2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

9.1.3.2 Microalgal Harvesting/ Dewatering and Algae Feedstock Logistics

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Algae Platform

Deborah Newby, Ph.D.
Idaho National Laboratory

Goal Statement

To advance algal biofuel feasibility through:

- **Investigation of algal dewatering**
- **Consideration of post harvest stability**
- **Characterization of algae feedstock and its potential use in formulated feedstocks**

Establish algae as a sustainable high-impact feedstock

Quad Chart Overview

Timeline
Project Start Date: 10/01/10
Project End Date: 09/30/13
Percent Complete: 90%

Barriers
Ft-D: Sustainable Harvesting
Ft-B: Sustainable Production
Ft-N: Feedstock Processing

Budget
Total Project funding: $1.2M
DOE Share: 100% ($844K AARA)
Funding for FY12: $422K
Funding for FY13: $350K

Partners/Collaborators
Utah State University (Algal Growth)
OriginOil (CRADA)

Project Overview

Objectives:

- Analytically assess cross-flow membrane technology to assess applicability to algal harvesting
- Characterize algae feedstock including post harvest stability
- Examine the use of algae as a component of blended feedstocks

Outcomes:

- Provide methods to overcome key barriers to algal harvest and stability
- Use stability analyses to inform decisions on algal feedstock logistics
- Advance algae as a sustainable high-impact feedstock in the near term through insertion into terrestrial biomass supply chain

1 - Approach

- Parametrically test embedded membrane cross-flow filtration to determine applicability to algae dewatering

- Flux and cost estimates (go/no go)

- Investigate post harvest stability

- Characterize algae feedstock

- Assess potential for use of algae in formulated feedstocks

Enhanced flux, erosion resistant membranes for biomass separations — Part I

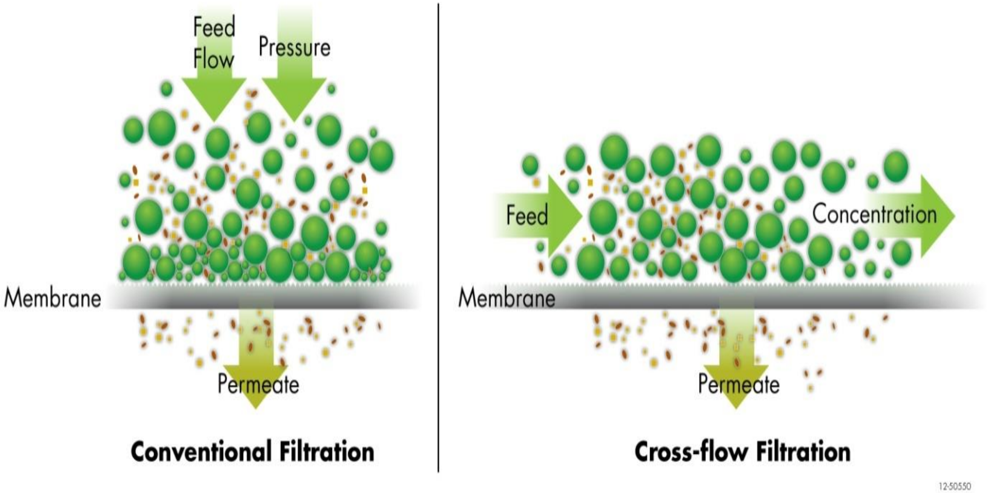
Enhanced flux, erosion resistant membranes for biomass separations — Part II

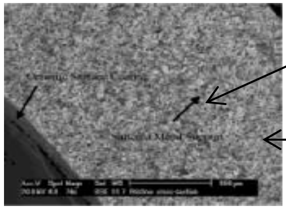
Membrane Technology Newsletter, November and December 2004

2 - Technical Accomplishments

Parameters

- Pore size
- % ceramic
- Transmembrane pressure
- Nitrogen back flush
- Strains and mixed populations





