ALGAE BIOMASS SUMMIT

Advancing the State of Technology thru DOE funded algae cultivation R&D at the Arizona Center for Algae Technology and Innovation

Thursday, September 19, 2019

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One little cell, a world of possibilities.

AzCATI
Arizona Center for Algae Technology and Innovation

ASU Ira A. Fulton Schools of Engineering
Arizona State University

ATP3
Algae Testbed Public-Private Partnership

DISCOVR

U.S. DEPARTMENT OF ENERGY

SOT Project Partners

ATP3 Algae Testbed Public-Private Partnership

AzCATI Arizona Center for Algae Technology and Innovation

NREL National Renewable Energy Laboratory

Sandia National Laboratories

Cal Poly San Luis Obispo

UTEX The Culture Collection of Algae at The University of Texas at Austin

Georgia Tech

cellana algae-based products for a sustainable future

Florida Algae, LLC

U.S. Department of Energy

Valicor Renewables

Harmon Consulting

Commercial Algae Professionals From Concept to Commercialization

Litree

evodos Dynamic Settlers

ASU LightWorks

ASU Ira A. Fulton Schools of engineering Arizona State University

DISCOVR

Pacific Northwest National Laboratory

Los Alamos National Laboratory Est. 1943

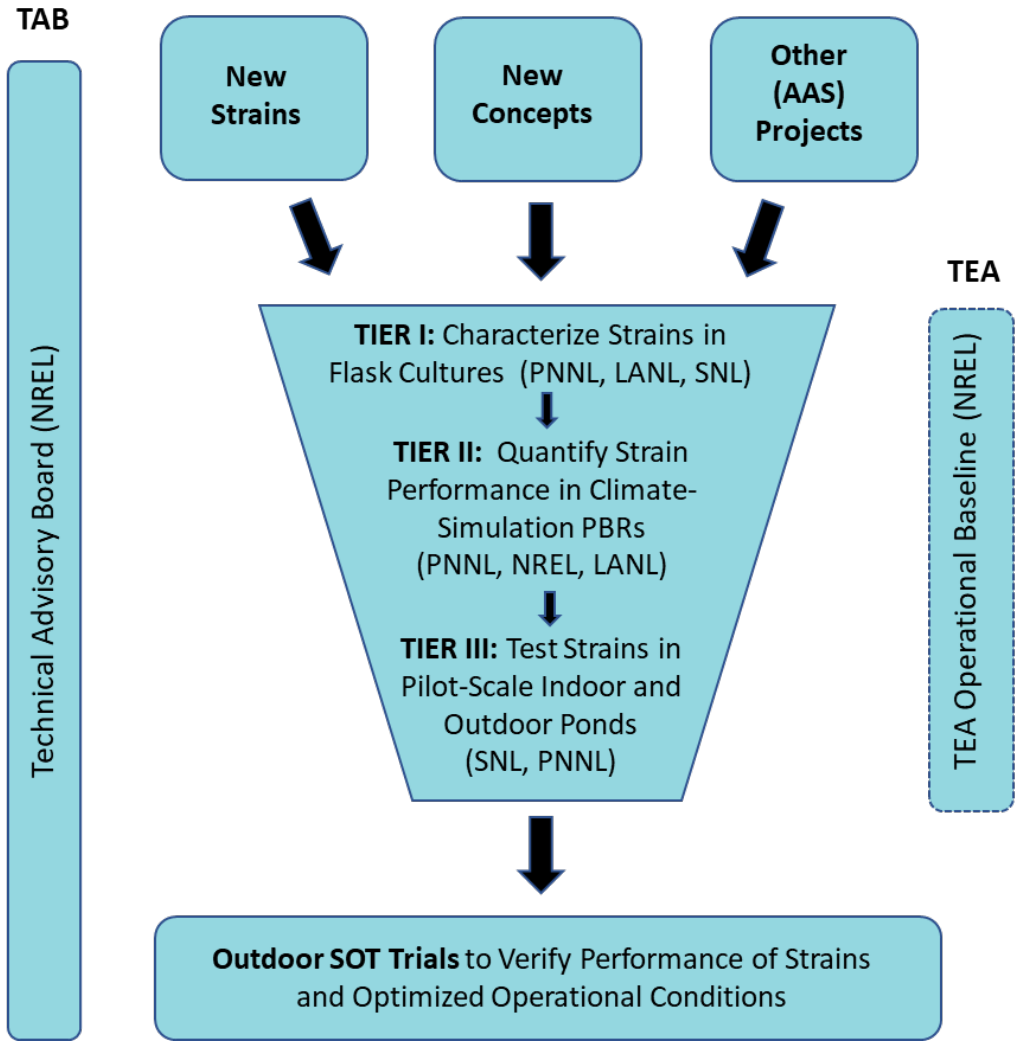
NREL National Renewable Energy Laboratory

