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DISCOVR PROJECT
BETO PEER REVIEW

U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) 2017 Project Peer Review

Algae DISCOVR Project: Development of Integrated Screening, Cultivar Optimization, and Validation Research

March 7, 2017
Advanced Algal Systems

Michael Huesemann, PI
PNNL / LANL / SNL / NREL

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The Microalgae Biofuels Challenge

- **Reduce** total microalgae **biofuels production costs** to **$3/GGE** by 2030 with or without **co-products** (MYPP 2016)
- **Double** 2016 BETO State of Technology (**SOT**) **Biomass Productivities** by 2020 (based on recent PEAK FOA)

Table 1: Current BETO SOT and PEAK FOA Productivity Performance Targets

Season	2016 BETO SOT ($g/m^2/day$), ash free basis	2020 PEAK Performance Target ($g/m^2/day$)
Spring	11.1 *(Nanno)*	22
Summer	13.3 (*Desmo*)	26
Fall	7.0 (*Desmo*)	14
Winter	5 *(Nanno)*	10
Annual average	9.1	18
**Nanno* refers to *Nannochloropsis maritima KA32* (saline media) and *Desmo* refers to *Desmodesmus sp. C046* (saline media)		

DISCOVR Project Goals and Outcomes

Goals

- **Reduce total microalgae biofuels production costs to $3/GGE** by 2030 by developing an **integrated screening platform** for the **rapid identification of high productivity strains with cellular composition suitable for biofuels and bioproducts for resilient, year-round outdoor cultivation** via crop rotation.
- **Overcome limitations of previous strain prospecting efforts** such as low success rate and unrealistic laboratory test conditions.

Outcomes

- **Standardized identification, deep characterization, and delivery of robust, high productivity microalgae strains** to the bioenergy and bioproducts communities, such as **industry** and **BETO funded projects**.
- **Streamlined, coordinated effort** to capitalize on consortium labs' **complementary core capabilities in environmental simulation and productivity prediction, robustness evaluation, biomass valorization, and strain improvements**.

Quad Chart

Timeline

- Start date: 10-1-2016
- End date: 9-30-2019
- Percent Complete: 10%

Targets and Barriers

- MYPP 2030 Target: $3/GGE
- Aft-C – Biomass Genet. & Development
  - The productivity and robustness of algae strains…could be improved by screening
- Aft-E – Algal Biomass Characterization
  - Strain library of biochemical composition

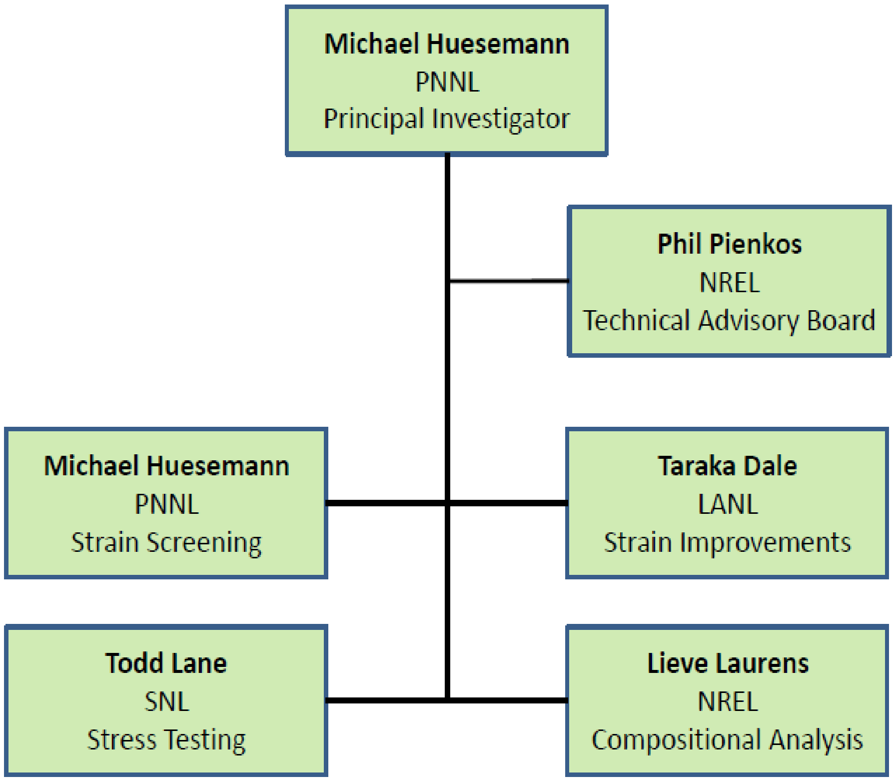
Budget

	FY 16 Costs	FY 17 Costs	Total Planned Funding (FY 17-Project End Date)
DOE	$0 K	$1.5M	$6.1M

Partners

- LANL (Taraka Dale, 21%)
- SNL (Todd Lane, 29%)
- NREL (Lieve Laurens, 16%)
- ATP[3] (John McGowen, 4%)

DISCOVR Project Management Structure



Meetings

- Biweekly teleconferences with PI and technical leads
- Quarterly meetings with TAB
- Annual face to face meetings

Quarterly Reports and Tracking of Milestones

- Data flows through the PI
- PI tracks milestones and generates all reports with input from technical leads
- Synthesis of results into publication and solutions tracked and mediated by PI

- Decision making is through consensus of PI and technical leads
- Technical leads are responsible for achieving task milestones
- PI retains ultimate decision-making authority

Acknowledgements

- **BETO ALGAE TEAM**
- **LANL**
  - Taraka Dale
  - Amanda Barry
  - Tari Kern
  - Hajnalka Daligault
  - Sangeeta Negi
- **NREL**
  - Philip Pienkos
  - Lieve Laurens
  - Ed Wolfrum
  - Mike Guarnieri
  - Stefanie Van Wychen
- **PNNL**
  - Scott Edmundson
  - Will Louie
  - Rob Kruk
- **SNL**
  - Todd Lane
  - Pamela Lane
  - Jeri Timlin
  - Tom Reichardt
  - Carolyn Fisher
  - Deanna Curtis
  - Kumal Poorey
  - Jaclyn Murton

Technical Advisory Board (TAB)

TAB Members

- **Philip Pienkos**, Chair (NREL)
- **John Benemann** (MicroBio Engineering)
- **Louis Brown** (Synthetic Genomics)
- **Valerie Harmon** (Harmon Consulting)
- **Craig Behnke** (Sapphire)
- **Juergen Polle** (CUNY)

Role of the TAB

- **Review results and progress** in comparison with work plans
- **Maintain an industry-relevant focus** and knowledge of recent technology advances and challenges
- **Provide input on strategic goals** and directions
- **Meet quarterly** by webinar and annually in person

- **First TAB meeting** was held on February 21, 2017
- Discussed Tier I strain selection and DISCOVR media composition

February 17, 2017

DISCOVR Delivers Comprehensively Characterized Strains

Characterization of Productivity and Robustness

DISCOVR

Genome Sequencing, Functional 'Omics, Metabolic Mapping

Greenhouse: Comprehensive Knowledge Base of Algal Feedstocks

Genetic Blueprint of Microalgae Carbon Productivity

Strain Improvement: Genetic Modification & Non-GM Strategies

- Algae Biotechnology Partnership
- Functional Characterization of Cellular Metabolism
- Multi-scale Characterization of Improved Algae Strains
- Breeding Algae for Long Term Stability& Enhanced Biofuel Prod'n

Strategy

Use a multi-lab consortium approach to establish a state-of-the-art platform for the deep *characterization of new strains under outdoor-relevant conditions*