Embedded ceramic-SS frit interface

Open SS frit – no ceramic embedded

Ceramic embedded into stainless steel support

2 - Technical Accomplishments/Progress/ Results (cont'd)

Flux rates of multiple species of algae (0.5 g/L)

Algal Species	Flux Rate [L/(m²-h)]			
Hours	0.5 hr	1 hr	2 hr	5 hr
C. gracilis	216	162	124	94
S. dimorphus	590	436	356	208
***Chlorella* (USU 80)**	114	119	143	134
P. typicum	164	163	132	110

- **In all of the conditions tested permeation flux values are over 90 L/(m^2-h)**
- **For industrial processes using CFF it has been suggested that 30-40 L/(m^2-h) are considered acceptable**

  Rose et al., *Cross-Flow Ultrafiltration Used in Algal High Rate Oxidation Pond Treatment of Saline Organic Effluents with the Recovery of Products of Value.* Water Science & Technology, 1992. **25**(10): p. 8.

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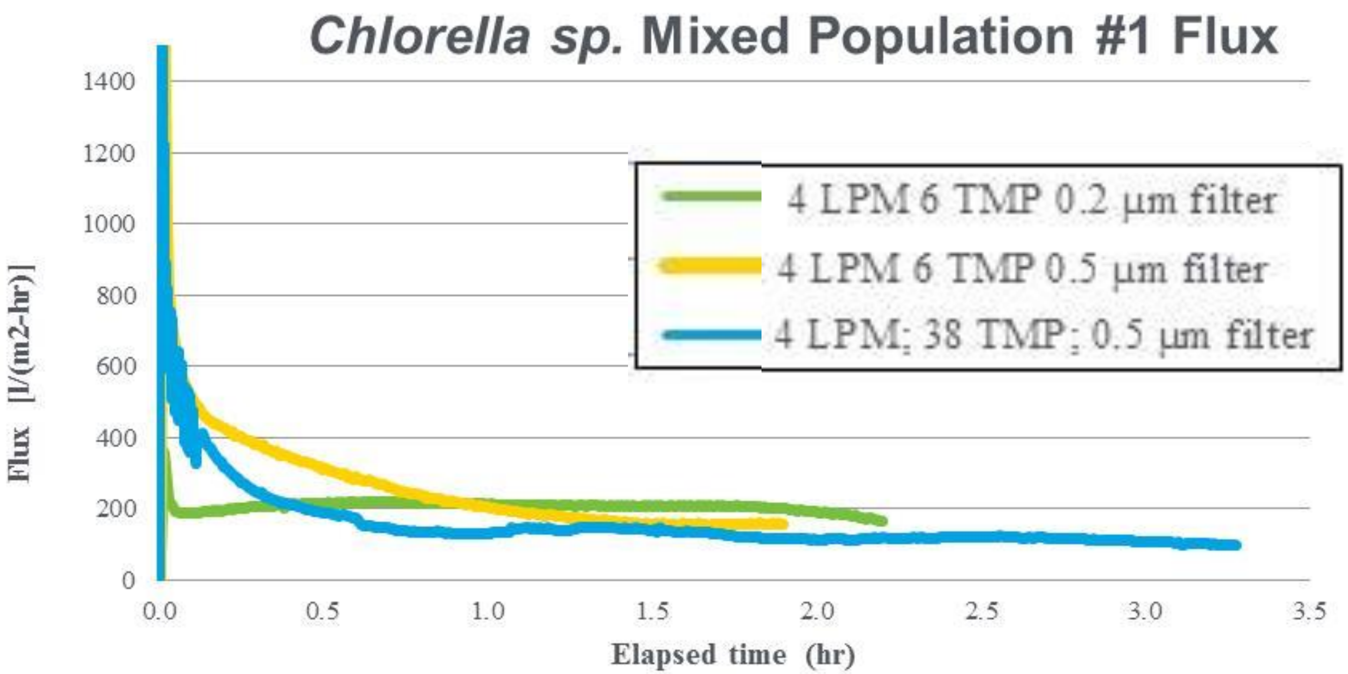
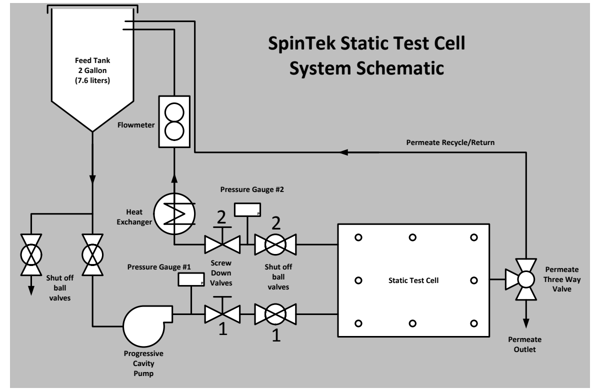
2 - Technical Accomplishments/Progress/ Results (cont'd)



