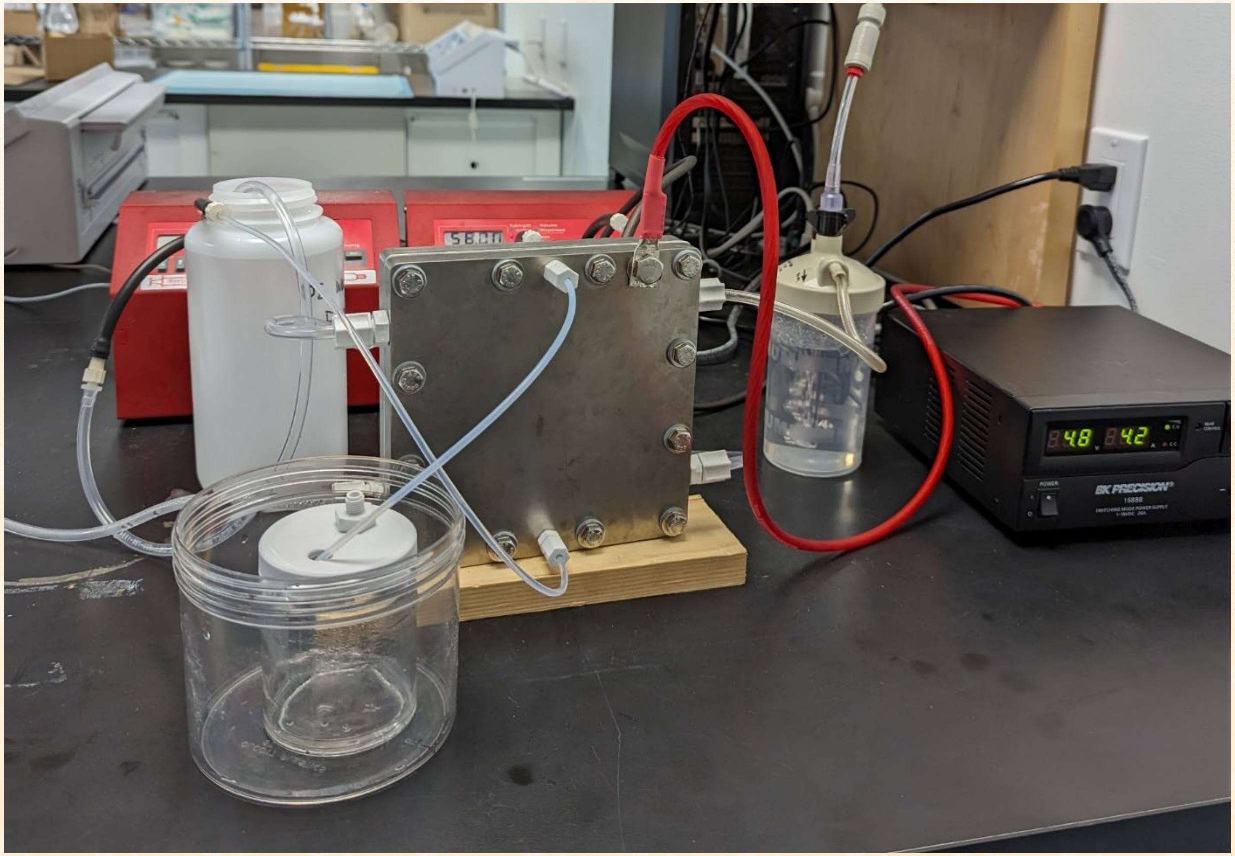
Simulate Flow Distribution



Simulate Flow Distribution

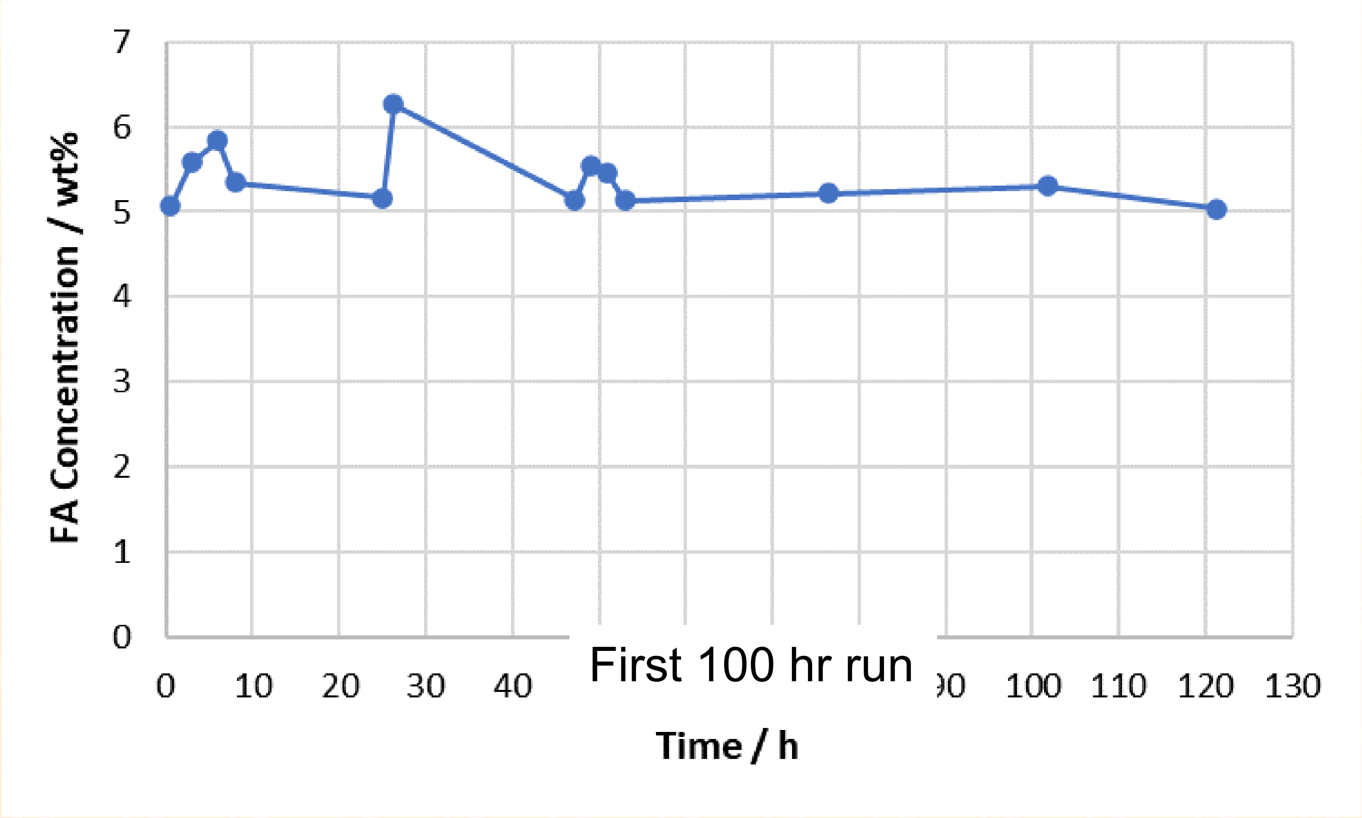


Picture Of Device



Milestones 1.1.2, 1.2.3, 5% formic acid from simulated blast furnace gas for ≥24 hours (Oct 2023), ≥ 100 hr (Jan 2024)

Simulated blast furnace gas: 25% CO, 30% CO_2, 3% H_2, ~~10 ppm of SOx~~ , N_2 bal.



Simulated power plant gas next - O_2 is a problem

Background: Strain Development`

- Wild type *P. renovo* intolerant to formate > 5 milli-molar
  - No growth on formate alone
- Need to express formate dehydrogenase (FDH) to enable growth
  - FDH from *Cupriavidus* or *Candida*