Leverage the expertise at LANL and LBNL/JGI to deliver the *data and tools* required to understand algae metabolism and develop GM tools

Use a range of expertise & approaches across Labs to deliver *improved algae strains, and a suite of tools* that are effective in our top strains of interest and are also broadly applicable to new strains of interest (from DISCOVR or external stakeholders)

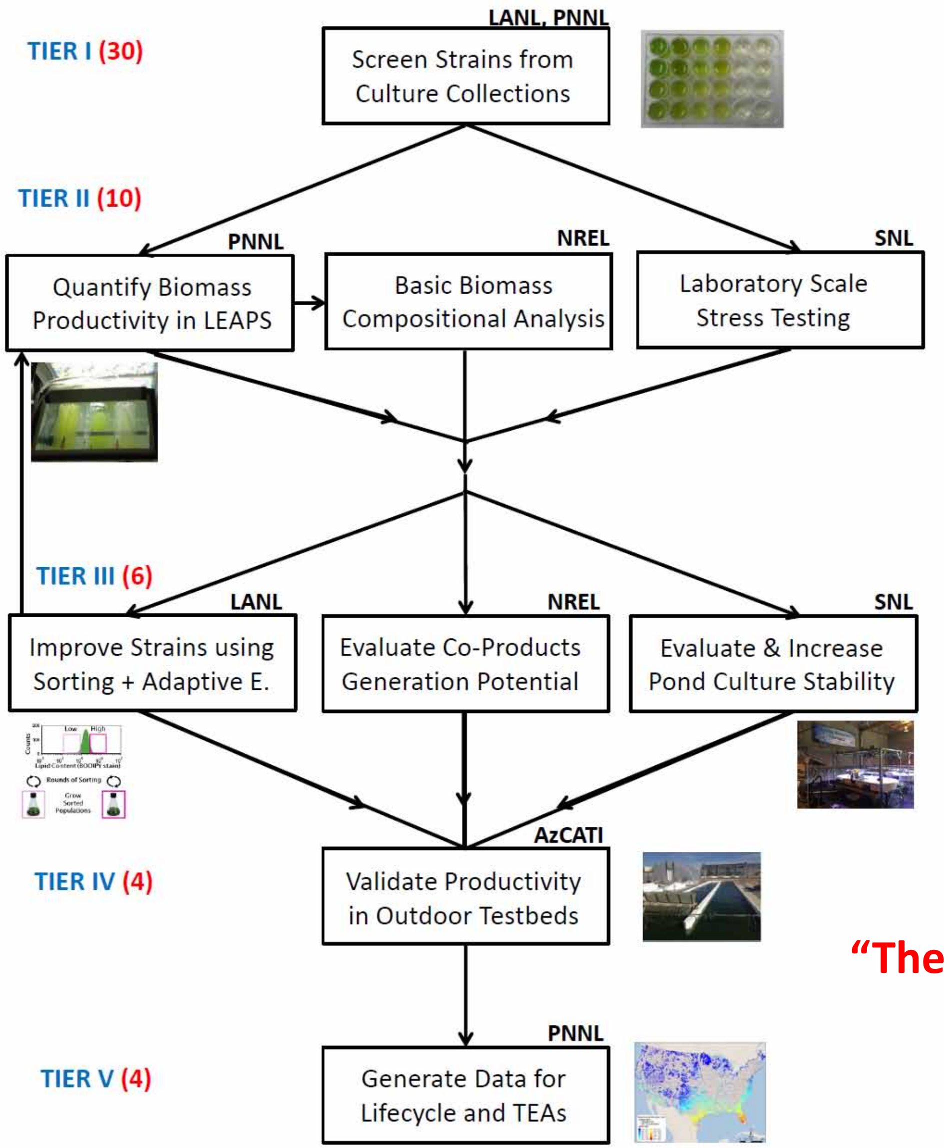
GOAL: *Deliver deeply characterized and improved strains, with accompanying data and tools, to stakeholders including industry, academics, and other BETO projects (e.g. BioFoundry)*

DISCOVR Synergistically Leverages Core Capabilities

DISCOVR builds on national lab core capabilities developed separately and using different strains in other BETO-funded projects:

- **Climate-Simulated Culturing and Growth Modeling (PNNL)**
  - NAABB Consortium Project
  - Microalgae Analysis AOP (1.3.1.102) (FY15-FY16)
  - Regional Algae Testbed Partnership, RAFT (1.3.5.111) (FY14-FY17)
- **Biological Protection and Control of Algal Pond Productivity (SNL)**
  - ATP^3 Consortium Project (1.3.5.101) (FY14-FY16)
  - TABB Project (1.3.2.300)
  - Algae Polyculture Production and Analysis AOP (1.3.1.103) (FY16)
- **Strain Improvement by Non-GMO Techniques (LANL)**
  - 1.3.2.100 Multi-scale Characterization of Improved Algae Strains (1.3.2.100)
- **Advanced Tools for Biomass Compositional Analyses (NREL)**
  - Algal Biomass Valorization (ABV, 1.3.4.300)

Approach Project Overview and Work Flow*



Critical Success Factors

- **Very unique state-of-the-art** technical **capabilities** are employed at each TIER.
- **Complementary core competencies** of the consortium national labs are **applied together** to make progress towards BETO's **$3/GGE target**.
- **Team members** have track record of **successful collaboration**.

"The Whole is Greater than the Sum of its Parts"
(Aristotle)

***Numbers in red designate the number of strains tested at each TIER for both rounds of screening.**

Approach   Rapid Strain Screening in Microplates

Challenges

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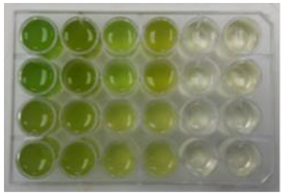
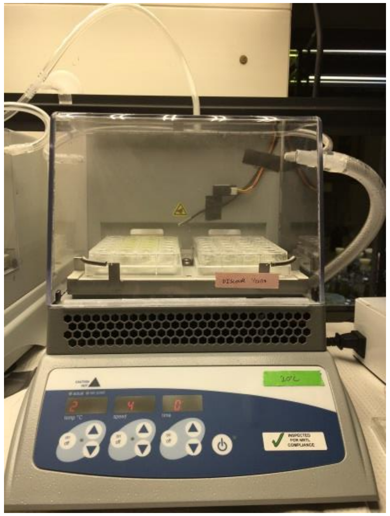
- Very few strains so far have been **rigorously characterized** in terms of their suitability for high productivity outdoor cultivation:
  - Temperature and salinity tolerance range
  - Maximum specific growth rate (related to productivity)
  - Tolerance to high O_2 and low pH
- Current methods are **non-standardized and labor intensive**



Approach

- Use **semi-automated** temperature-controlled **wellplate incubation system** and **BioTek microplate reader**
- Measure the **maximum specific growth rate** as a function of **temperature, salinity, O_2, pH, C-source**



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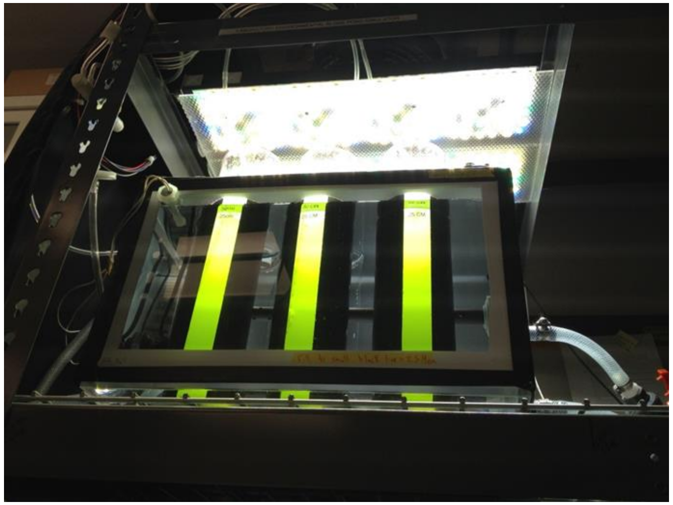
Approach Climate-Simulated Culturing

Challenge

- **Quantify seasonal areal biomass productivities** in the **laboratory** under conditions **simulating outdoor testbeds** in Arizona.
- There are currently **no** outdoor **pond simulator photobioreactors** that **accurately predict biomass productivity in outdoor ponds**.

