# AzCATI

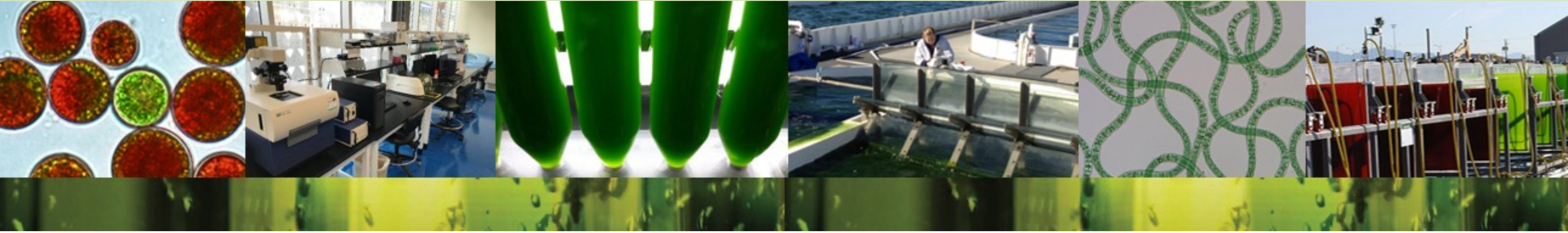
Arizona Center for Algae Technology and Innovation

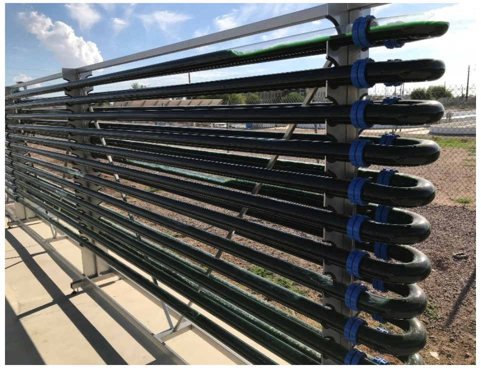
One little cell, a world of possibilities.

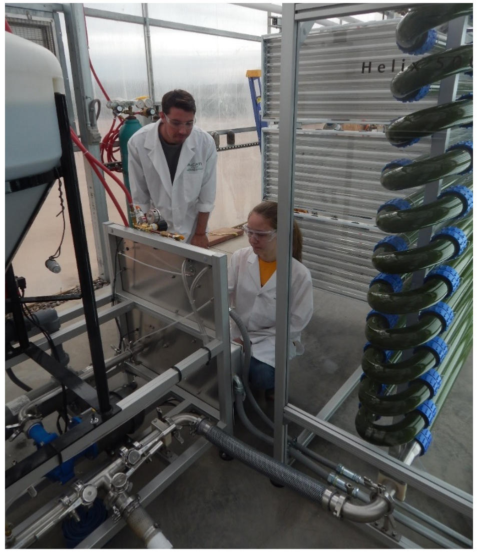
Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel
June 6th -7th, 2022

Dr. John A. McGowen
Director of Operations and Program Management

DISCOVR | ASU LightWorks Arizona State University | ASU Ira A. Fulton Schools of Engineering Arizona State University | U.S. DEPARTMENT OF ENERGY







www.azcati.asu.edu

## Who we are:

The Arizona Center for Algae Technology and Innovation (AZCATI) is located at Arizona State University's Polytechnic Campus and is part of the Fulton Schools of Engineering.

## The Center's Mission:

AzCATI serves as a national algae testbed to accelerate the advancement of algae technology development and commercialization through innovative **research**, **education**, and **collaboration**.

Ira A. Fulton Schools of Engineering
Arizona State University

SCIENCE foundation ARIZONA
Innovation at Work

Arizona Center for Algae Technology and Innovation

# AzCATI: Connect and Collaborate

## AzCATI has an extensive network of collaborators both within and outside of ASU with partners offering access to wide range of expertise, research capacity and high-quality services.

### Core research areas at ASU/AzCATI include

- Bioprospecting, algal taxonomy and physiology
- DNA-based strain-typing services
- Algal consortia
- Carbon capture and utilization
- Carbon dioxide air capture and membrane delivery
- Water and wastewater treatment
- Acidophilic red algae for multi trophic production of biomass and valuable co-products
- Development of heat tolerant systems for cultivation in hot-arid environments
- Novel sensor development for water and soil quality, and process monitoring
- Biomass extraction and conversion to biobased products with focus on circular/regenerative pathways/technologies
- Long term cultivation studies and crop protection
- Process integration and system scale-up
- Technoeconomic analysis and life cycle assessment

## Serving the algae industry

### Strain Identification & Isolation

Isolate specific strains and provide unialgal, or axenic cultures for clients that have issues with mixed or contaminated cultures.

### Biomass Production & Supply

Supply biomass production and culture maintenance services to industry and academic customers from laboratory to pre-commercial scale, including genetically engineered strains. Extensive experience conducting outdoor cultivation trials and GMO-TERA application support.

### Analytical Services

Provide analytical services to measure microalgae growth, biochemical composition and water (culture media) quality characteristics.

### Equipment Testing

Our testbed is equipped with existing infrastructure for plug-n-play testing of algae cultivation systems, harvesting and dewatering pilot equipment, and other algae innovations.

### Education & Training

We offer courses ranging from basic algae taxonomy and physiology to in-depth, hands-on training using advanced analytical techniques and data analytics for improved operations.

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### Sharing High Impact Data

Central to AzCATI's mission is the sharing of data from our Department of Energy (DOE) funded long-term cultivation trials, setting the standard for the acquisition of high-quality productivity data and proximate analysis to help inform the assessment of the current state-of-technology (SOT) for algal based biotechnology.

## Serving the algae industry

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# Establishment of the SOT Experimental Framework

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## A key priority for AzCATI was the development of test bed facilities that can be State and National resources for universities, industry and the national laboratories.

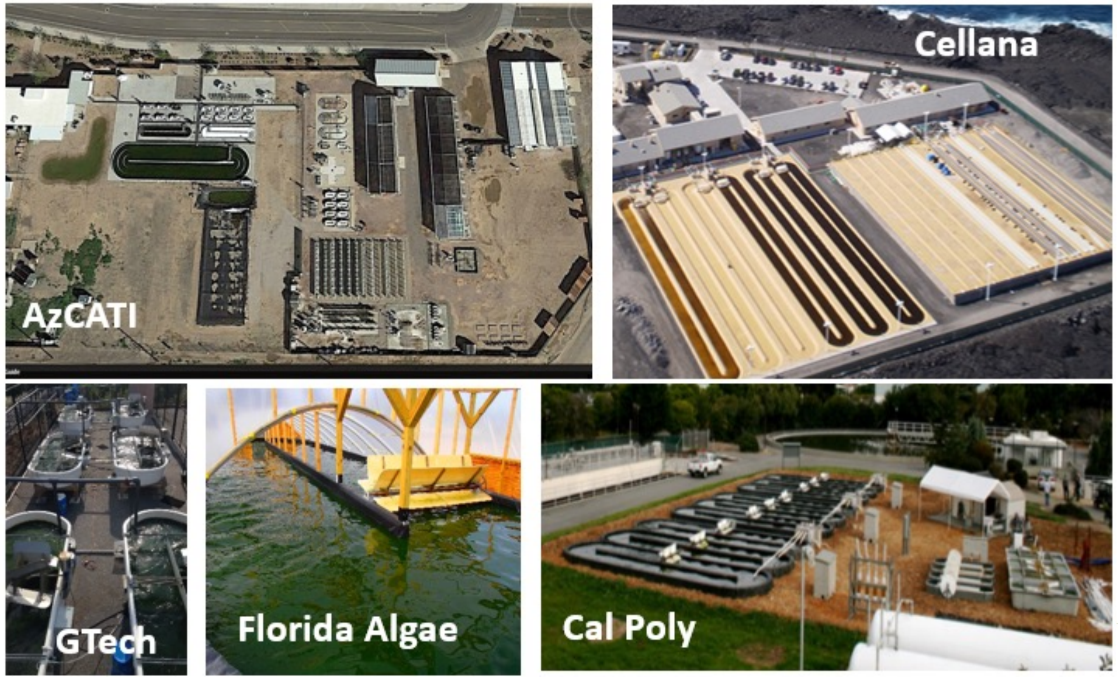
ATP[3] Algae Testbed Public-Private Partnership

ATP[3] period of performance 2013-2018

### Objectives:

Provide increased stakeholder access to algae facilities, expertise, and high-quality services.