Mixed population = pond surrogate

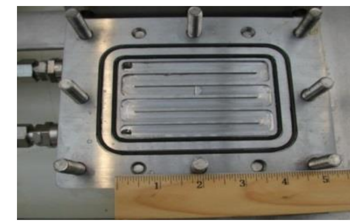
Flux rate ~150 L/(m^2-h)

2 - Technical Accomplishments/Progress/ Results (cont'd)

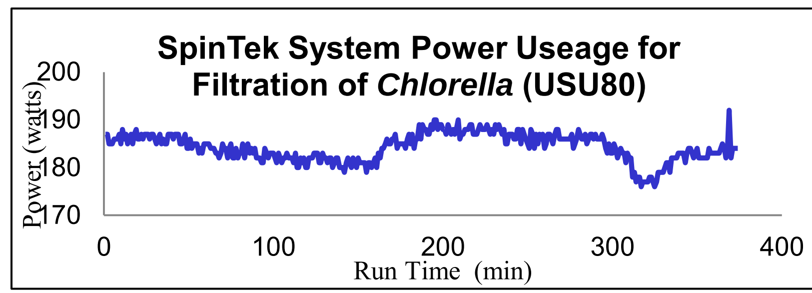


0.00465 m^2

0.185 kwh



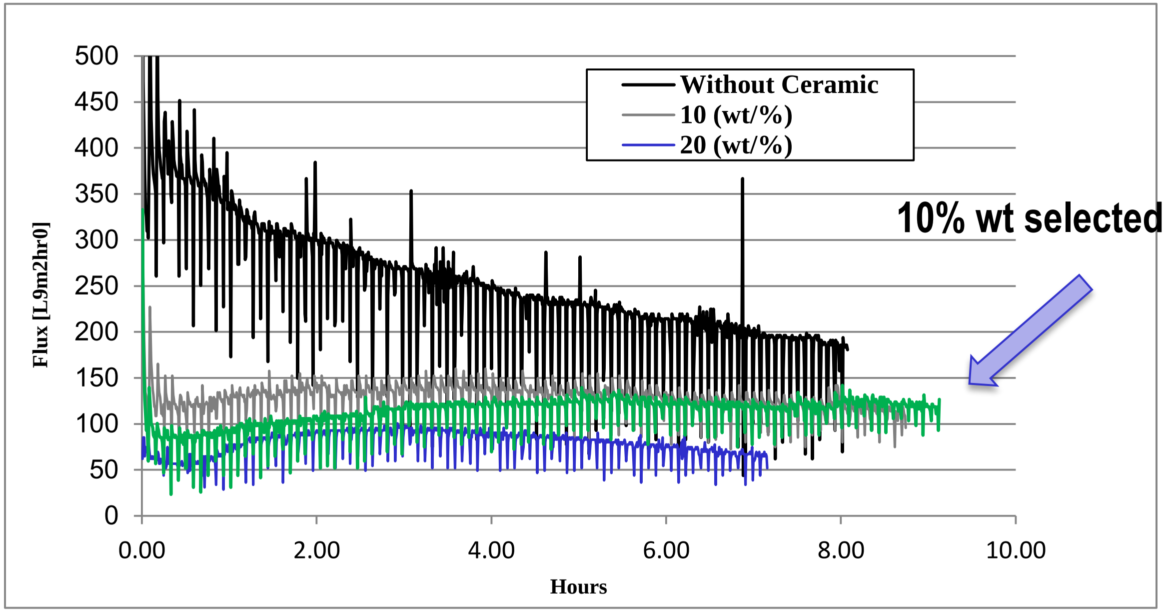
- **CFF scales linearly**
- **Costs go down with addition of additional units**
- **Harvesting rate of 1000 L/hr is achievable**