Approach

- Culture **Tier II** strains in PNNL's validated **Laboratory Environmental Algae Pond Simulator (LEAPS)** photobioreactors using light and temperature scripts generated by PNNL's **Biomass Assessment Tool** (BAT) for Arizona testbeds.



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LEAPS Accurately Simulates Outdoor Ponds

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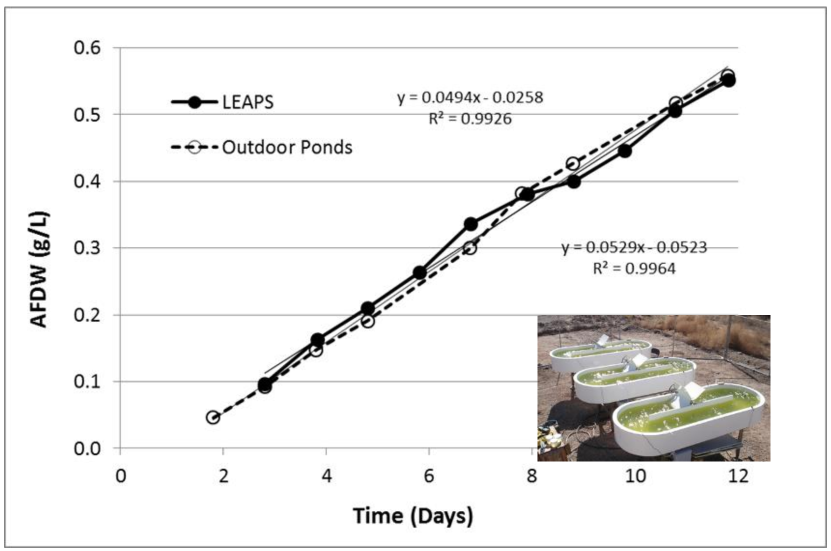
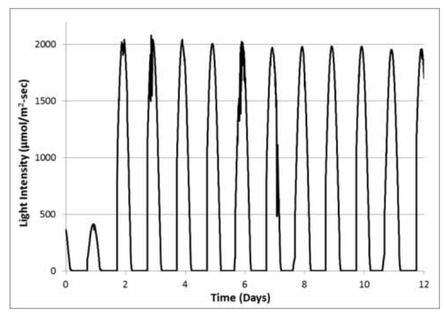
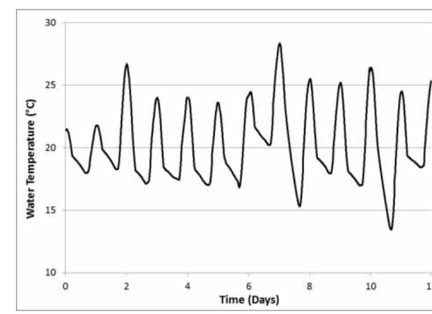
- Executes seasonal light and temperature scripts **accurately**
- Performance has been **validated** by repeating three outdoor pond experiments for different strains in the LEAPS
- Biomass productivity in LEAPS was **the same as** in outdoor ponds
- Currently the **world's most reliable pond simulator photobioreactor**



Light Intensity Script



Water Temperature Script



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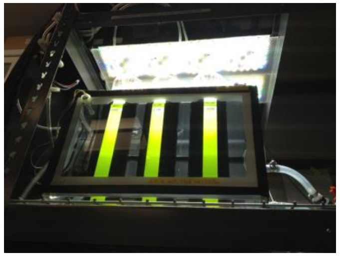
Biomass Compositional Analysis

Challenges

- Critical need for compositional comparisons of strains with integrated **valuable co-product characterization** to **reduce cost** of biofuels
- Evaluate **suitability** of microalgae strains for
  - **HTL pathway** (rapid biomass growth unconstrained by co-products)
  - **CAP pathway** (rapid biomass growth and early transition to high carbohydrate and lipid content)

Approach

- **Tier II Strains**: Determine biomass composition of nutrient replete and deplete samples taken from LEAPs bioreactors:
  - Total carbohydrates and sugar profile
  - Protein content
  - Lipid content and fatty acid profile



- **Tier III Strains:** Analyze biomass samples for co-products such as sterols, carotenoids, omega-3-fatty acids, phycocyanin, etc.

* HTL = hydrothermal liquifaction, CAP = Combined Algal Processing (extraction of lipids for fuels, anaerobic digestion of waste biomass)

Approach Culture Stability/Resilience Testing

Challenges

- **Eliminate** or **reduce risk** of **pond crashes**
- Identify strains' **resistance to predation** (e.g., rotifers) and fungal infections **prior to** conducting **outdoor testbed trials**

Approach

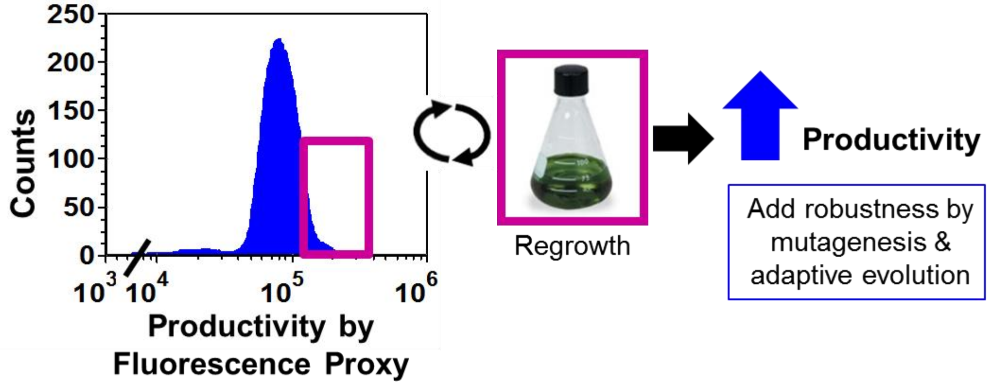
- **Tier II Strains:** Use previously developed assays to quantify resistance of algal communities to predation and infections
- **Tier III Strains:** Conduct tests in the SNL Algal Testbed (**Crash Lab**):
  - **Induce pond culture crashes** via addition of deleterious species identified in TIER II testing
  - Determine **conditions** under which resistance persists
  - Use **spectroradiometric monitoring** for creation of robust signatures of pond infection
  - Use data combined with **machine learning** to inform cultivation decision making

Challenge

- **Significantly increase (>20%) biomass** and/or **lipid productivity** of top performing **Tier III strains**
- **Increase environmental robustness** (e.g., temp/salinity tolerance)

Approach

- Apply approaches already developed at LANL to **improve strain phenotypes without genetic modification**:
  - **Fluorescence activated cell sorting**
  - **Adaptive evolution**
- Test new phenotypes in **LEAPS** to **validate improved productivity**