Perform multi-site long term cultivation trials to provide high impact data for resource, technoeconomic and life cycle assessments and inform the State of Technology (SOT) for algae cultivation.





Regional testbed facilities for the partnership are physically located in **Arizona, Hawaii, California, Georgia, and Florida.**

Valicor Renewables · Commercial Algae Professionals · Harmon Consulting · Litree · Evodos

**Standardized framework of methods and metrics for multi-site outdoor cultivation trials**


Funded under Advancements in Sustainable Algal Production (ASAP)
Topic Area 2: Regional Algal Feedstock Testbed Partnership DE-FOA-0000615



Laurens, L., et al, https://doi.org/10.1016/j.algal.2017.03.029.
McGowen, J., et al, https://doi.org/10.1016/j.algal.2017.05.017
Knoushaug, E., et al, https://DOI.org/10.1038/sdata.2018.267
McGowen, J. et al https://do.org/10.2172/1780639
Harmon, V. et al, https://doi.org/10.1016/j.algal.2021.102249

DISCOVR established in 2017 and will run thru 2025

**TAB**

Technical Advisory Board (NREL)

**New Strains**

**New Concepts**

**Other (AAS) Projects**

**TIER I:** Characterize Strains in Flask Cultures (PNNL, LANL, SNL)

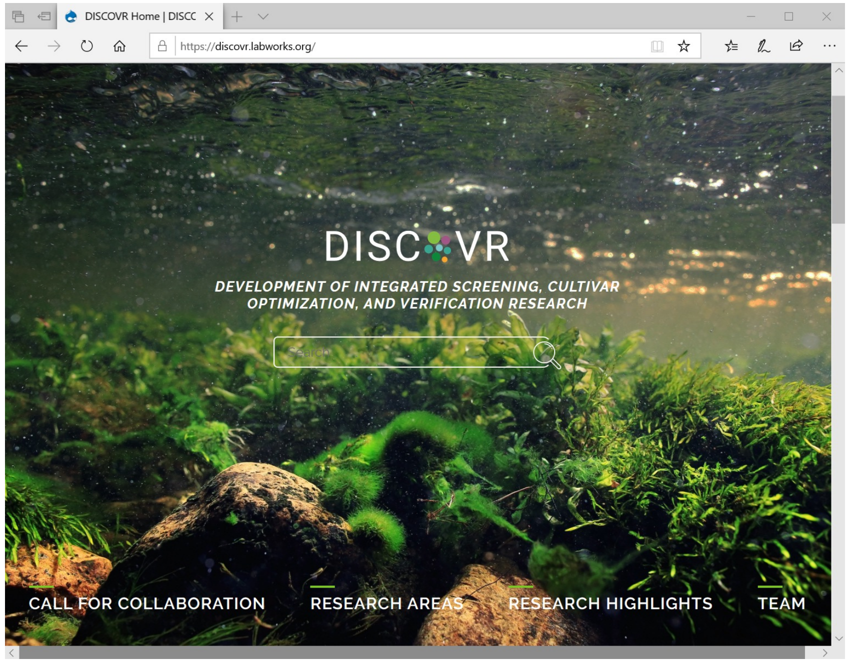
**TIER II:** Quantify Strain Performance in Climate-Simulation PBRs (PNNL, NREL, LANL)

**TIER III:** Test Strains in Pilot-Scale Indoor and Outdoor Ponds (SNL, PNNL)

**TEA**

TEA Operational Baseline (NREL)

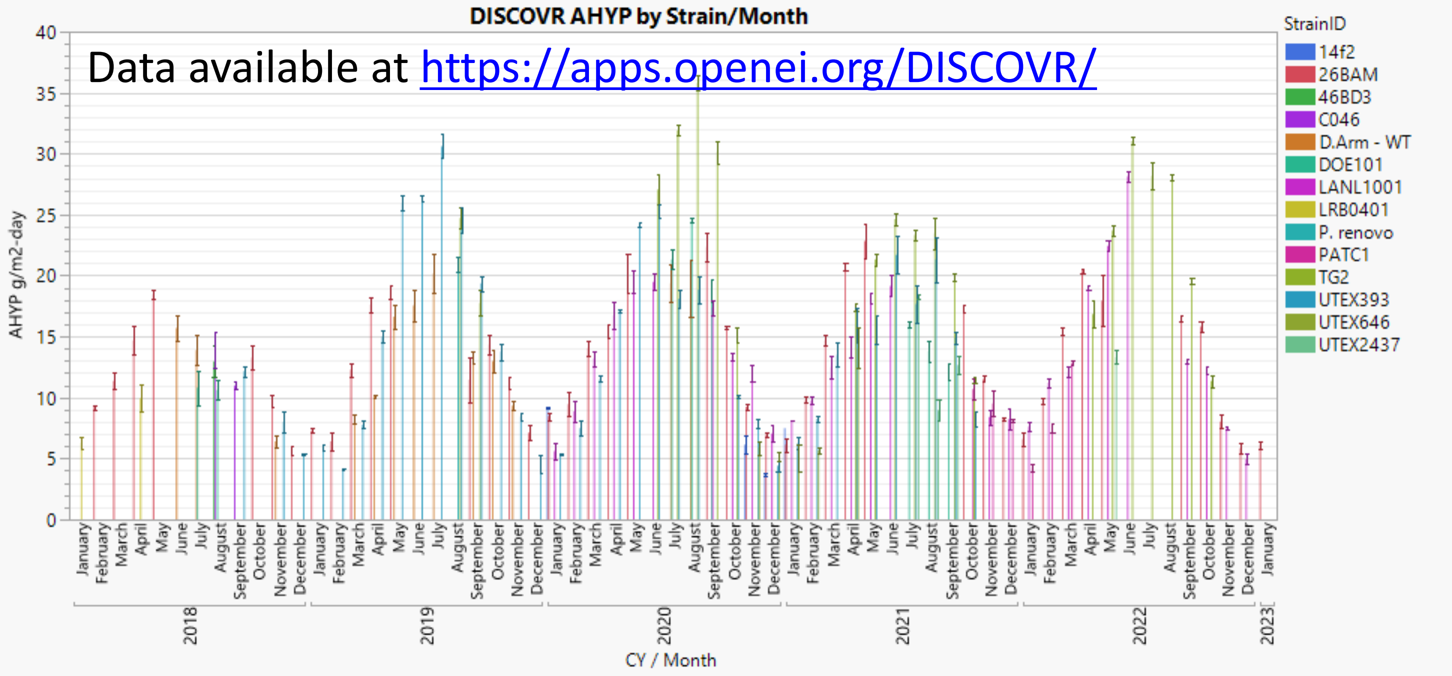
**Outdoor SOT Trials** to Verify Performance of Strains and Optimized Operational Conditions




https://discovr.labworks.org/

*Standard 4.2 m$^2$ open raceway ponds (ORP) for SOT cultivation trials at AzCATI. Typically run simultaneously in triplicate.*