Results: Cassettes with different FDH's to identify formate tolerant strains

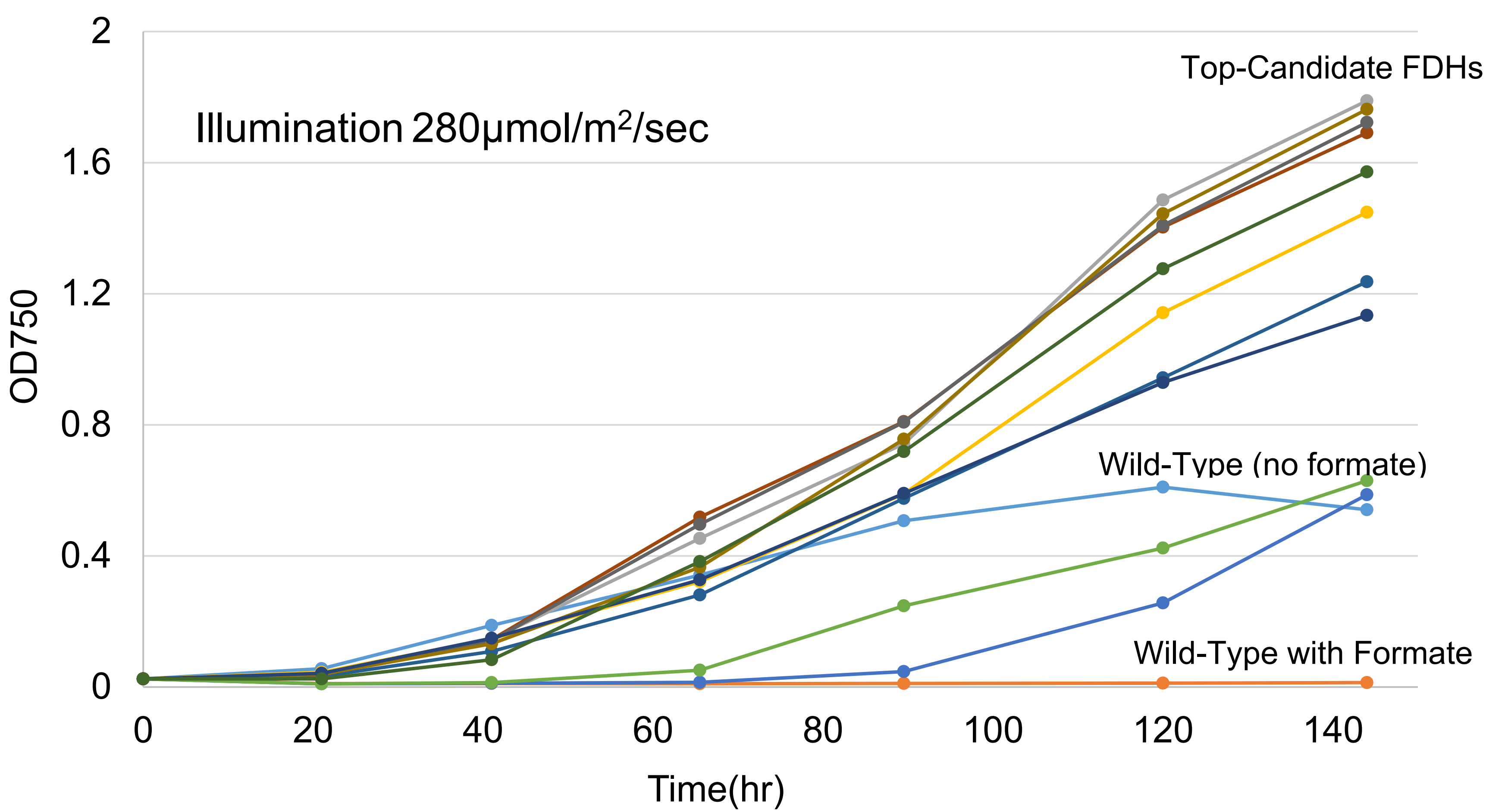
10 mM

25 mM

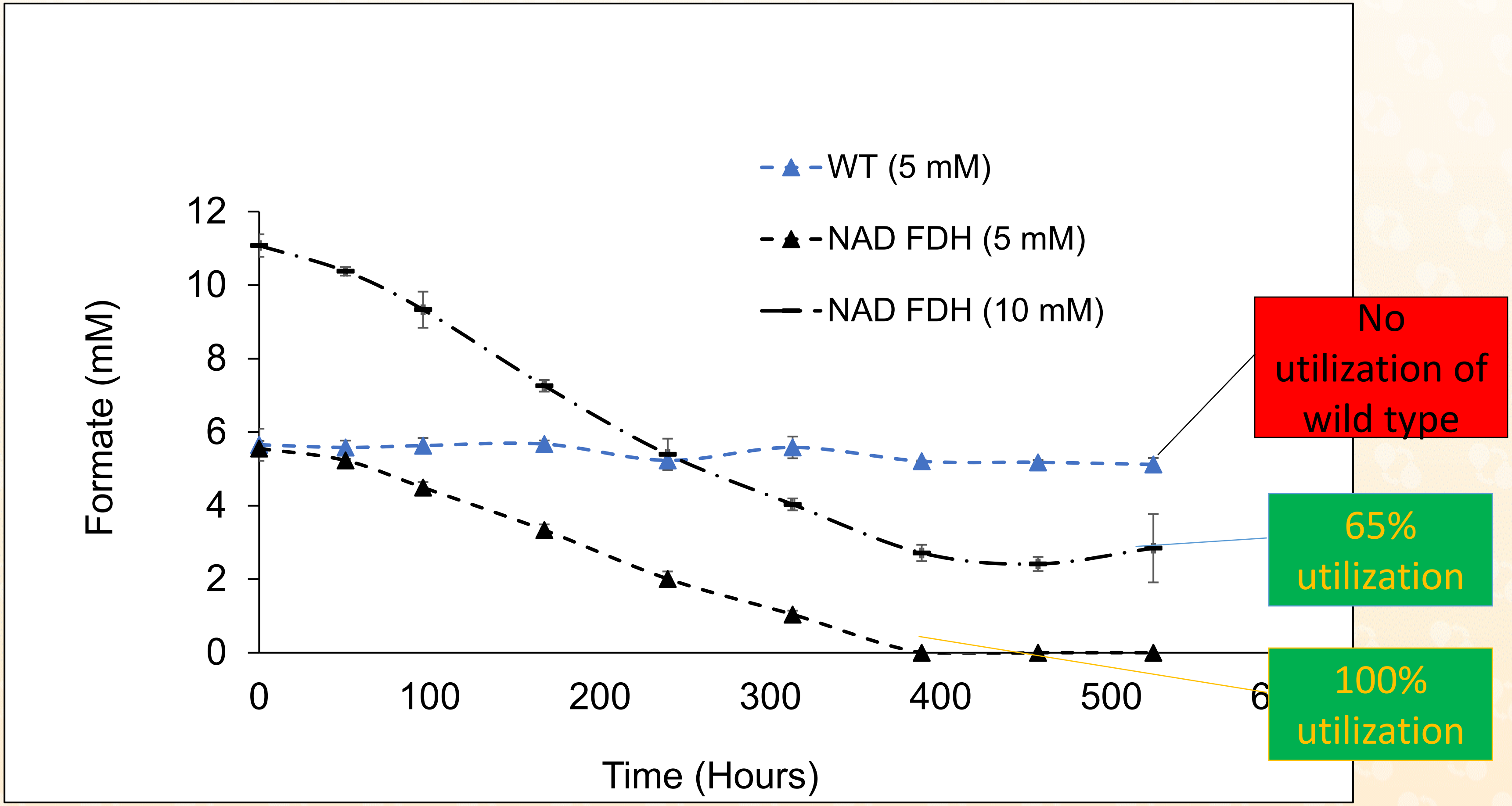