Time to produce 100ml	Time to produce 1000ml or 1L	Time to produce 1000L or 1m3	Time to produce 1000L or 1m3	Multiply by 0.185 to get:	Flux (expt'l)
(min)	(min)	(min)	(hr)	(kwh)	[l/(m^2-hr)]
0.1	1	1000	17	3	12903
1	10	10000	167	31	1290

2 - Technical Accomplishments/Progress/ Results (cont'd)

Impact of Ceramic Loading on Filtration



10% wt selected for additional analyses

- Native membranes' flux rate decreased in a nearly linear fashion
- Embedded membranes provided constant flux over the course of the test period.

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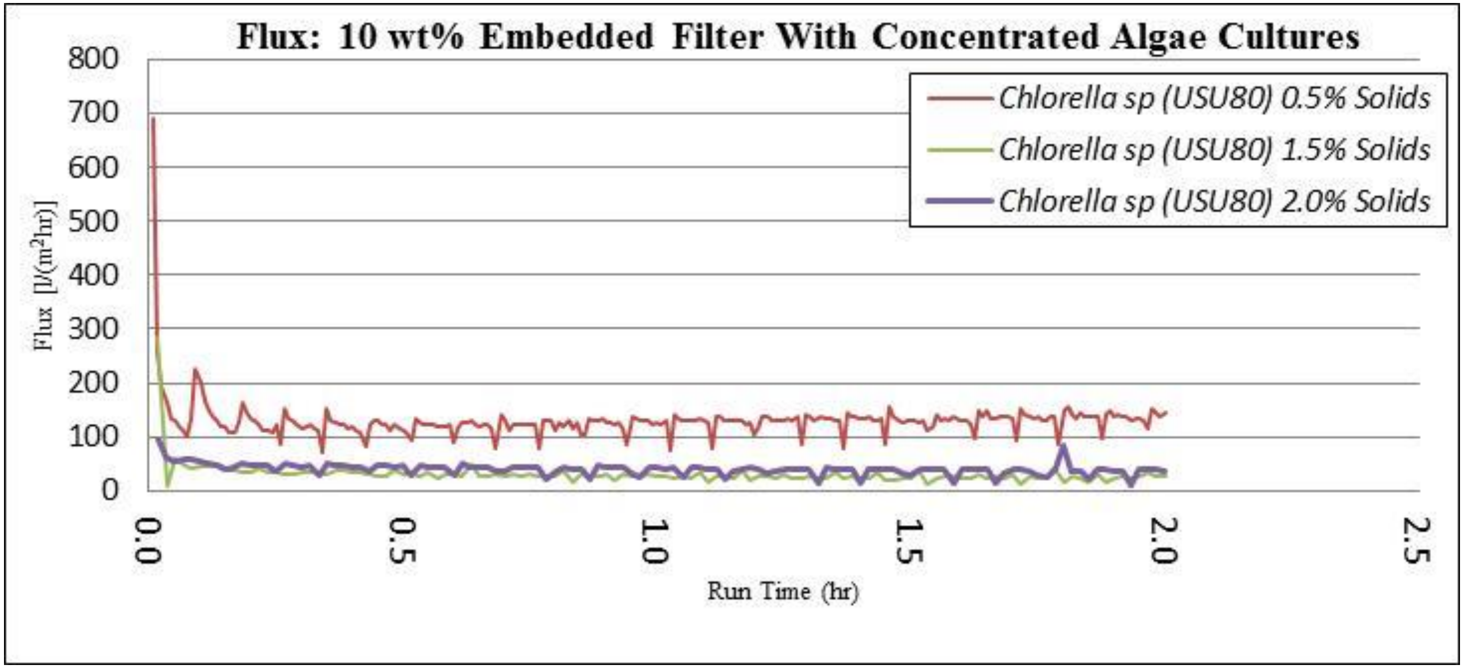
2 - Technical Accomplishments/Progress/ Results (cont'd)