Sandia National Laboratories

AzCATI Arizona Center for Algae Technology and Innovation

DISCOVR Project Framework – Proposed Revision

New Strains and Concepts are Tested in Pipeline Prior to SOT Trials



ATP³ Primary Objectives

Strain Identification & Isolation

Biomass Production & Supply

Analytical Services

Education & Training

Equipment Testing

ATP³ offers access to a wide array of services, capabilities and facilities:

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

Collaborative Open Testbeds

- Form a national network
- Provide access to stakeholders
- Share knowledge, accelerate learning
- Accelerate R&D outcomes
- Reduce technology and business risk

Collect and Distribute High Impact Data

- Unified research programs
- Pipeline for collection of **high-quality cultivation data** to support algae computational **modeling** including biomass productivity, techno-economic, and life cycle assessment.
- Make data available publically

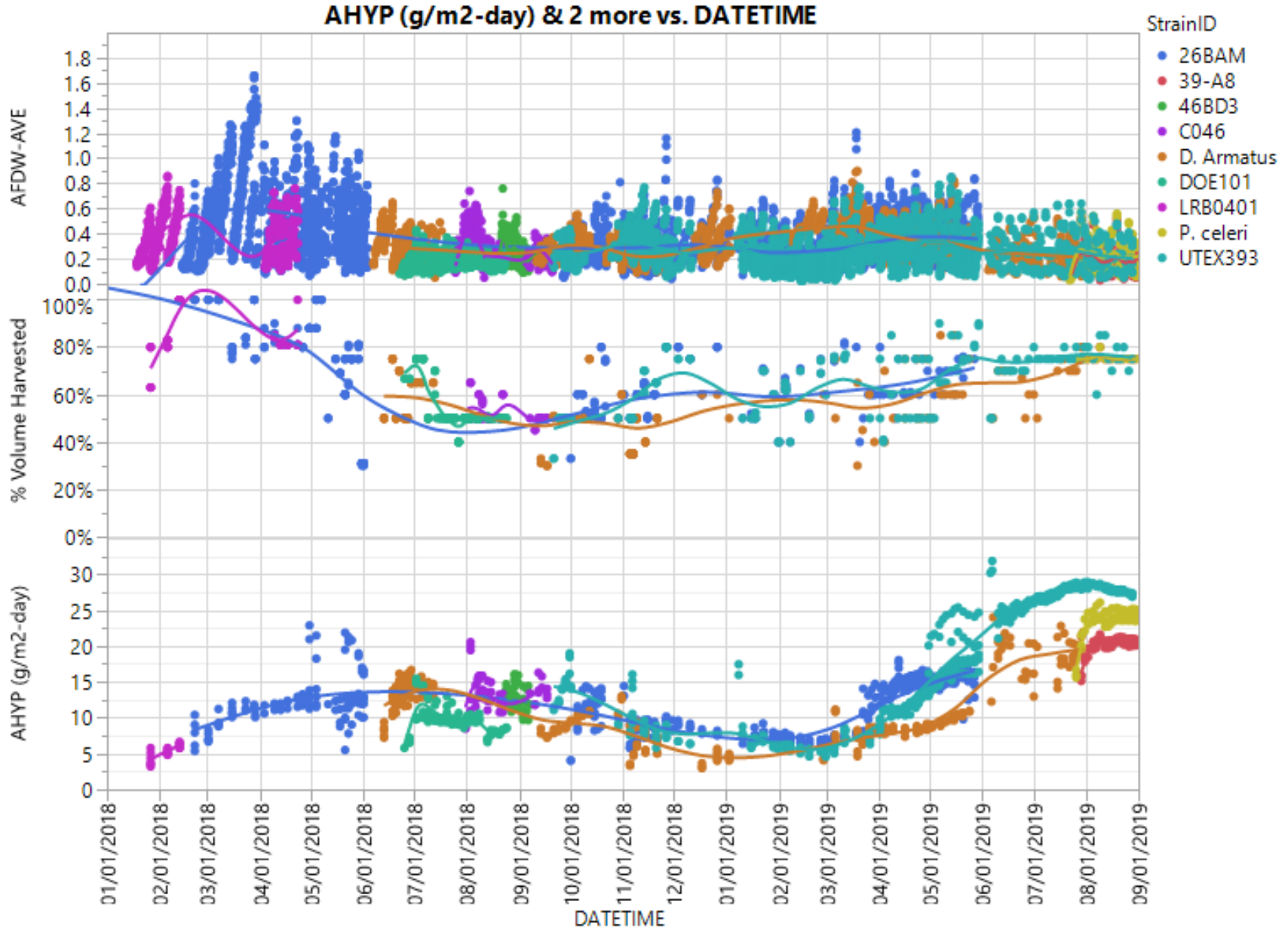
High Impact Data:
Long Term Algal Cultivation Trials