Testing in Outdoor Ponds

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Objectives

- **Quantify seasonal biomass productivities** in outdoor ponds in Arizona
- Demonstrate at **least 20% greater productivities** relative to benchmarks
- Evaluate **co-product** generation at scale
- **Harvest** sufficient biomass for **conversion studies** (by others)

Approach

- Conduct **outdoor cultivation** studies at the Algae Testbed Public Private Partnership site in Mesa, Arizona (**ATP^3**)

Approach Productivity Mapping for TEAs/LCAs

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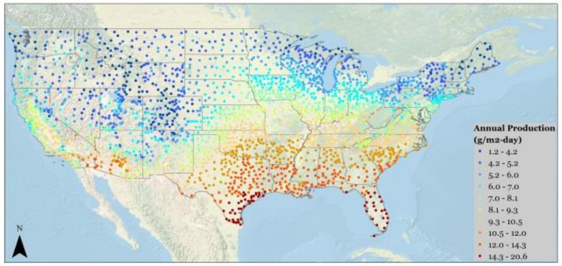
Objectives

- Generate **areal biomass productivity maps** for those strains performing best in outdoor ponds
- Identify geographic regions of **maximum annual biomass productivity** using **crop rotation** and optimized **pond operational strategies**
- Provide input data for **TEAs** and **LCAs** (conducted by other projects)

Approach

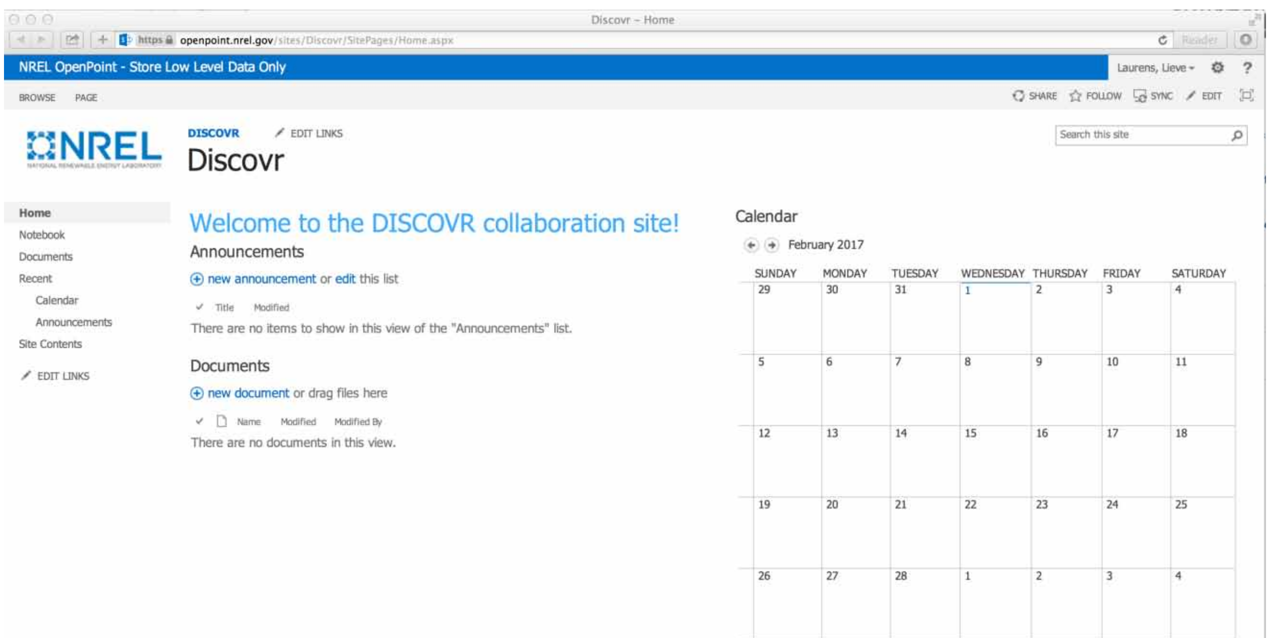
- Experimentally determine all required biomass growth **model input parameters**
- Run the **species-specific Biomass Assessment Tool (BAT)** to generate maps for different crop rotation and pond operation scenarios



Annual biomass productivity map for *Chlorella sorokiniana* DOE 1412

Approach   Data Management and Dissemination

- **Interlaboratory collaborative data management system** is established for sharing documents and raw data (NREL Sharepoint)
- Scientific Data Management system for productivity and composition will be leveraged from ATP^3 established system with curated data made available on **OpenEI.org**
- Strain sequence data will be hosted at LANL's **Greenhouse.lanl.gov**



OpenEI
Open Energy Information
Share knowledge.

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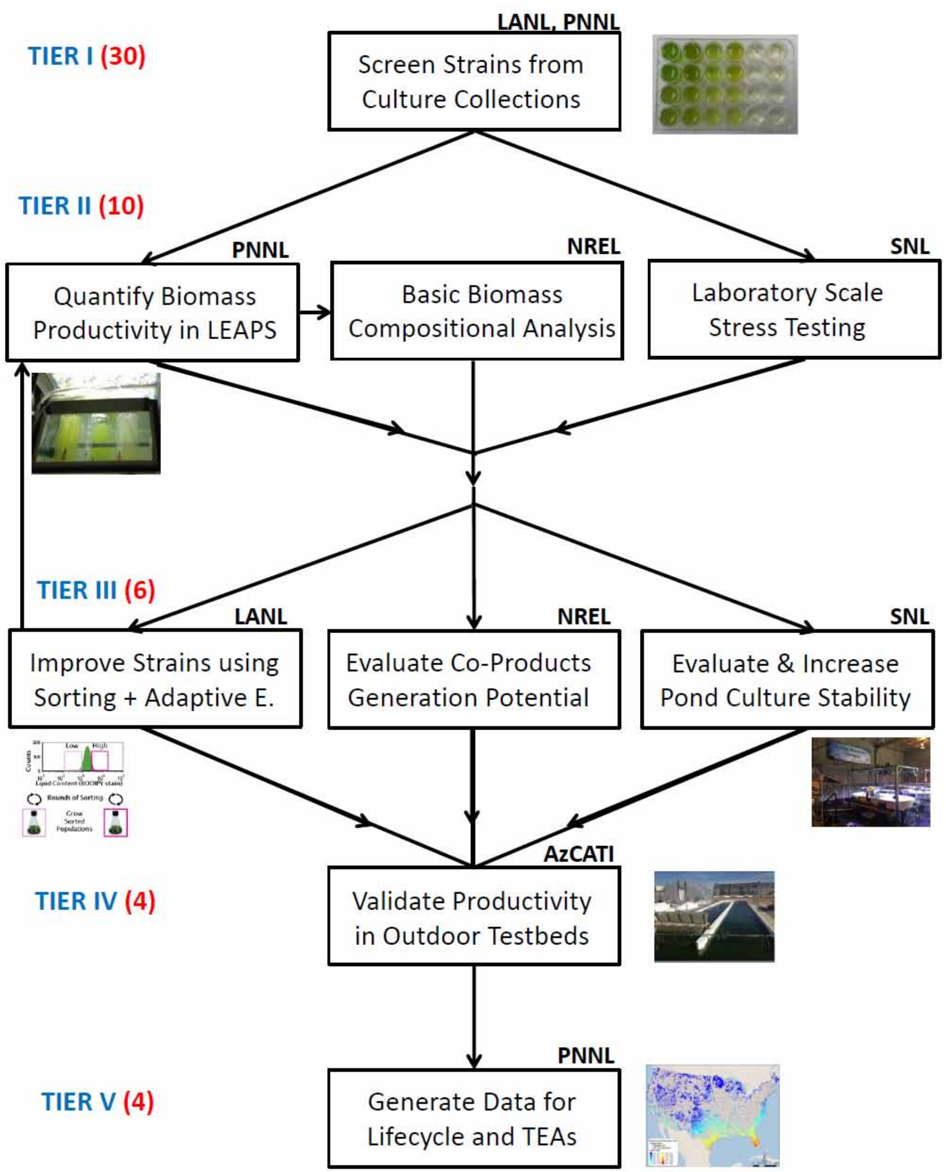
Future Work and Early Accomplishments



Go/No Go Decision

- **Successfully completed TIER I, II, and III testing of the first batch (round) of strains (3/2018)**
- **Demonstrated at least 20% improvement in biomass productivity relative to benchmark strains (3/2018)**

TIER I Strain Acquisition for Screening

Outcome

- **Acquire and revive at least 30 strains existing in culture collections** and the algae community **with the potential** to meet BETO's algae **productivity goals** *via* improved growth, biochemical composition, and outdoor robustness.