- Starting concentration influences membrane performance over time
- % solids influences fluid properties
- Lower concentration, higher sustained flux

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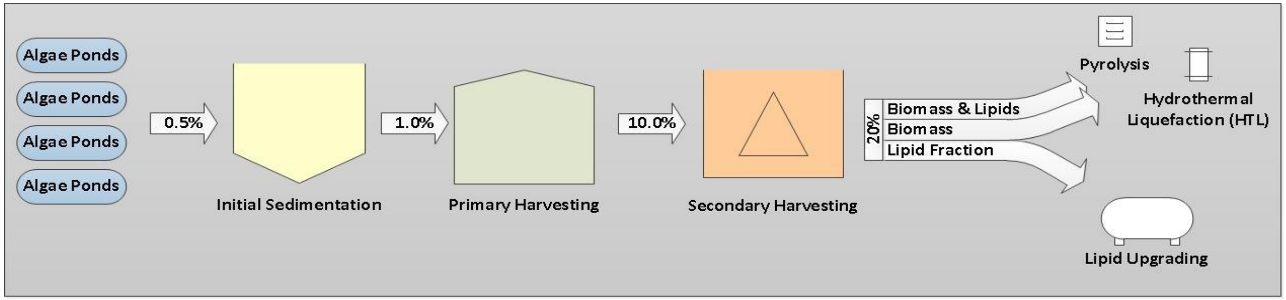
2 - Technical Accomplishments/Progress/ Results (cont'd)

Applicability of embedded membrane cross-flow filtration

- Flux rates exceed threshold for industrial applications
- Higher flux maintained with lower initial concentration
  - Pond water to roughly <5% solids
  - Algal biomass capture and clarification of water for recycle (final dewatering step)



Typical process flow diagram for algal dewatering

8% solids

2 - Technical Accomplishments/Progress/ Results (cont'd)