ATP^3 set standards, conducting harmonized, rigorous, and objective **long term cultivation trials** to provide a realistic assessment of the **state of technology** for algal based biofuels and bioproducts.

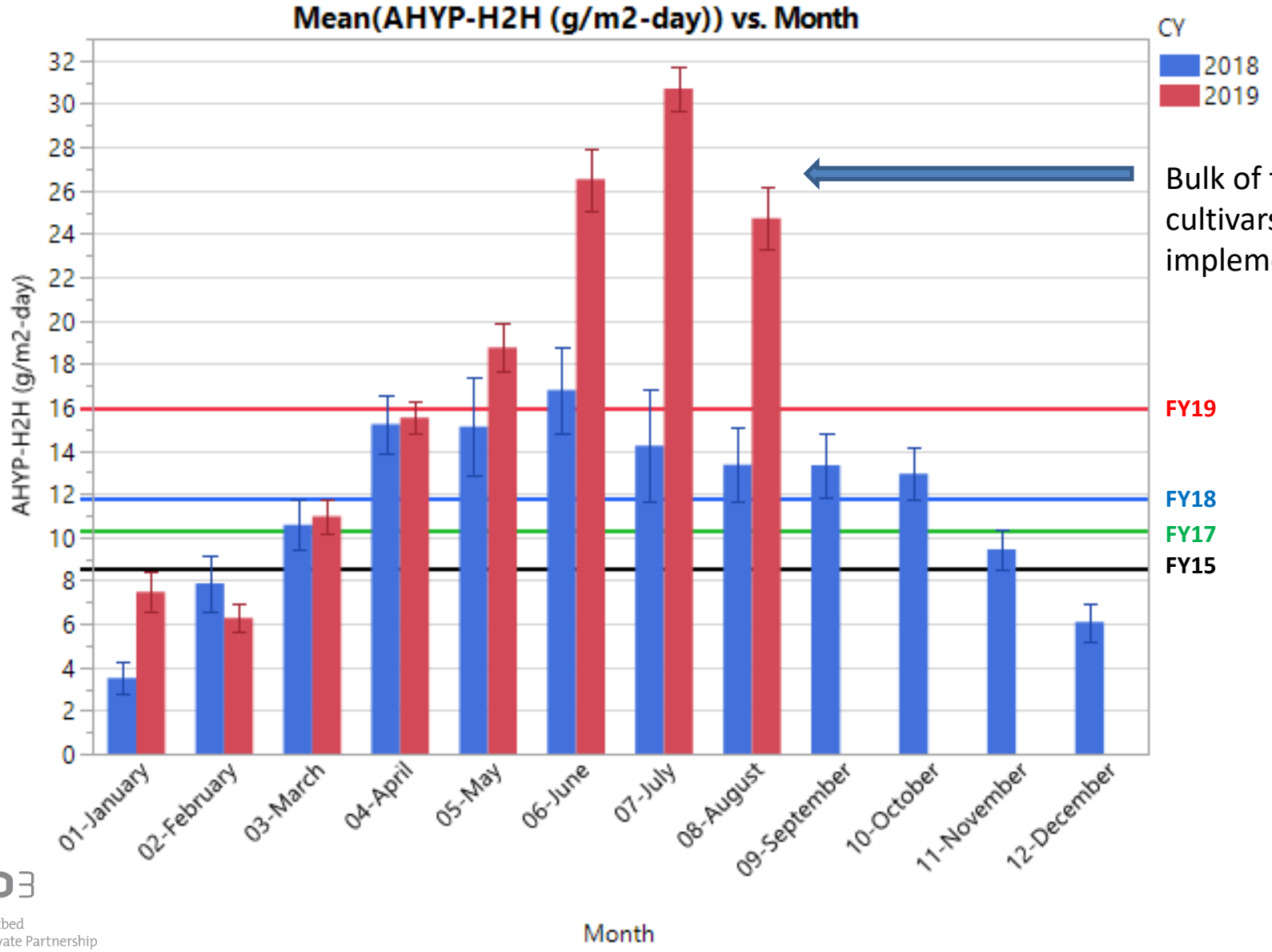
- Our Unified Field Studies (UFS) at the testbed sites along with our Advanced Field Studies (AFS) enabled **comparisons of promising production strains at meaningful scale** across variable conditions, season over season, year over year – *enabling **agronomics***
- Our **harmonized and validated** SOP's for analytical and production processes ensured **data integrity** across all sites with protocols and data from the UFS and AFS publicly available and providing a critical resource to TEA and LCA analysis yielding **high impact, validated data** http://en.openei.org/wiki/ATP3