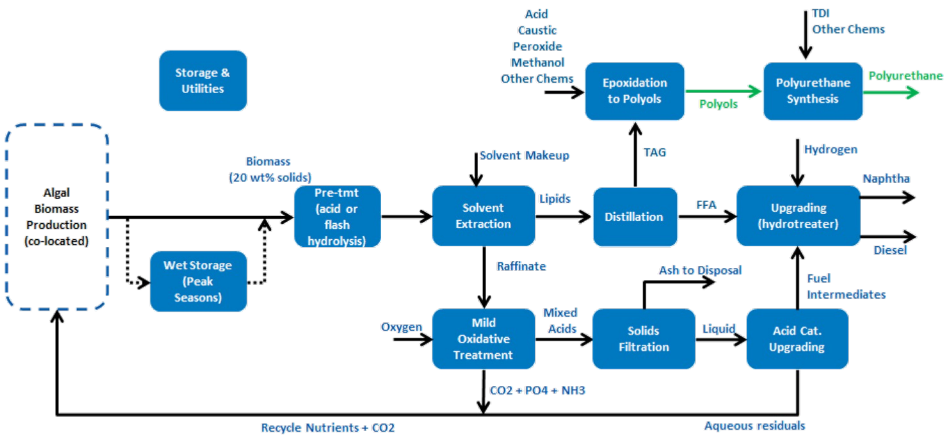
- **Under DISCOVR – a 60% improvement from 2018 to 2022**
  - 117% improvement in annual average productivity since inception of SOT analysis in 2015
  - >330 days per year since 2019
- **Averaged >10% per year since 2015, but only 5.5% for last 3 years**
  - Have we reached a plateau in productivity gains?
  - Can this be overcome with the current cultivars and biotic and abiotic conditions at the AzCATI site?
- **BETO target = 25 g/m²-day annual average by 2030**
  - requires ~ 5% year over year improvement
- **A drop in annual average productivity was observed in 2021, primarily driven by lower summer and early fall productivity – year over year performance observations critical**

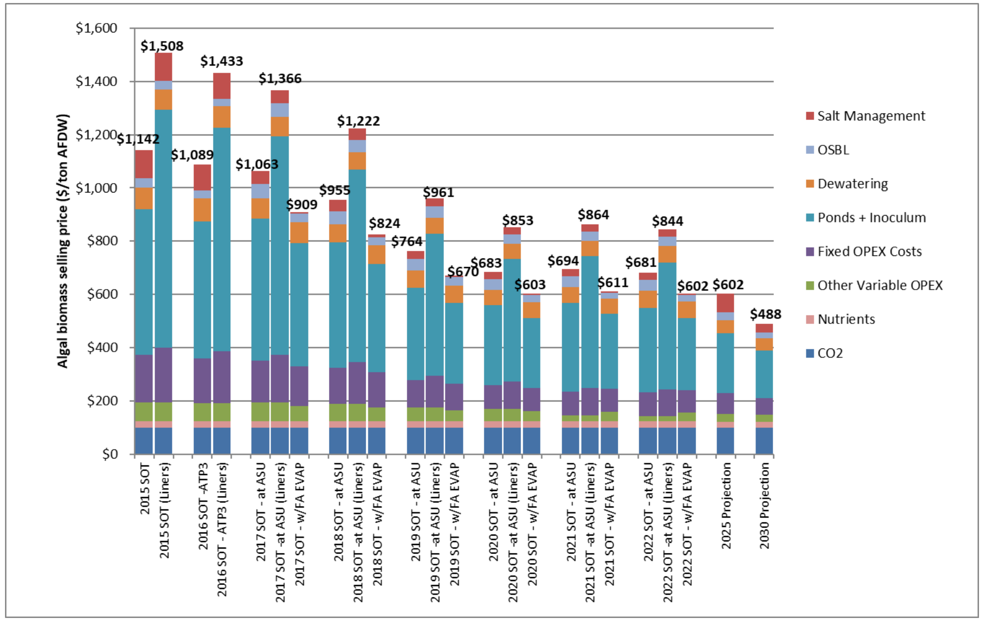



| Season | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|
| Fall | 6.8 | 7 | 8.5 | 9 | 11.4 | 15.0 | 19.1 | 16.2 |
| Winter | 5 | 5 | 5.5 | 7.7 | 6.5 | 8.3 | 8.3 | 9.0 |
| Spring | 11.4 | 11.1 | 13.2 | 14.8 | 18.6 | 18.5 | 19.4 | 19.9 |
| Summer | 10.9 | 13.3 | 14.1 | 14.9 | 27.1 | 31.6 | 23.8 | 29.1 |
| **Average** | **8.5** | **9.1** | **10.3** | **11.6** | **15.9** | **18.4** | **17.6** | **18.6** |
| **Total days** | **<150** | **<150** | **<150** | **256** | **328** | **353** | **360** | **356** |
| Year over year (YOY) Improvement | N/A | 7% | 13% | 12% | 37.0% | 15.4% | -3.9% | 5.2% |
| SOT Improvement since 2015 | | 7% | 21% | 36% | 87% | 115% | 107% | 118% |

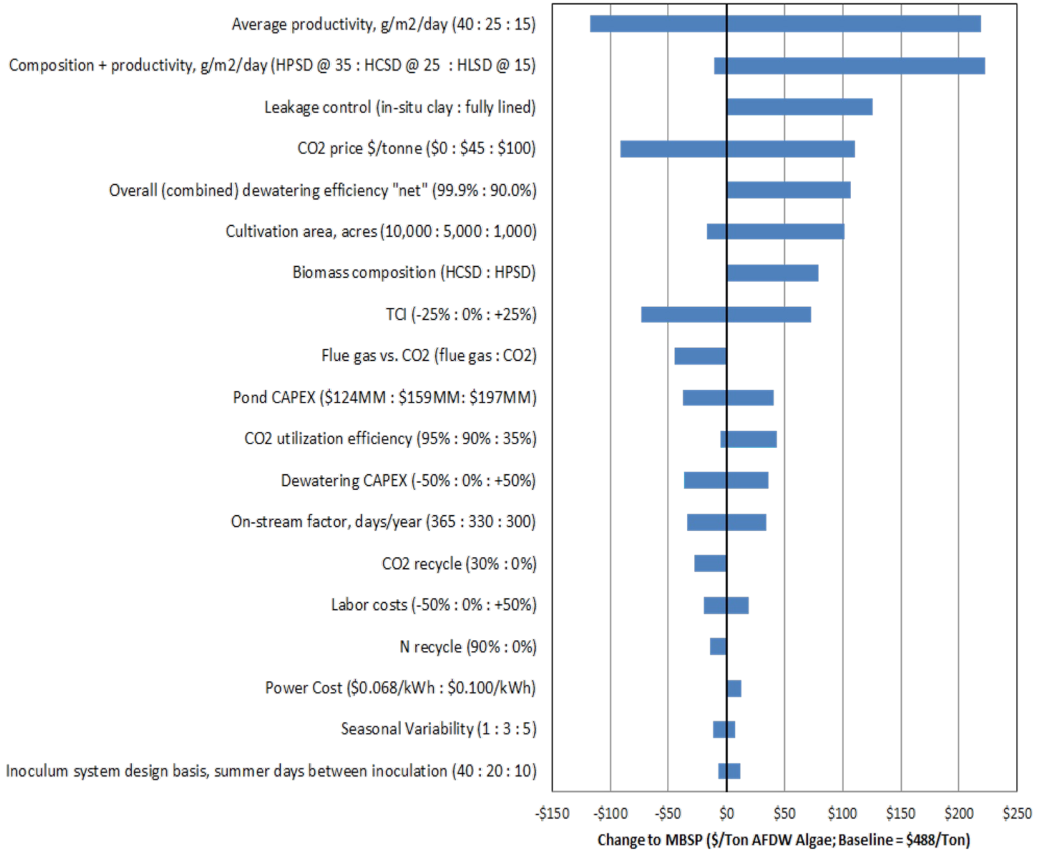
DISCOVR

Pacific Northwest NATIONAL LABORATORY · Los Alamos NATIONAL LABORATORY EST. 1943 · NREL Transforming ENERGY · Sandia National Laboratories · AzCATI Arizona Center for Algae Technology and Innovation · MINES