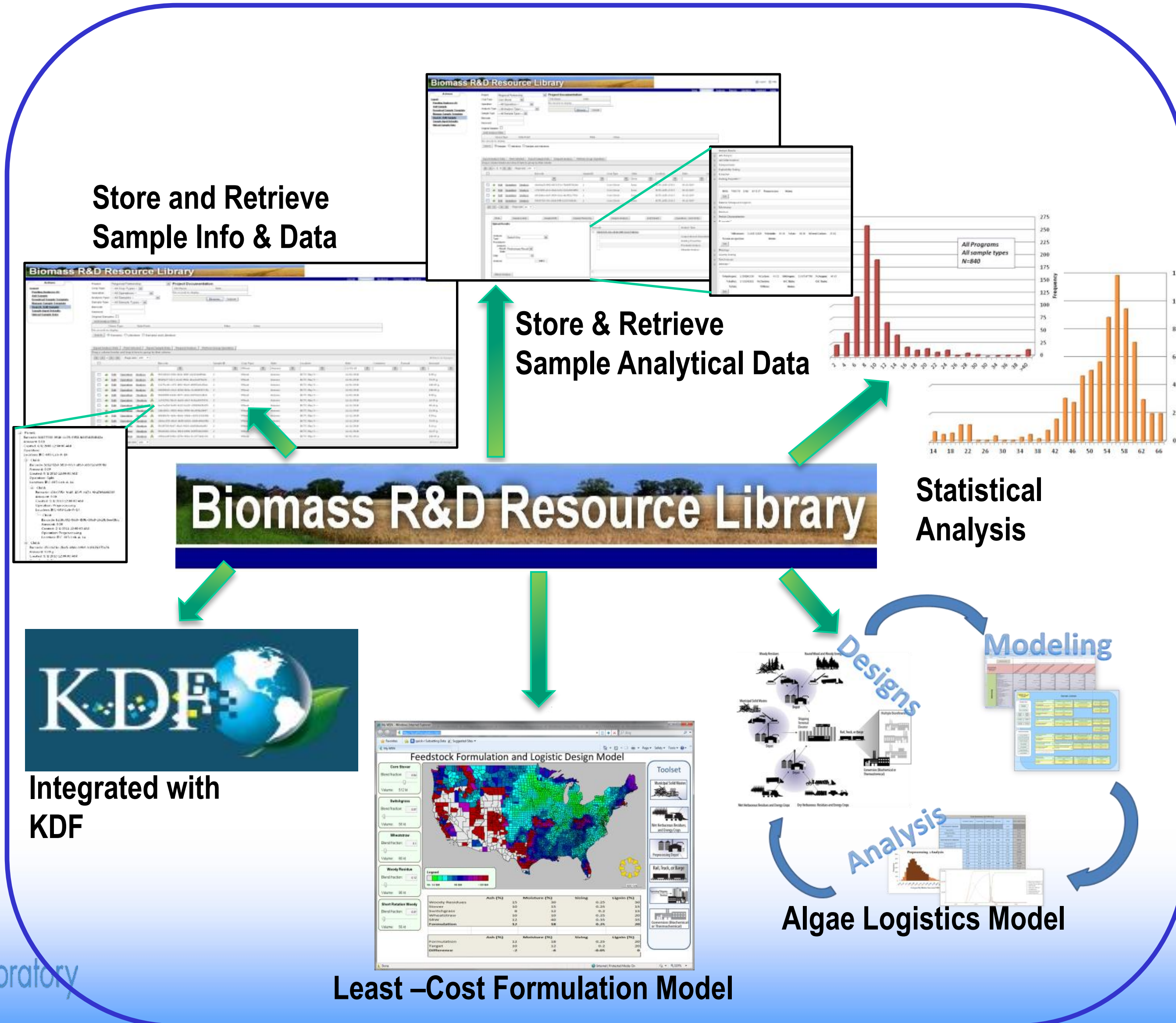
Post harvest stability and feedstock characterization are critical elements in algae feedstock logistics

- What do you do with excess biomass when production exceeds processing capacity?
- How long can you store algae before processing?
- What are the relationships between conversion pathway and stability?

- Initiated post harvest stability investigation
  - Dialogue with NREL on algal characterization and identification of synergies (LAPs)
  - Extension of Biomass Library
  - Lipid stability (literature search)

2 - Technical Accomplishments/Progress/ Results (cont'd)

- Store, track & retrieve sample information, logistical & analytical data
- Utilizes sample hierarchy to track and retain sample history
- Incorporation of analytics toolset
- Incorporated algal feedstock parameters to facilitate entry of algal biomass samples
- Expanded to include characterization data for include algal biomass



2 - Technical Accomplishments/Progress/ Results (cont'd)

Key Milestones/Deliverables	Due Date	Status
Complete literature review assessment of impact of moisture on lipid stability and provide report	6/30/11	Completed
Project Summary Report: Cross-flow filtration of multiple algal strains and mixed populations using embedded membranes (INL/EXT-13-28828)	9/30/12	Completed
Extend Biomass Library to include algal feedstock characteristics	12/31/12	Completed
Identify pathway and methodology for integrating algae with terrestrial biomass feedstock supply system	12/31/12	Upcoming

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3 - Relevance

Addresses Key Barriers

Ft-D: Sustainable Harvesting

Ft-B: Sustainable Production

Ft-N: Feedstock Processing

Technology/research Benefits

- Chemical-free dewatering , sustainability
- Feedstock stability drives design decisions (capacity, storage, depot, conversion pathways, etc)
- Feedstock characterization (BETO FY14)
- Feedstock upgrading/blending (BETO FY14)
- Cost reduction through improved algal logistics
- Supports MYPP 2022 goal of maximizing the production of biofuels