- The SOT experimental framework established under ATP^3 carried forward across all DOE projects performed with AzCATI including DISCOVR – *allows for data to be **readily utilized in the SOT framework** regardless of project more efficiently leveraging the DOE AAS portfolio*

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

2018/2019 SOT Cultivation Trials



2018/2019 SOT Cultivation Trials



Bulk of the year over year improvement from better cultivars and successful crop protection strategy implementation this summer

FY2019 DISCOVR SOT Results

Season	Prod. g/m2-day	Strain	Days	operation conditions	Prod. g/m2-day	Strain	Days	operation conditions
Summer	15.4	Desmo sp.	51.0	20 cm - Semi	27.1	UTEX 393	85.0	20 cm - Semi
Spring	15.2	26BAM	80.0	10 cm - Semi	18.6	UTEX 393/26BAM	84.0	10/20 cm (26BAM/393)- Semi
Winter	7.7	26BAM	46.0	10 cm - Batch	6.4	26BAM	91.0	10 cm - Semi
Fall	8.5	Nanno ('16)	42.0	25 cm - Batch	11.4	C046/26BAM	66.0	20/10 cm (Sep-Oct/Nov) - Semi
Average	**11.7**		**54.8**		**15.9**		**81.5**	
Year over year (YOY) Improvement	n/a		Total days	219.0	35.6%		Total days	326.0