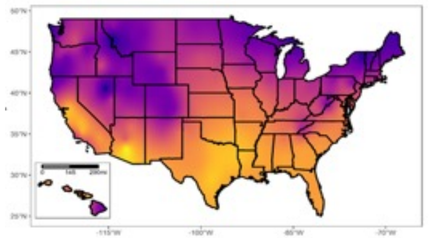


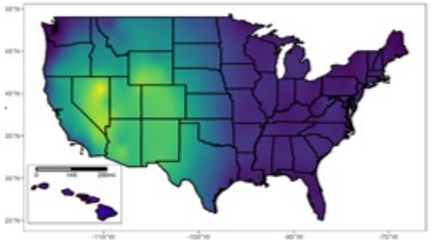

# Primary cost drivers (algae farm)*



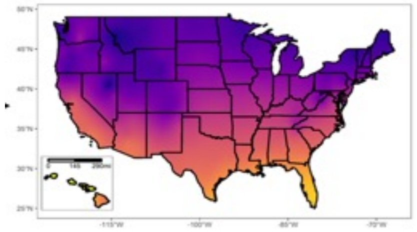

## Temperature Tolerance Map



## Water Demand Map



## Areal Productivity Map



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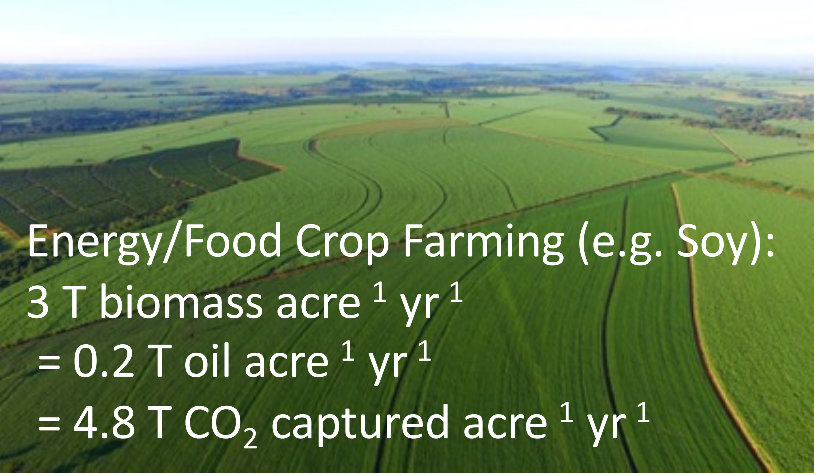
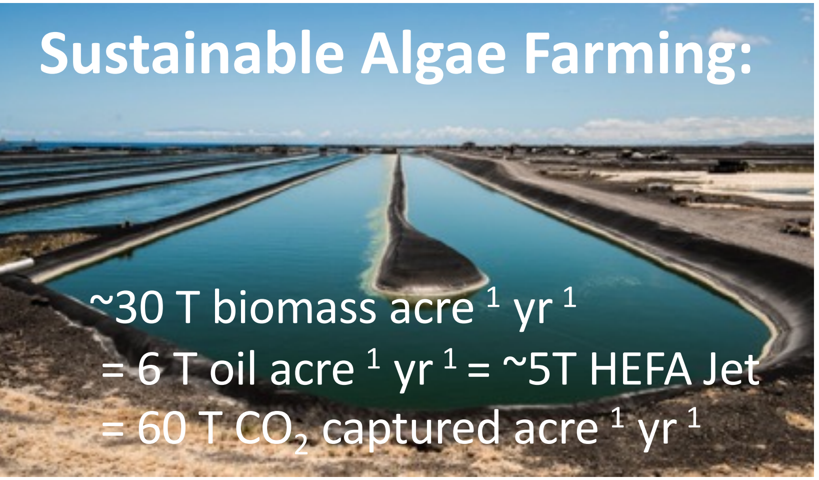


Energy/Food Crop Farming (e.g. Soy):
3 T biomass acre$^{1}$ yr$^{1}$
= 0.2 T oil acre$^{1}$ yr$^{1}$
= 4.8 T $CO_2$ captured acre$^{1}$ yr$^{1}$



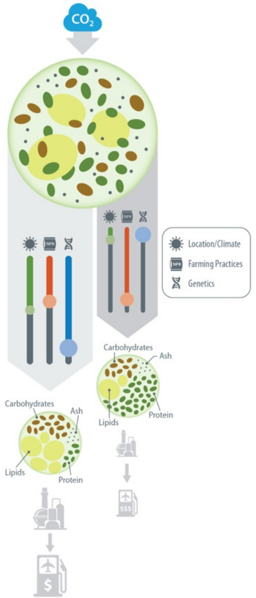
**Sustainable Algae Farming:**

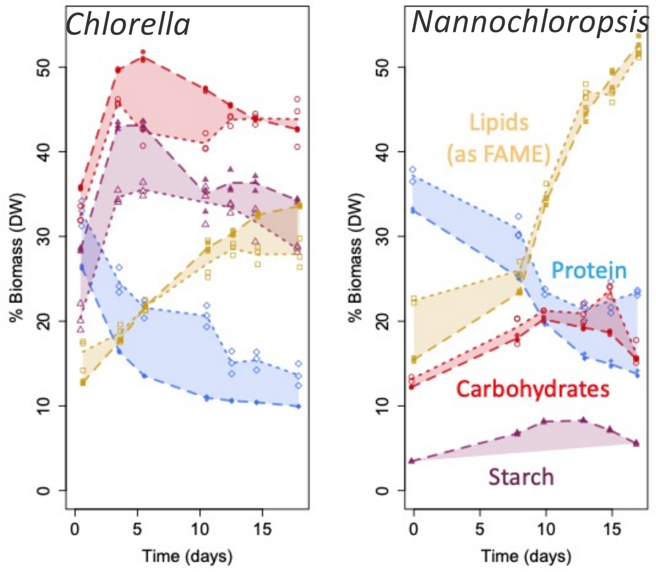
~30 T biomass acre$^{1}$ yr$^{1}$
= 6 T oil acre$^{1}$ yr$^{1}$ = ~5T HEFA Jet
= 60 T $CO_2$ captured acre$^{1}$ yr$^{1}$

| | NEPmax ($gCO_2$ $m^{-2}$ $d^{-1}$) | NEP (net ecosystem productivity) ($gCO_2$ $m^{-2}$ $year^{-1}$) |
|---|---|---|
| Maize* | 80.6 | 2108 |
| Wheat * | 42.9 | −135 |
| Algae+ | 60 | 16,000 |