Approach

- Identify, order, and revive strains from culture collections
- Conduct 16S/18S sequencing to determine level of contamination
- Clean-up cultures and confirm using 16/18S sequencing
- Adapt strains to DISCOVR low cost media and deliver to PNNL

Milestones

- **Identify, order, receive, revive 1st batch of TIER I strains (12/2016)**
- **Identify, order, receive, revive 2nd batch of TIER I strains (6/2017)**

TIER I Strain Acquisition for Screening

Batch 1 Strains (FY17)

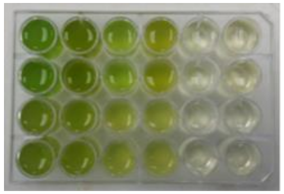
- Screen at least **15 strains** (**21 have been selected**)
- 12 are **marine or brackish** water strains
- 9 are **freshwater** strains, including from the NAABB program
- **Benchmark** strains:
  - Warm Season (fresh water): ***Chlorella sorokiniana*** DOE 1412 (NAABB)
  - Cold Season (fresh water): ***Scenedesmus obliquus*** DOE 0152.Z (NAABB)

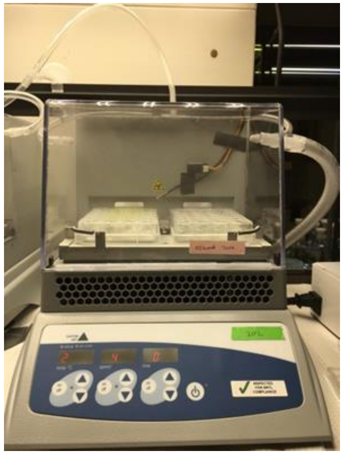
Strain No.	Alga Strain	Brief Taxonomy	Collection	Characteristic
1	*Chlorella sorokiniana* DOE 1412	Green-Trebouxiophyceae	CUNY	**BENCHMARK STRAIN** freshwater, cold-sensitive, Max ~42°C
2	*Chlorella autotrophica* CCMP243	Green-Trebouxiophyceae	NCMA	Euryhaline/marine- Milford, Connecticut
3	*Stichococcus minor* CCMP819	Green-Trebouxiophyceae	NCMA	Brackish, Florida Keys
4	*Stichococcus minutus* CCALA727	Green-Trebouxiophyceae	CCALA	Cold tolerant, Svalbard, Arctic circle, subglacial
5	*Chloromonas reticulata* CCALA870	Green-Chlorophyceae	CCALA	Cold Tolerant, Scotland, Alpine
6	*Synechococcus elongatus* UTEX 2973-sub. 1	Cyanobacteria	UTEX	Brackish, thermotolerant (40 C), sub. 1 is stable at 20 C
7	*Synechococcus elongatus* CCMP 1630	Cyanobacteria	NCMA	Marine, Max ~40°C, Tyrrhenian Sea, Robust
8	*Picochlorum oklahomensis* CCMP 2329	Green-Trebouxiophyceae	NCMA	Brine pool, Max ~40°C
9	*Stichogloea doederleinii* CCMP823	Phaeothamniophyceae	NCMA	Plankton bloom Freshwater, Max ~35°C (Not yet received from NCMA)
10	*Pleurochrysis carterae* CCMP647	Coccolithophore	NCMA	Salton Sea, robust
11	*Agmenellum quadruplicatum* UTEX2268	Cyanobacteria	UTEX	Marine, isolated from fish-pens mud, Puerto Rico
12	*Chlorococcum minutum* UTEX 117	Green-Chlorophyceae	UTEX	Terrestrial, (Bombay, India)
13	*Coelastrella sp. DOE0202*	Green-Sphaeropleales	CUNY	Freshwater, high harvestibility, CUNY
14	Unknown Green Alga DOE1044	Green-Chlorophyceae	UTEX	(high biomass productivity-CUNY/NAABB)
15	*Desmodesmus sp.* DOE1357	Green-Sphaeropleales	UTEX	(high biomass productivity-CUNY/NAABB)
16	*Chlorococcum sp.* DOE1426	Green-Chlorophyceae	UTEX	(high biomass productivity-CUNY/NAABB)
17	*Unknown Green Alga* DOE1116	Green-	UTEX	(high biomass productivity-CUNY/NAABB)
18	*Chaetoceros muelleri CCMP194*	Bacillariophtya-centric diatom	NCMA	Saline crater lake, Galapagos Islands
19	*Surirella sp. CCMP3162*	Bacillariophtya-pennate diatom	NCMA	isolated from Salt Lake (Lake George), North Dakota-(Revival unsuccessful)
20	*Rhodomonas salina CCMP1319*	Cryptophyte	NCMA	Marine
21	*Thalassiosira weissflogii CCMP1051*	Bacillariophtya-centric diatom	NCMA	Brackish, warm water, King Kalakaua's Fishpond, Kahaluu, Hawaii
22	*Tisochrysis lutea CCMP463*	Haptophyta - golden alga	NCMA	Marine, aquaculture

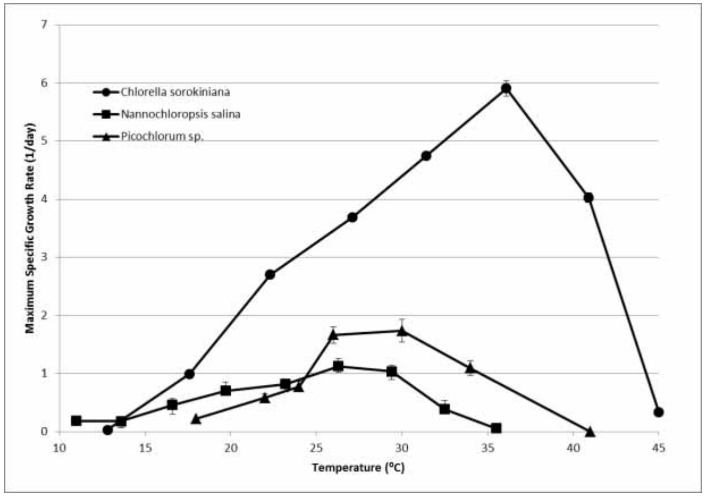
TIER I Strain Screening on Microplates

Outcomes

- Identify **fast growing strains**, compare to **benchmark** strains
- Determine **temperature** and **salinity** tolerance range
- Quantify tolerance to **oxygen** and low **pH**
- Assess **heterotrophic growth** potential (cellulosic hydrolysates)