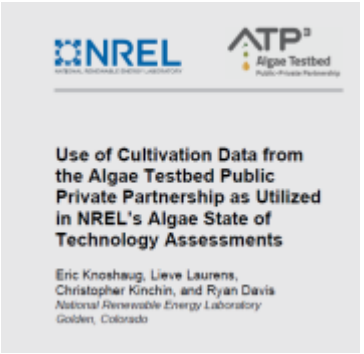
36% improvement in annual average productivity achieved under the DISCOVR SOT campaigns in FY2019 relative to FY2018

Season	Month	Productivity g/m2-day	AFDW at Harvest g/L	Days	Strain	Season Avg.
Summer	Aug-19	24.3	0.36	28	UTEX393	27.1
	Jul-19	30.6	0.48	30	UTEX393	
	Jun-19	26.3	0.43	27	UTEX393	
Spring	May-19	26.3	0.48	28	UTEX393	18.6
	Apr-19	17.7	0.61	28	26BAM	
	Mar-19	11.8	0.57	28	26BAM	
Winter	Feb-19	6.3	0.32	28	26BAM	6.4
	Jan-19	7.0	0.41	25	26BAM	
	Dec-18	5.9	0.6	38	26BAM	
Fall	Nov-18	9.7	0.40	27	26BAM	11.4
	Oct-18	13.5	0.38	23	26BAM	
	Sep-18	10.9	0.36	16	C046	

NREL TEA Sets SOT Benchmarks

Season	2015 SOT (ATP³)	2016 SOT (ATP³)	2016 SOT (ABY1 Performer)	2017 SOT (ATP³)	2018 SOT (ATP³/ DISCOVR/ RACER)	2019 SOT (DISCOVR)	2030 Projection
Summer	10.9	13.3	17.5	14.1	15.4	27.1	35.0
Spring	11.4	11.1	13.0	13.2	15.2	18.6	28.5
Fall	6.8	7.0	7.8	8.5	8.5	11.4	24.9
Winter	5.0	5.0	4.8	5.5	7.7	6.4	11.7
Average	**8.5**	**9.1**	**10.7**	**10.3**	**11.7**	**15.9**	**25**
Max variability	**2.3:1**	**2.7:1**	**3.6:1**	**2.6:1**	**2.0:1**	**4.2:1**	**3.0:1**
MBSP ($/ton, 2016$)	**$1,142**	**$1,089**	**$960**	**$909**	**$824**	**$670**	**$488**

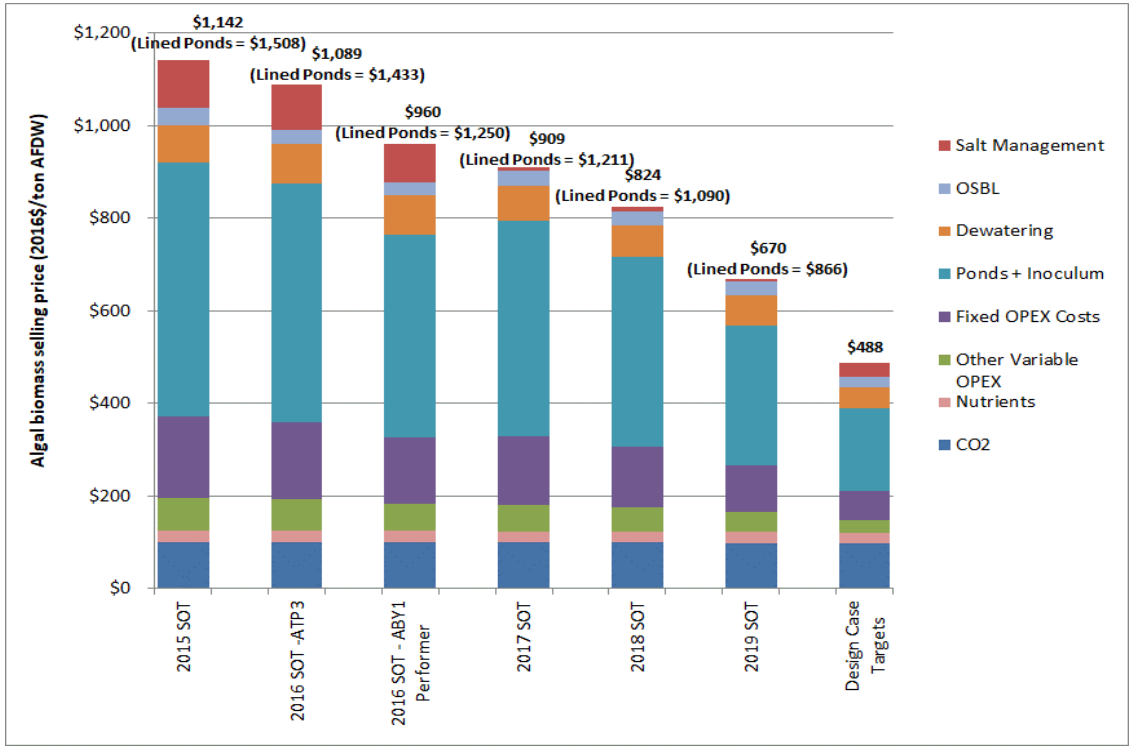
ATP3 cultivation data and methods available at:
http://www.nrel.gov/docs/fy17osti/67289.pdf