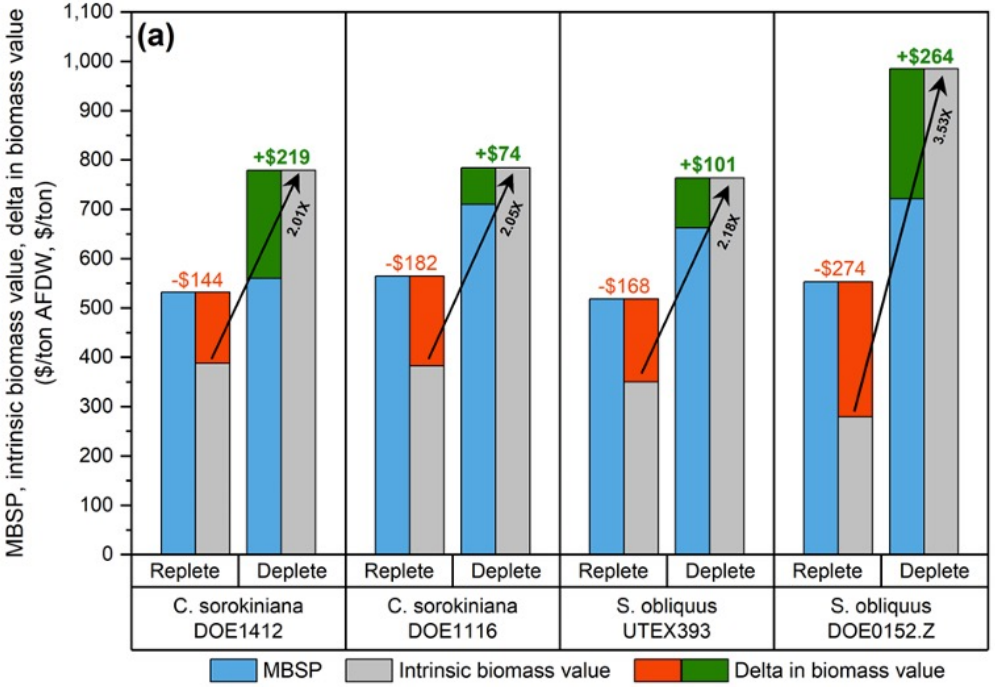
*Gilmanov et al., 2013
+Algae SOT (2021) https://www.nrel.gov/docs/fy18osti/70715.pdf

- Areal yield of biological storage intermediates (starch, lipids) for bioenergy can exceed terrestrial crops
- Substantial decarbonization potential thanks to high net ecosystem productivity
- Algal biomass composition is not static, rather highly responsive to cultivation manipulation and species, tailoring biomass quality for end-product use
- Shifting to >40% carbohydrates and/or >40% lipids can yield positive economic return for selected strains for a select biorefinery




Analytical Biochem. 2014 (452) 86-95




Klein, B., Davis, R., Laurens, LM., (2023) Algal Res, 72, 103094

NREL Transforming ENERGY

# Algal Biomass Composition Drives Down MFSP

Early ⟶ Mid ⟶ Late

Ferm Carbs

| Metric (%DW) | *Scenedesmus* | | | *Chlorella* | | | *Nannochloropsis* | | |
|---|---|---|---|---|---|---|---|---|---|
| | Early | Mid | Late | Early | Mid | Late | Early | Mid | Late |
| Ash | 5.6 | 2.3 | 2.1 | 4.7 | 2.1 | 2.6 | 14.2 | 13.6 | 5.1 |
| Ferm Carbs | 20.9 | 46.3 | 37.9 | | | | | | |
| Mannitol | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2.1 | 2.2 |
| Other carbohydrates | | | | | | | | | |
| Glycerol | 0.7 | 2.9 | 4.5 | 1.4 | 2.5 | 4.5 | 1.4 | 2.8 | 6.4 |
| | | | | | | | | | |
| Lipids (as FAME) | 6.6 | 26.5 | 40.9 | 13 | 22.1 | 40.5 | 12.3 | 25.6 | 57.3 |
| | | | | | | | | | |
| Chlorophyll | 3.0 | 1.2 | 1.2 | 5.8 | 2.4 | 2.1 | 3.0 | 1.8 | 0.3 |
| **non-FAME lipids** | | | | | | | | | |
| Nucleic acids | 4.06 | 1.47 | 0.99 | 4.61 | 1.05 | 0.94 | | | |
| | | | | | | | | | |
| **Energy content, HHV (BTU/lb)** | 9,165 | 10,070 | 11,122 | 9,219 | 9,372 | 10,822 | 9,192 | 10,104 | 13,160 |
| | | **$5.80** | **$5.10** | | | | | | |

| MFSP ($/GGE) | **$13.10** | **$5.80** | **$5.10** |
|---|---|---|---|

Laurens, L. *et al.*, 2017, Energy and Environmental Science, 10, 1716-1738

# Current Challenges/Gaps

- Data availability for long term cultivation at pilot/commercial scale remains scarce
  - Recent publication (2022) on year long cultivation in 1x500 $m^2$ raceway
  - Annual average = 20 $g/m^2$-day
  - Most studies <<100 $m^2$ and never more than several months to 1 year

Photosynthesis Research (2022) 154:303–328
https://doi.org/10.1007/s11120-022-00984-x

ORIGINAL ARTICLE

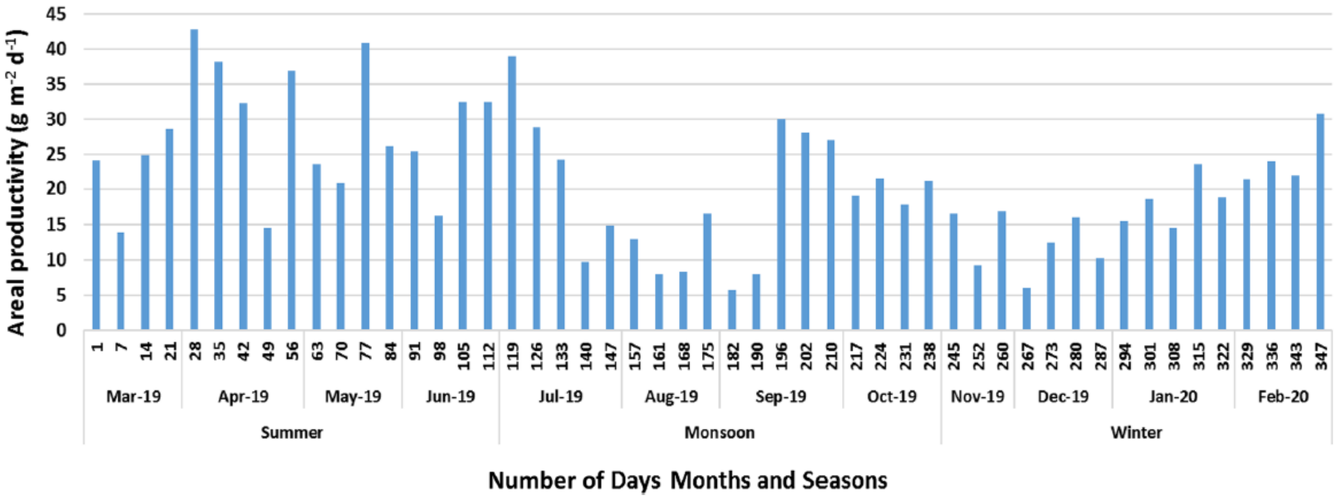
**Year-round sustainable biomass production potential of *Nannochloris* sp. in outdoor raceway pond enabled through strategic photobiological screening**

Kenny Paul[1] · Mahadev Gaikwad[1] · Poonam Choudhary[2] · Natarajan Mohan[2] · Puja Pai[1] · Smita D. Patil[1] · Yogesh Pawar[1] · Akshay Chawande[1] · Arun Banerjee[1] · Vinod Nagle[1] · Meenakshi Chelliah[2] · Ajit Sapre[1] · Santanu Dasgupta[1]

Received: 18 June 2022 / Accepted: 4 November 2022 / Published online: 25 November 2022


Reliance Industries algae development site, India

- Current DISCOVR work while multi-year and multi-cultivar, is still pre-pilot scale and limited to single location
  - Improvements observed thru a combination of strain selection and crop rotation and pest management
  - McGowen et al., 2022 [https://doi.org/10.1016/j.algal.2023.102995](https://doi.org/10.1016/j.algal.2023.102995)
- Developing effective integrated pest management (IPM) is required and is likely strain/site dependent