50 mM

75 mM

Results Growth on 10 mM formate



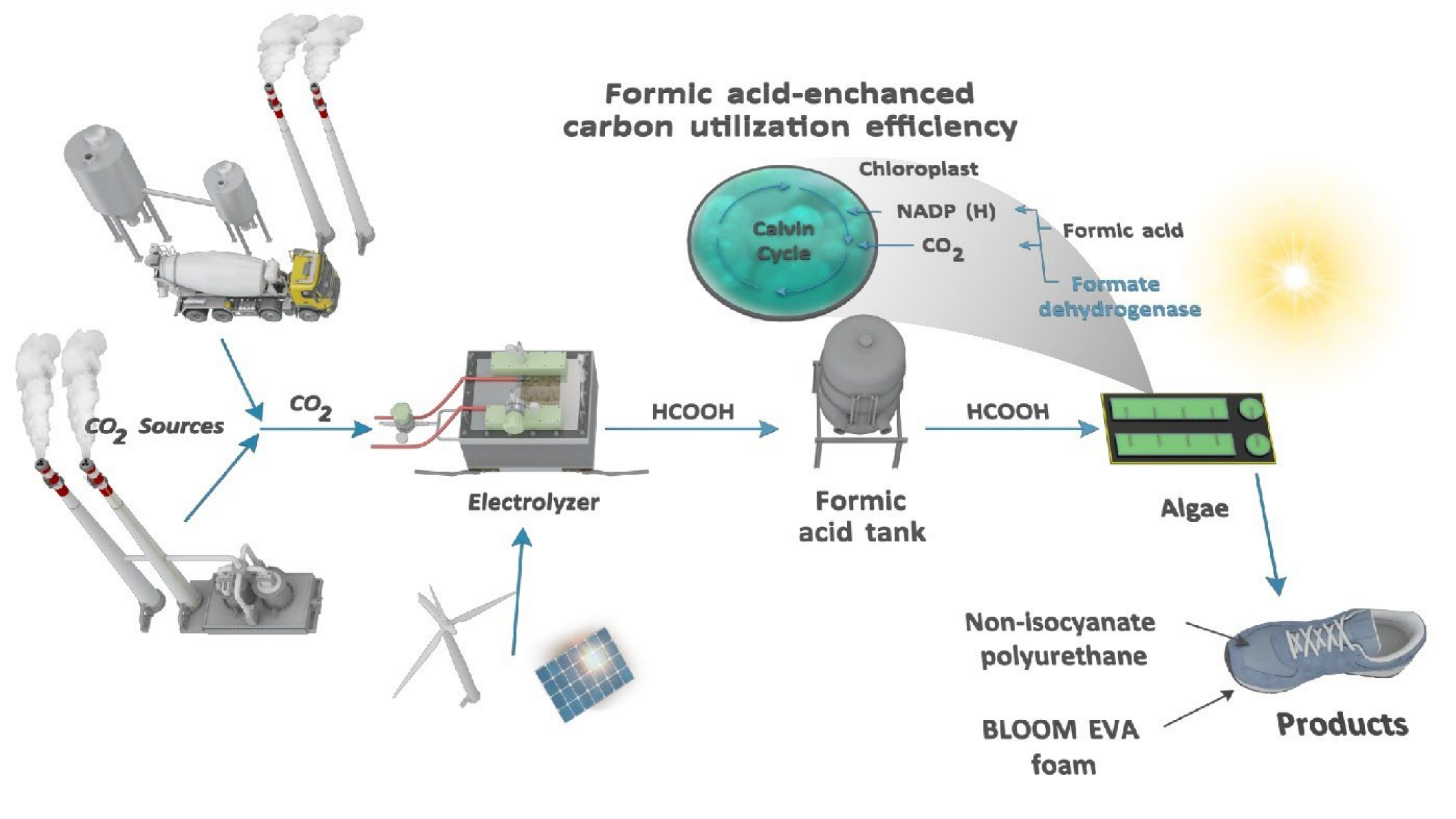
Milestone 2.1.1. March 2024 >50% formate utilization