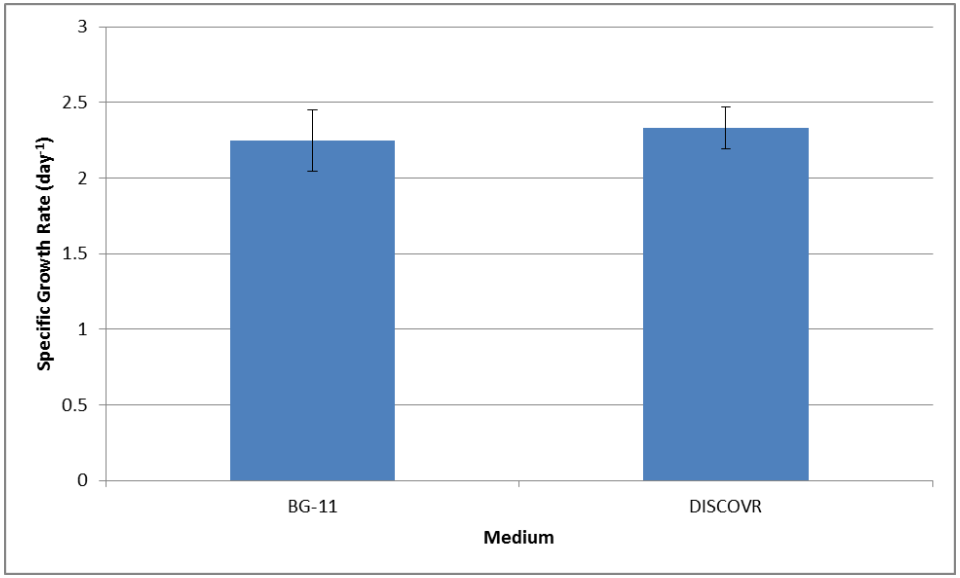
Milestones

- **Complete screening of 1st batch of TIER I strains (3/2017)**
- **Complete screening of 2nd batch of TIER II strains (3/2018)**

Strain Screening on Microplates

Development of Industrially Relevant DISCOVR Media

- **Ammonium sulfate** is primary N source, reflecting dominant form of recycled N following biomass conversion processes (HTL, CAP)
- **N:P ratio** = 16:1 (Redfield)
- DISCOVR media support growth up to **800 mg/L AFDW**
- DISCOVR freshwater medium supports growth as well as **BG-11**
- Media have been reviewed by **Technical Advisory Board**



Benefits

- **Less Expensive than BG11**
- **Proxy for Recycled Media**
- **Harmonized with NREL Design Case**

Climate-Simulated Culturing

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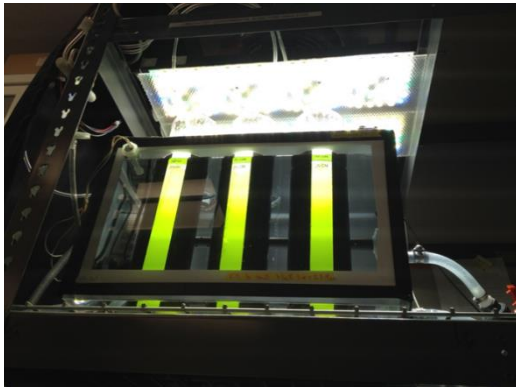
Outcomes

- Quantify **seasonal areal biomass productivities** of top Tier I strains under conditions simulating outdoor testbeds in Arizona (ATP^3, UA)
- Generate biomass for NREL **compositional analyses**
- Test **harvestability** (settling time)
- Strains with **productivities >20%** greater than benchmarks pass to **Tier III**



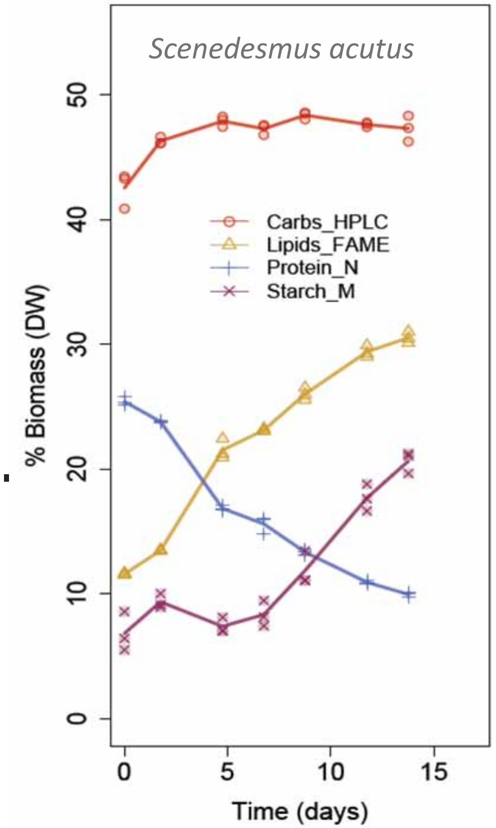
Milestones

- **Quantify biomass productivities of at least 5 TIER I strains (9/2017)**
- **Quantify biomass productivities of at least 5 TIER I strains (9/2018)**

TIER II + III Biomass Compositional Analysis

Outcomes

- **Tier II Strains**: Determine biomass composition of nutrient replete and deplete samples taken from LEAPs bioreactor using established methods:
  - **Determine biochemical shift profile under nutrient depletion**
  - **Integrate composition with productivity data supporting TEA/LCA**
- **Tier III Strains: Identify set of critical economic co-products** present in respective species taken from cultures for co-products such as sterols, carotenoids, omega-3-fatty acid, phycocyanin, …



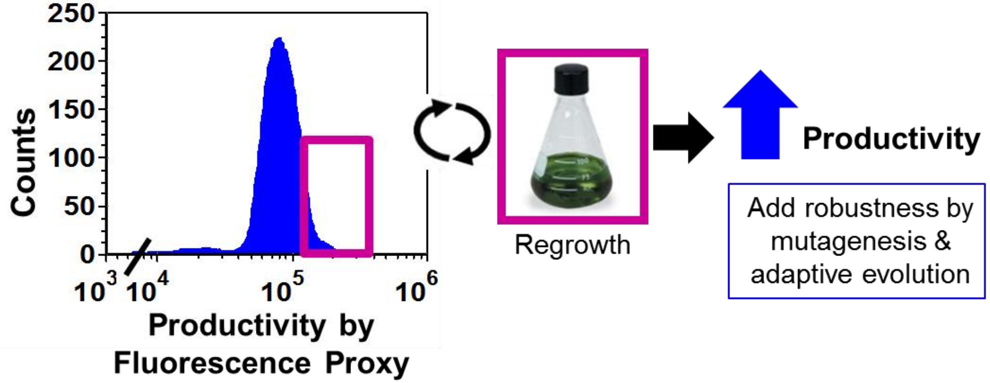
Milestones

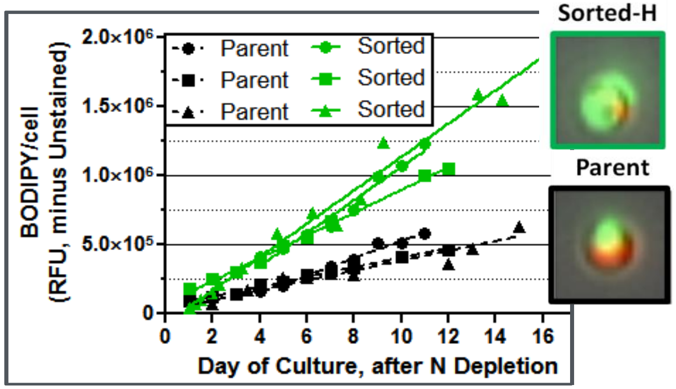
- **Determine biochemical composition of 5 TIER II strains (9/2017)**
- **Determine detailed composition of 3 TIER III strains and conduct pretreatment severity testing for CAP process (3/2018)**