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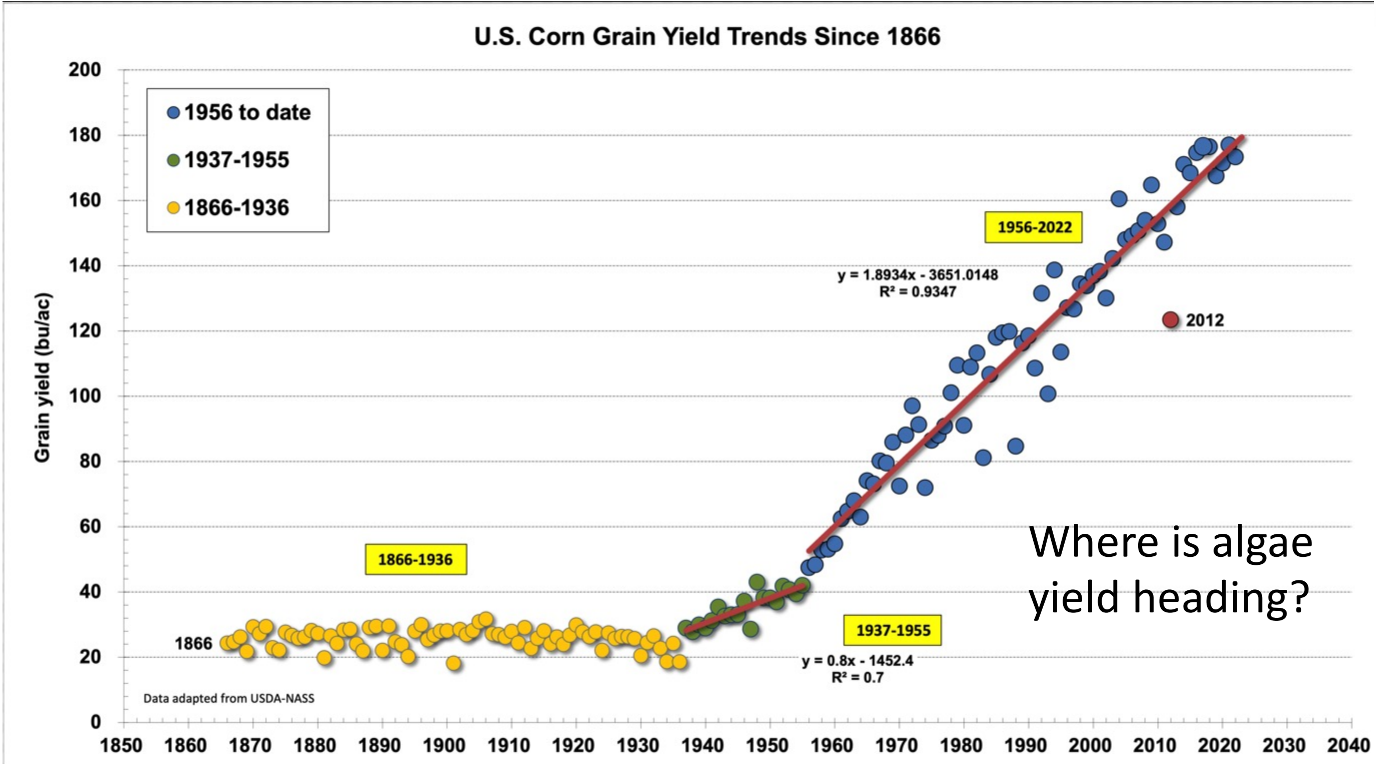
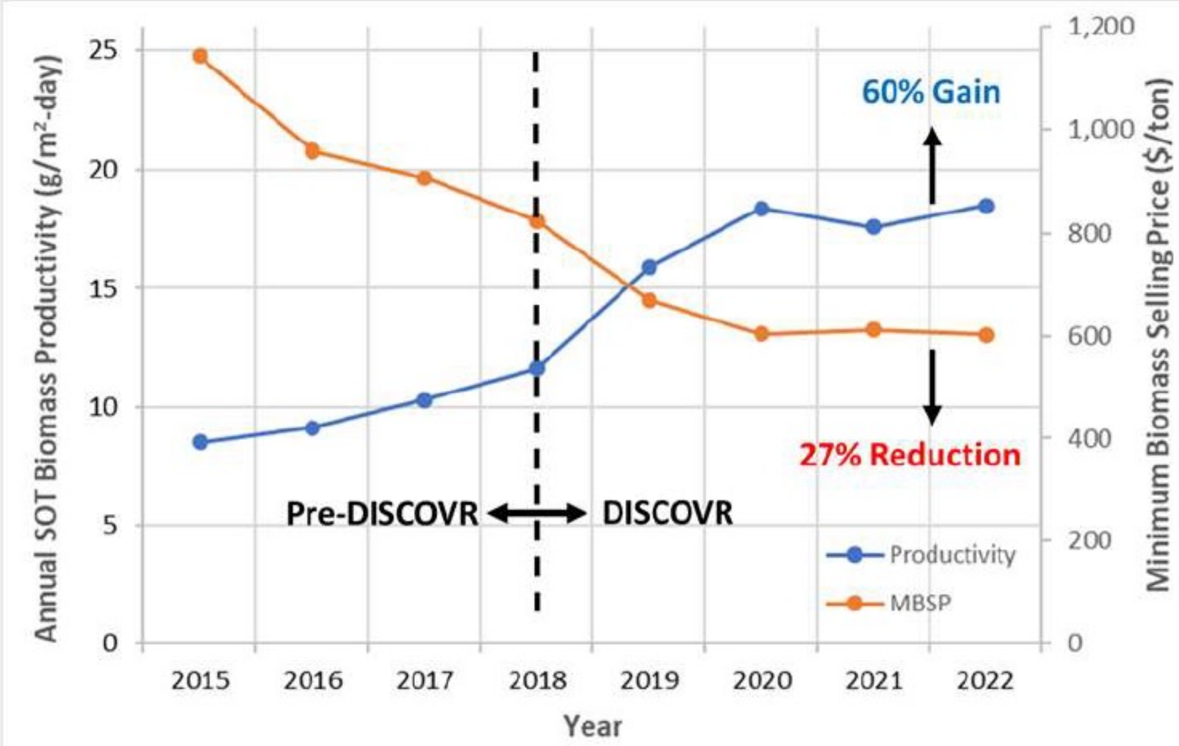
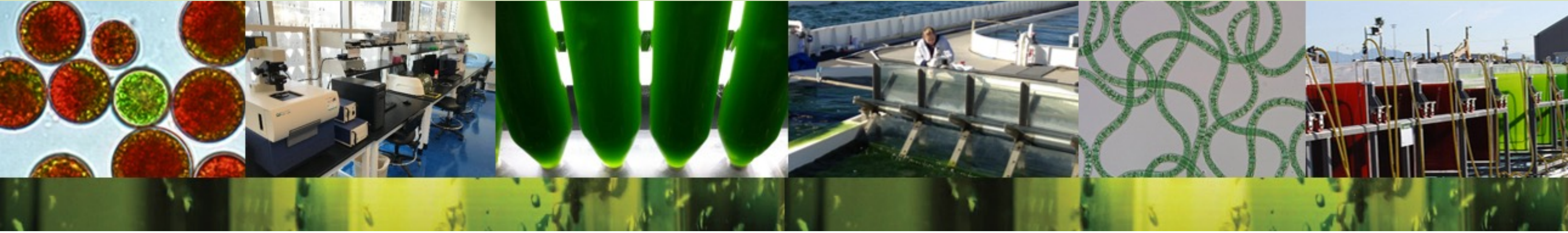
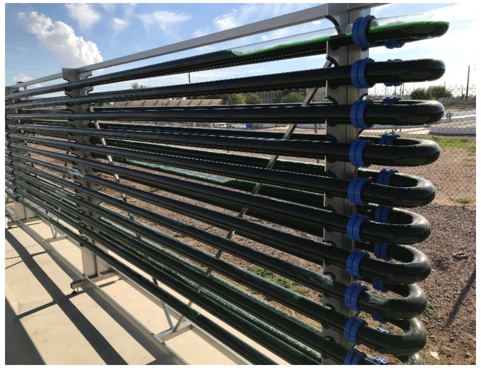
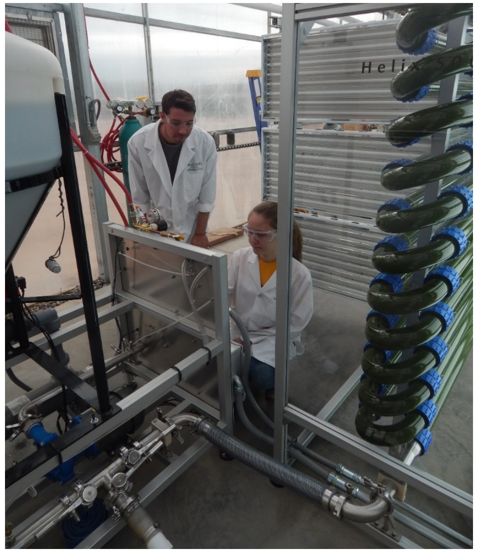