Status Vs BP1 milestones

Item	Date
Revised Management Plan ✓	8-Mar-23 ✓
100 cm² cell designed ✓ and parts ordered✓	29-May-23 ✓
100 cm² electrolyzer producing 5% formic acid at ≥100 mA/cm² from simulated flue gas for ≥24 hrs ✓	04-Oct 23 ✓
100 cm² electrolyzer producing 5% formic acid at ≥100 mA/cm² from simulated flue gas for ≥100 hrs	04-Jan 24 ✓
Design, synthesize, and transform 5 formate dehydrogenase enzymes into P. renovo. Achieve >50% formate utilization	31-Mar 24 ✓
Acid pretreat biomass and quantify lipid class and fatty acid profile, utilize extant database to predict NIPU performance.	4-May 24
Generate 0.5 kg of biomass for downstream product testing	31-July 24
Utilize biomass composition to evaluate expected bioplastic conversion performance	31-July 24
100 cm² electrolyzer producing ≥5% formic acid from simulated flue gas at a current of ≥100 mA/cm² for ≥250 hours	31- July 24

Plans for future testing commercialization



Summary Slide

- Program moving forward
  - Demonstrated scaling of electrolyzer 20x
    - Active area from 5 cm^2 to 100 cm^2 (100 hr)
  - Demonstrated *P. renovo* strains that grow on formate (5x than previous)
    - outperform wild type on atmospheric CO_2, Illumination 280µmol/m^2/sec