Strain Improvement

Outcomes

- **Increase (>20%) biomass** and/or **lipid productivity** and/or **environmental robustness** of top performing **Tier III strains** via:
  - **Fluorescence activated cell sorting**
  - **Adaptive evolution,** combined with **chemical mutagenesis**





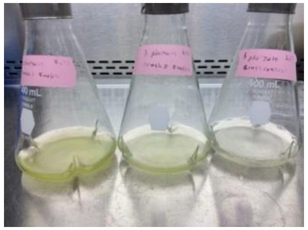
Milestones

- **Generate at least two improved strains (≥20% improvement in coproduct content or biomass productivity relative to parent) for hand-off to PNNL for LEAPS evaluation (6/2019)**

TIER II Culture Stability/Resilience Testing

Outcomes

- Develop **predator/pathogen panel**
  - Identify 25 commercially available **predator species** for initial testing
  - Test predator species for **culture stability** and **activity** against a panel of 3 ”standard” algae
  - Develop **standardized laboratory-scale crash protocol**
  - Identify set of relevant **environmental culture conditions**
  - Develop a panel of at least 8 deleterious species
- Characterize selected algal strains under selected environmental conditions against predator panel
  - **Identify strains with the broadest predator and pathogen resistance at lab scale**



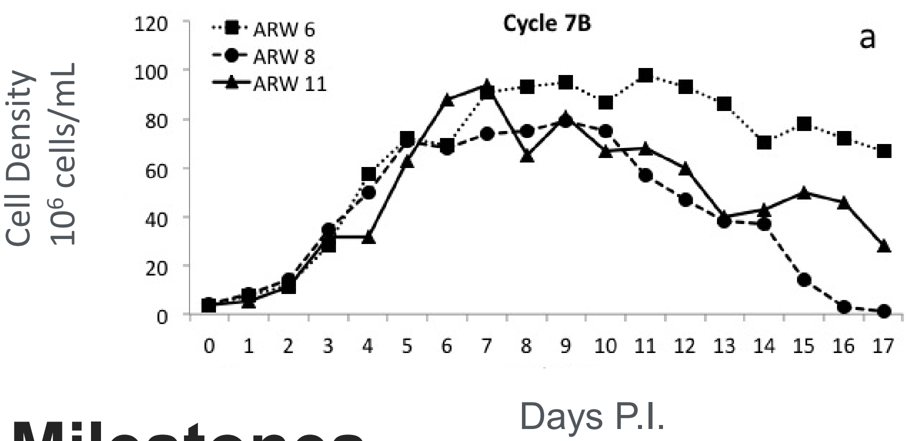
Milestones

- **Complete testing four predator initial panel (3/2017)**
- **Complete lab-scale testing (9/2017)**

TIER III Culture Stability/Resilience Testing

Outcomes

- Complete tests in the SNL Algal Testbed (**Crash Lab**):
  - **Induce pond culture crashes** via addition of deleterious species identified in TIER II testing
  - Determine **conditions** under which resistance persists



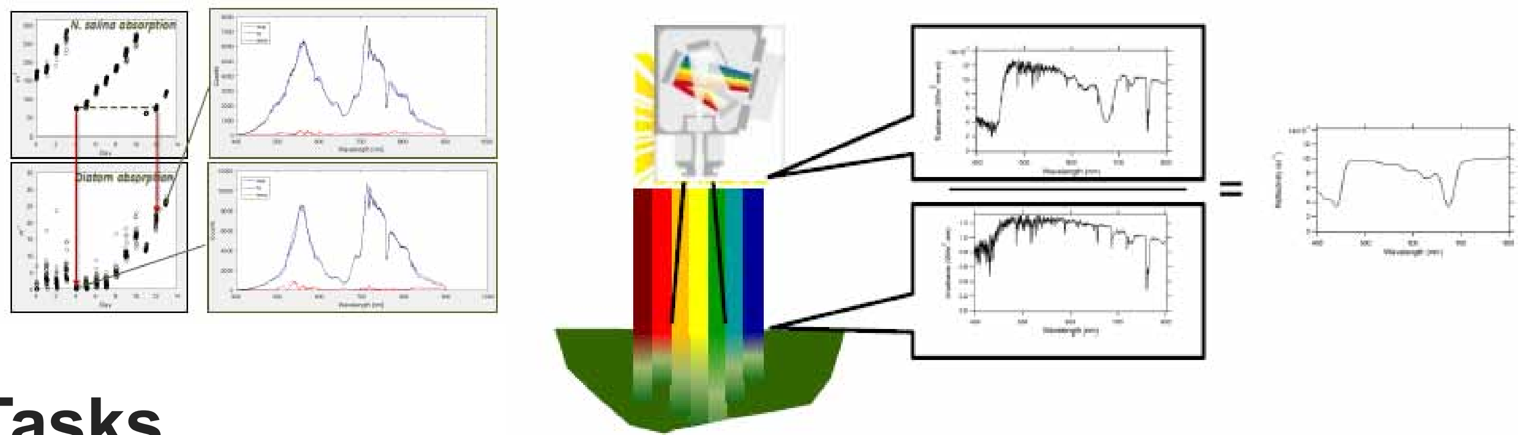
Milestones

- **Demonstrate standard crash assays at 1000L pond scale (6/2017)**
- **Complete pond scale evaluation of predation resistance of 2-4 algal strains (12/2018)**

TIER II+III Spectroradiometric Monitoring

Outcomes

- Identify and characterize the **spectral signatures** resulting from the **interaction of algae with multiple, diverse pests** relevant to production scale algal culture in a stand-off fashion



FY17 Tasks

- **Analysis of field trial data** from crashing ponds collected in the ATP[3] AFS trials to identify **optical signatures** of functional pest presence
- **Multifactorial (temp and salinity) experiments** on one algal/pathogen pair to validate and assess the **sensitivity** and **specificity** of the **optical biomarkers** under relevant (and highly variable) field conditions.

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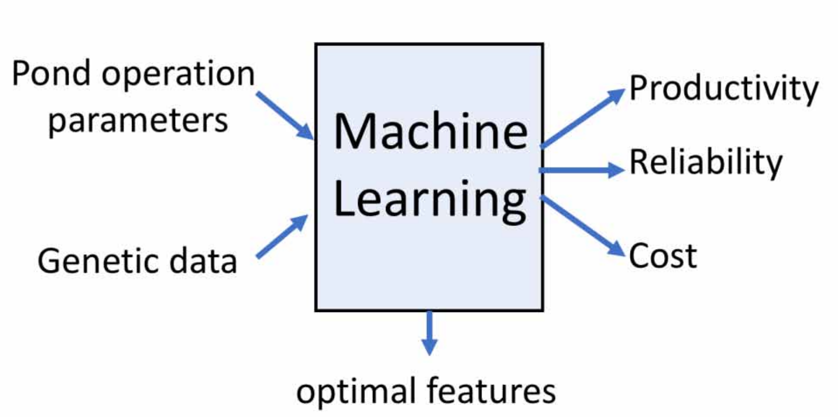
Outcomes

- **Leverage** the data generated by DISCOVR combined with those from RAFT and ATP^3 to **identify pond operation practices and parameters that enhance stability and productivity**

We will apply and ensemble machine learning methods, such as regression, random decision forests, Baysian network, clustering, support vector machines, artificial neural networks to achieve this goal.