- Understanding yield and yield stability requires multi-year observations to de-risk commercialization
- Major data gaps exist - full unit op integration performance extremely limited/non-existent
  - e.g., harvest/dewatering, media and nutrient recycle etc.
- Bulk of data generated by ATP3/DISCOVR under non-limiting conditions (in particular N:P and CO2 and at small scales - many assumptions in farm model at scale not yet addressed
- How far can we extrapolate data?
  - Productivity modeling/scaling, machine learning, etc.?







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# THANK YOU!!

**If interested in engaging with AzCATI, please contact**


**John.mcgowen@asu.edu**

**Ph: 480-727-1472**


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ASU Ira A. Fulton Schools of Engineering
Arizona State University

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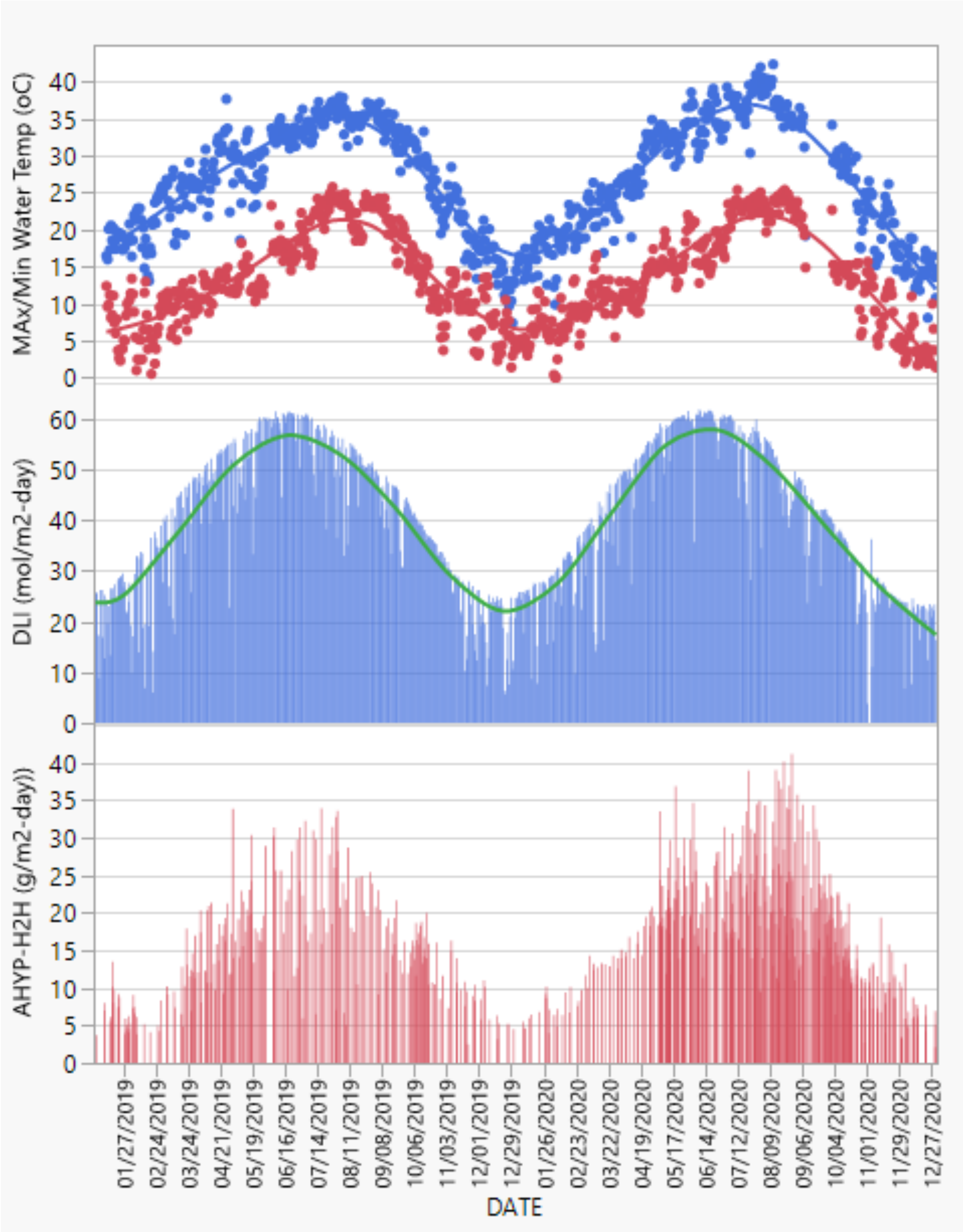
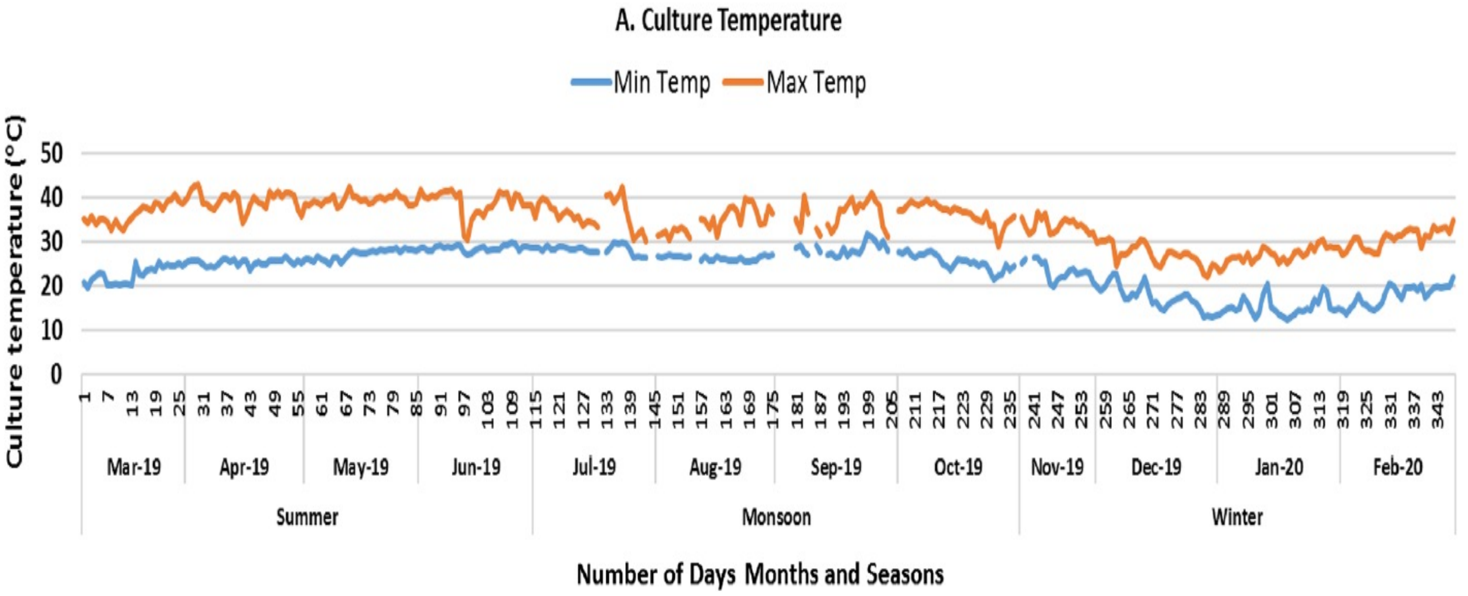
# What drives productivity? Light and Temperature