- Biomass SOT tracked since 2015
- Cultivation data furnished by test-bed partners led by ASU (supplemented by ABY1 industry performer in 2016)
- 2019 supported under DISCOVR – based on AzCATI test-bed trials

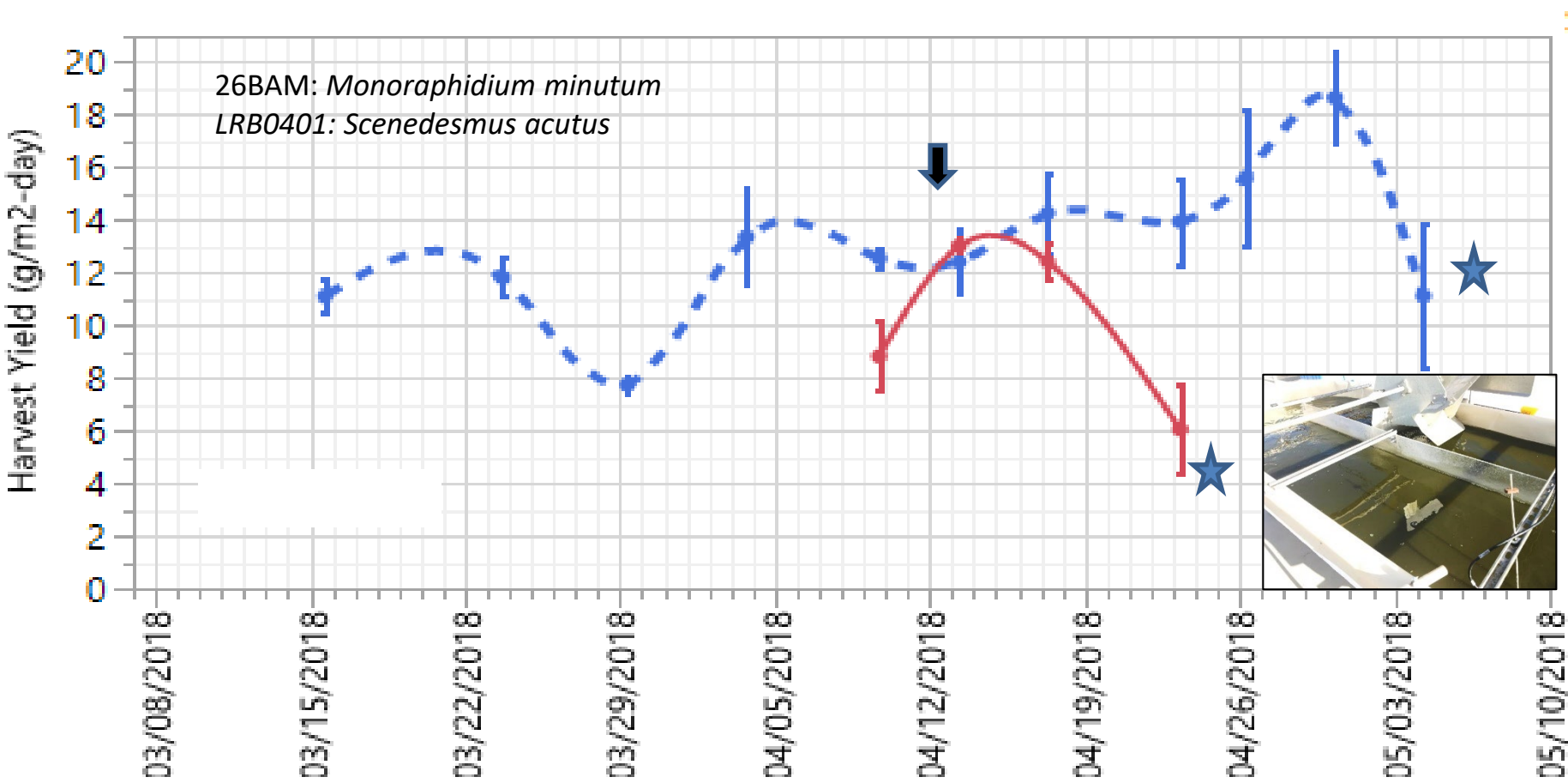
- Yearly improvements:
  - 2016: 7%
  - 2017: 13%
  - 2018: 14%
  - 2019: 36%
  - 2030: Only **4% per year required from 2019 onward**