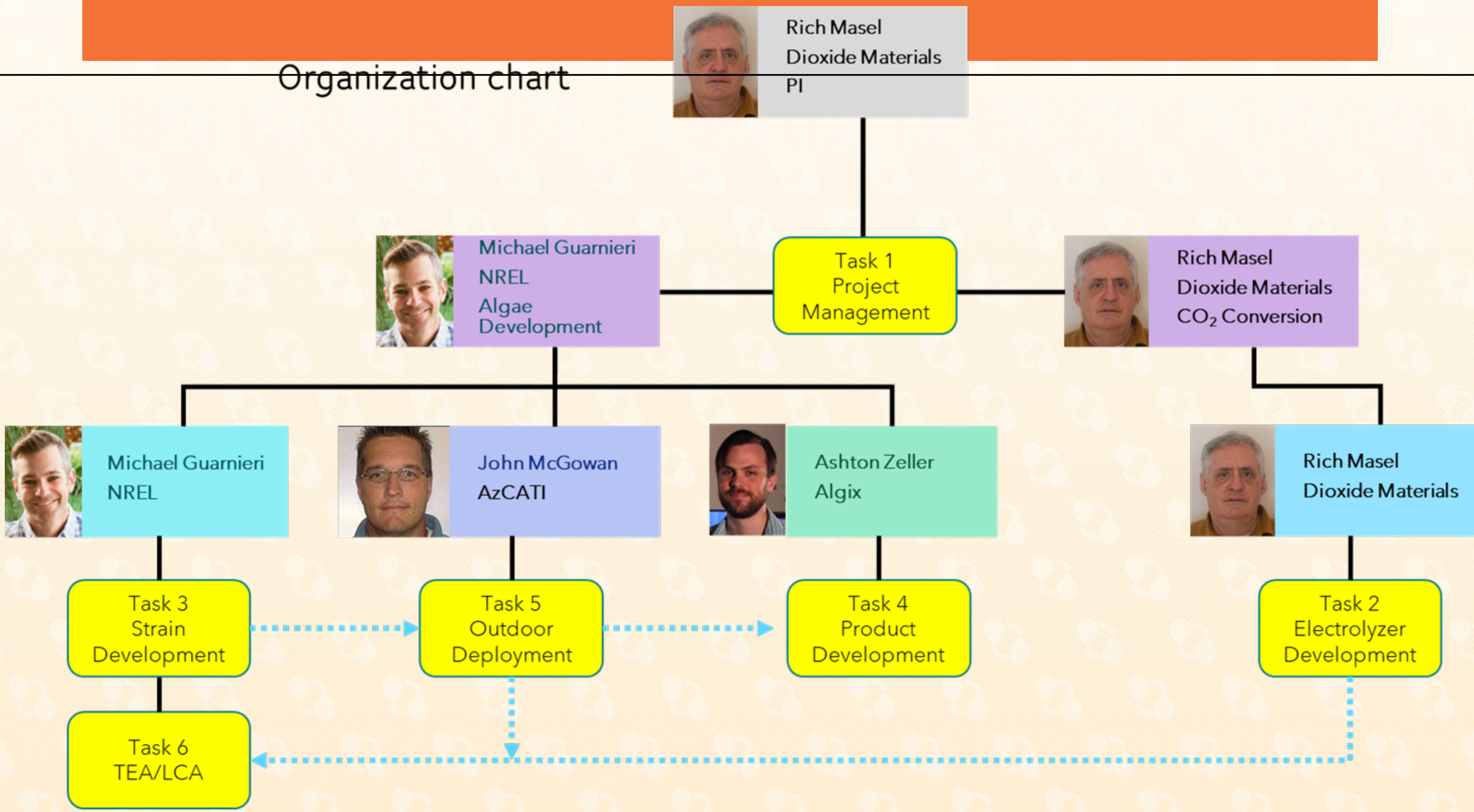
Acknowledgement

This work was supported by the department of energy under contract DE-FE0032186

Appendix

Organization Chart

Organization chart



Gantt Chart BP1

Project Lead: Dioxide Materilas

WBS	Task Name
1	**management**
1.1	PMP
1.2	kickoff
2	**Electrolyzer development**
2.1	**100 cm2 construction**
2.1.1	Design 100 cm2 cell
2.1.2	order cell
2.1.3	cell received
2.1.4	build and test BOP
2.2	**New center compartment**
2.2.1	Develop at least 5 possible center compartments
2.2.2	Test in 5 cm2 cell
2.2.3	5% at 200 mA/cm2 for 24 hours
2.3	**Testing 100 cm2 cell**
2.3.1	24 hour tests
2.3.2	5% formic acid for 24 hours
2.3.3	100 hour tests
2.3.4	5% formic acid for 100 hours with flue gas
2.3.5	250 hour tests
2.3.6	5% formic acid for 250 hours with flue gas
3	**Strain development**
3.1	Develop formate dehydrogenase variants
3.2	5 formate dehydrogenase variants
3.3	Generate unique algal strains
3.4	5 unique algal strains
3.5	characterize growth and uptake
3.6	strain down select
3.7	develop photobioreatcor
3.8	Photobioreactor approved and working
3.9	optimize performance
3.10	50% formate utilization
3.11	Best three strains
3.12	determine optimal growth conditions
3.13	Optimal growth conditions
4	**Cultivation and Outdoor Deployment**
4.1	Formic acid delivery to indoor photobioreactors
4.2	grow algae for testing
4.3	0.5 Kg of biomass produced
5	**Product development**
5.1	Characterize algal products
5.2	Algal products characterized