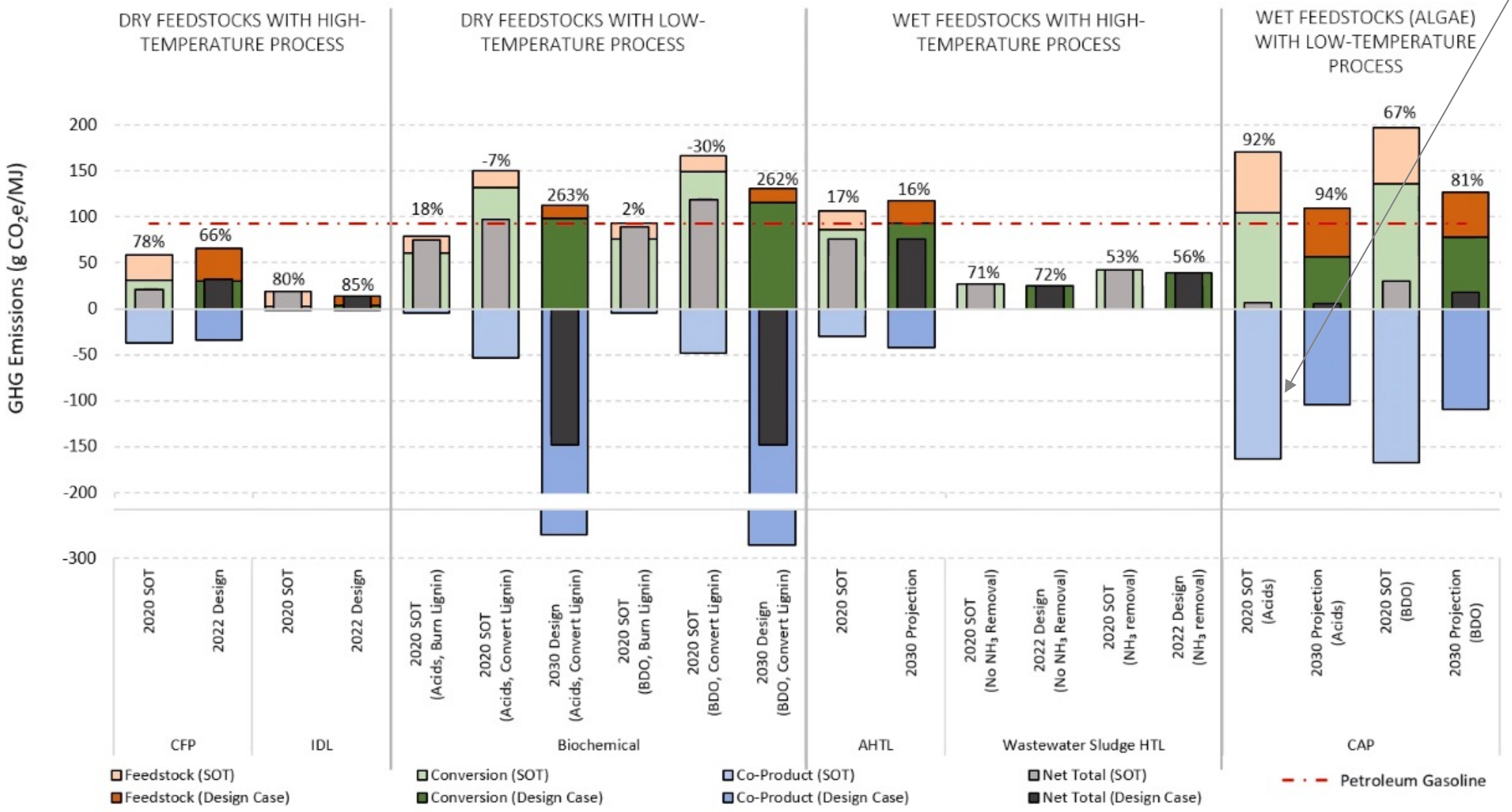



- Seasonal shifts in light and temperature have the largest effect on productivity for a given location and cultivar
- Depending on location, shoulder seasons can experience large swings in productivity and put significant pressure, positive and negative, on any particular strain



# Biorefinery Carbon Intensity (CI) Comparison

>90% CI reduction for algae pathways when focused on fuels, thanks to carbon negative bioproduct credits, assuming high carbohydrate/lipid profile




https://bioenergykdf.net/sites/default/files/2022-05/BETO-2020-SOT_FINAL_5-11-22.pdf

# AzCATI – A Research Laboratory and Testbed Facility for Algal Feedstock Production and Open R&D Collaboration

AzCATI
Arizona Center for Algae Technology and Innovation

# Open for Algae Business:
## Service Provider for the Algae R&D Community

- ***Project Activities***:
  - ✓ Biomass supply (1-100’s kg)
  - ✓ Equipment testing
  - ✓ Analytical testing
  - ✓ Culture maintenance and scale up (to 1000L)
  - ✓ Strain prospecting
  - ✓ Genetically engineered algae field trials
  - ✓ Education and Training Workshops
  - ✓ Contract R&D
  - ✓ Third-party validation
- ***Project Benefits***: access to facilities to drive technology R&D, de-risk and validate technological innovations
- ***>50 individual clients to date***
- ***>80 completed projects***

NREL National Renewable Energy Laboratory
Sandia National Laboratories
Los Alamos National Laboratory Est. 1943
INL Idaho National Laboratory
Cal Poly San Luis Obispo
University of Delaware
Old Dominion University
NRC·CNRC
PennState
Mines
Pacific Northwest National Laboratory
SRP Delivering more than power.™
aps
UK
OUC The Reliable One
nrg
Gore Creative Technologies Worldwide
Morgan Hill BioEnergy
intel
Nestlé Waters
evodos Separation Excellence. Today
Techverse, Inc. Advancing Energy Technologies
PPG
Diversified Technologies, Inc.
AlgEternal Technologies, LLC
HelioBioSys, Inc.
heliae
HelioPure
subitec
BioCellection Inc.
LIQ O FLUX
Carbon Collect
Litree
ZIVO Bioscience
SCHOTT glass made of ideas
Commercial Algae Professionals From Concept to Commercialization
Algenol Biofuels Cleaner - Greener - Cheaper
porelogix ultrafiltration systems
Reactive Surfaces Bringing Surfaces to Life
Advanced AgroBioFuels Feed, fuel and chemicals for the future
Pure Future