FY17 Tasks

- Develop a **predictive model for pond productivity and reliability** based on genetic data acquired from ATP^3 and RAFT consortiums.
- Use the **multipathogen/multialgal data** generated by DISCOVR to create **contamination models** that will inform pond **operation strategies** such as harvesting and re-inoculation.

TIER IV+V Pond Testing / Productivity Mapping

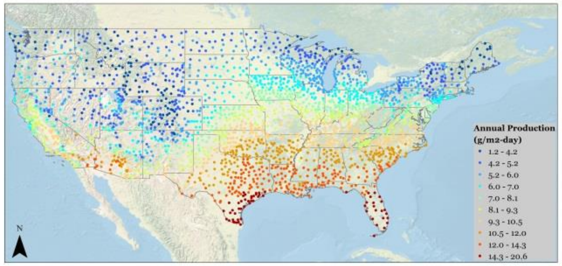
Pacific Northwest NATIONAL LABORATORY

Milestone for Outdoor Pond Trials

- **Complete outdoor pond testing for at least four TIER IV Strains (9/2019)**

Milestone for Productivity Mapping

- **Generate biomass productivity maps by species-specific Biomass Assessment Tool (BAT) for TIER V strains (9/2019)**



Annual biomass productivity map for *Chlorella sorokiniana* DOE 1412

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Relevance

- **Reduce total microalgae biofuels production costs to $3/GGE** by 2030 by developing an **integrated screening platform** for **identification of high productivity strains with cellular composition suitable for biofuels and bioproducts for resilient, year-round outdoor cultivation** via crop rotation.
- **Overcome limitations of previous strain prospecting** efforts such as low success rate, slow speed, and unrealistic laboratory test conditions.
- **Addresses critical research needs** stated in BETO's 2016 MYPP and National Algae Biofuels Technology Review (NABTR):
  - Stable high yield strains that resist predators in large-scale ponds (MYPP)
  - Strain screening and climate-simulated culturing (NABTR)
- **Addresses** the **need for cost reduction via valorization of biomass**, as presented by NREL at the Jan 2017 BETO quarterly SOT meeting.
- **Standardized identification, deep characterization, and delivery of robust, high productivity microalgae strains** to **industry** and other BETO funded projects (e.g., **Agile Biofoundry**).
- Workflow will **facilitate bioprospecting** by **algae biofuels stakeholders**.

Summary: The *Gold Standard* for Strain Characterization

- The DISCOVR project will develop a **standardized, industrially-relevant process** for **characterizing and comparing potential biofuels/bioproduct strains**.
- This project is a **streamlined, coordinated effort** to capitalize on consortium labs' **complementary core capabilities** in **environmental simulation and productivity prediction, robustness evaluation, biomass valorization**, and **strain improvements**.
- We aim to deliver new strains that **perform better than the current State of Technology**, in order to directly contribute to meeting BETO's goal of producing advanced biofuels **at <$3/GGE**.

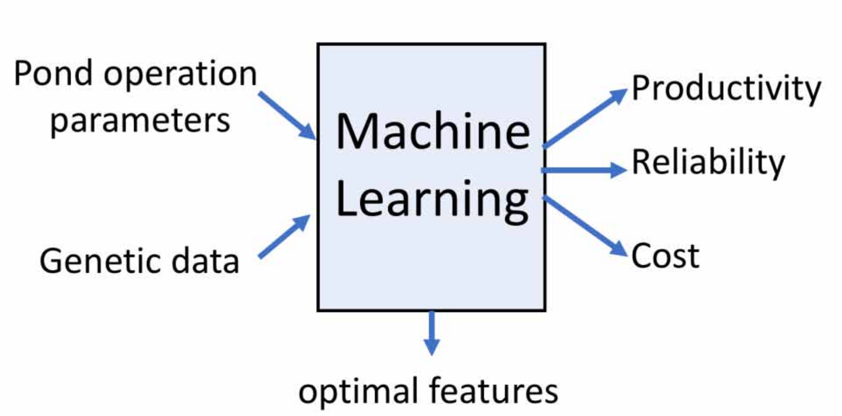
"The Whole is Greater than the Sum of its Parts" (Aristotle)

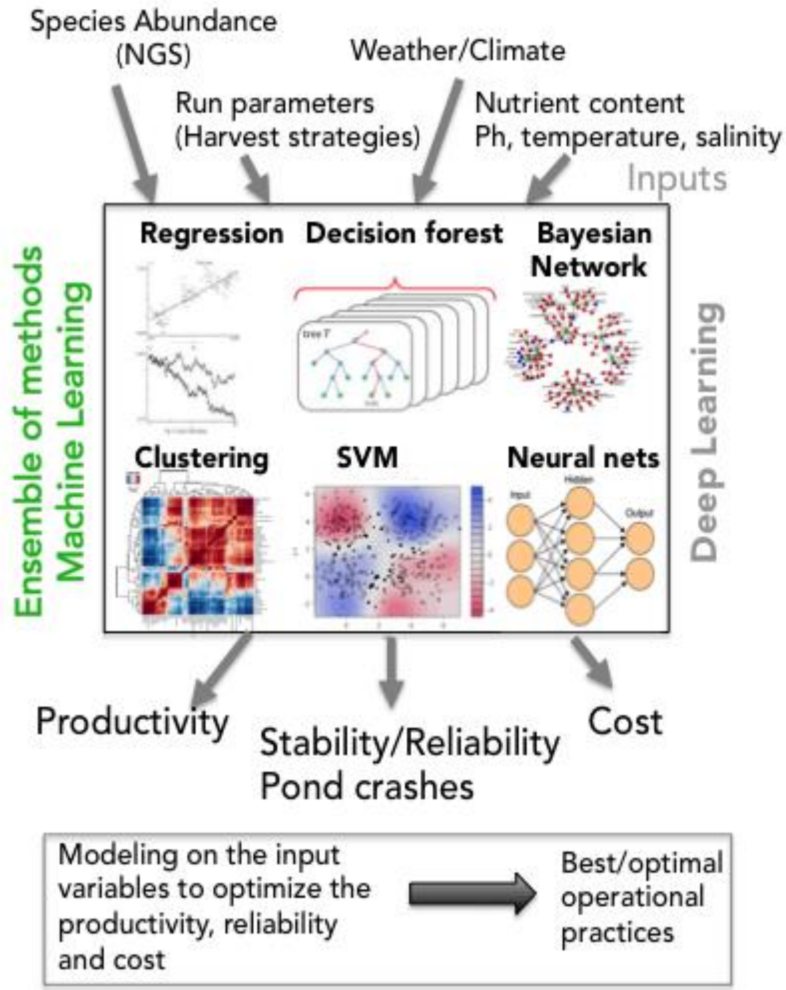
Supplemental Viewgraphs

Machine Learning

Sandia National Laboratories

We will apply and ensemble machine learning methods, such as regression, random decision forests, Baysian network, clustering, support vector machines, artificial neural networks to achieve this goal.





DISCOVR Publicity

https://www.sciencedaily.com/releases/2017/01/170113133049.htm

https://www.eurekalert.org/pub_releases/2017-01/dnnl-bmf011317.php

http://military-technologies.net/2017/01/13/biofuel-matchmaker-finding-the-perfect-algae-for-renewable-energy/

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http://www.algaeindustrymagazine.com/pnnl-seeking-perfect-algae-renewable-energy/

http://www.chemeurope.com/en/news/161401/biofuel-matchmaker-finding-the-perfect-algae-for-renewable-energy.html

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http://www.alternative-energy-news.info/headlines/biofuels/

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http://www.sequimgazette.com/news/sequim-lab-looks-to-find-the-best-biofuel-in-algae/