Establish algae as a sustainable high-impact feedstock

4 –Future Work

- **Post harvest stability**
  - Drives design decisions (capacity, processing, storage, depot, pathways, etc.)
  - Primary (algae) and secondary metabolism (co-cultures)
  - Chemical

- **Feedstock characterization**
  - Implement NREL LAPs
  - Continue to populate Biomass Library

- **Formulated feedstocks**
  - Hypothesize that proteins will denature with pressure and heat, form new bonds and structures with lipids and starches, serve as natural binders, strengthen pellets, increase BTU
  - Makes inefficient lipid extraction, and large and small-scale algae farms viable
  - Provides an access point for algae biomass utilization today, enabling algae to contribute to the $3/gallon goal immediately

4 –Future Work

- Use/develop analytical methods to understand post-harvest stability of algae
- Investigate impact of stability on storage, handling, logistics, blend, etc
- Explore algal biomass as a natural binding agent in densification
- Attempt to identify specifications that will facilitate blending of algal and terrestrial biomass to create high value formulated feedstocks
- Continue to populate the Biomass Library with characterized algal biomass

4 –Future Work

CRADA with OriginOil will be leveraged to provide biomass in support of algae feedstock characterization and stability studies

Alternative Dewatering Technology
- **Electrofloccculation**
- **Chemical free dewatering capability**
- **High processing capacity**
- **Large bioreactors provided to INL**

4 - Critical Success Factors

- **Success factors:**
  - Embedded membranes need further testing in the real world-open ponds configurations including testing at scale and comparison to embedded tubular membranes
  - Leverage NREL developed characterization protocols (synergies) to efficiently inform Biomass Library
  - Demonstration of upgrading of low-quality through algal formulation
  - Impact of feedstock stability on overall logistics (processing, capacity, storage, depot, etc.)

- **Potential challenges:**
  - Access to broad range of algal biomass and characterization data (NAABB and ATP3)
  - Complexity and uncertainty of algal feedstock characterization

- **Advancing the State of Technology:**
  - Paradigm shift to algae as a component of a formulated feedstock
  - Makes inefficient lipid extraction, and large and small-scale algae farms viable

Summary

- **While limited in scale, embedded membrane CFF shows promise with flux values are over 90 L/(m^2-h) across multiple strains** (literature suggests 30-40 L/(m^2-h) are considered acceptable)
- **CFF application best for initial concentrations of <5% solids**
- **Expanded growth and dewatering capabilities through CRADA**
- **Post harvest stability and feedstock characterizations are critical in developing optimized algal biofuel logistics (processing, capacity, storage, depot, etc.)**
- **Use of algae in formulated feedstock provides an access point for algae biomass utilization today, enabling algae to contribute to the $3/gallon goal immediately**

Acknowledgements

- Eric Peterson (INL)
- Dan Stevens
- Mark Stone
- Lance Seefeldt (USU)
- Jason Quinn
- Alex Leshnick (OriginOIl)

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Additional Slides

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Responses to Previous Reviewers' Comments

- Literature referenced suggesting flux rates reasonable for dewatering if scaled appropriately
- Mixed populations were added in addition to pure strains as they are better surrogates for pond cultures

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Publications and Presentations

- **D.M. Stevens, M.L. Stone, K.D. Schaller, E.S. Peterson, D.T. Newby. 2012. Defining the solution space of cross flow filtration for algal harvesting. Poster presentation (P2.41), 2nd International Conference on Algal Biomass, Biofuels, and Bioproducts, June 2012, San Diego, CA.**
- **Cross-flow filtration of multiple algal strains and mixed populations using embedded membranes. D.M. Stevens, M.L. Stone, E.S. Peterson, and D.T. Newby, INL/EXT-13-28828.**