Strain rotations, operational adjustments



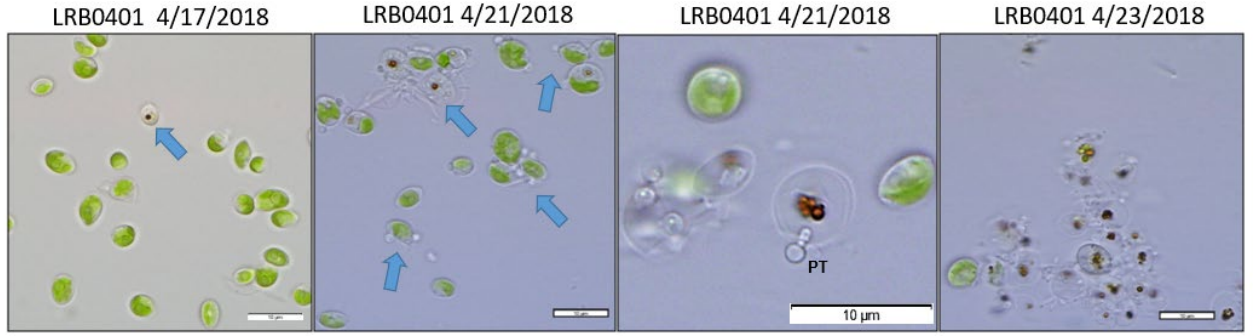
What's (one of) the problem(s)?

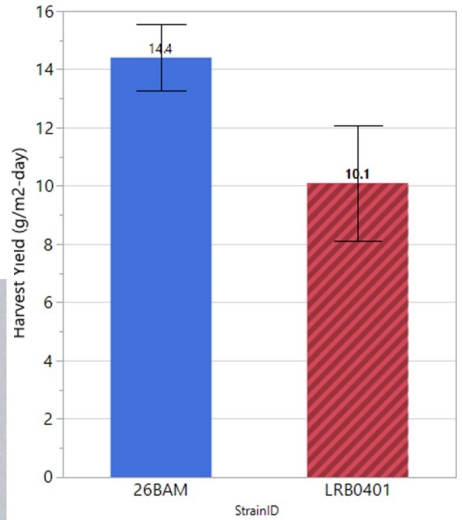
Narrator: "Things that keep killing your cultures…"



- 1st sign of chytrid via microscopy. Present for both strains.
- 26BAM more robust than LRB0401 maintaining high productivity ~2 weeks longer

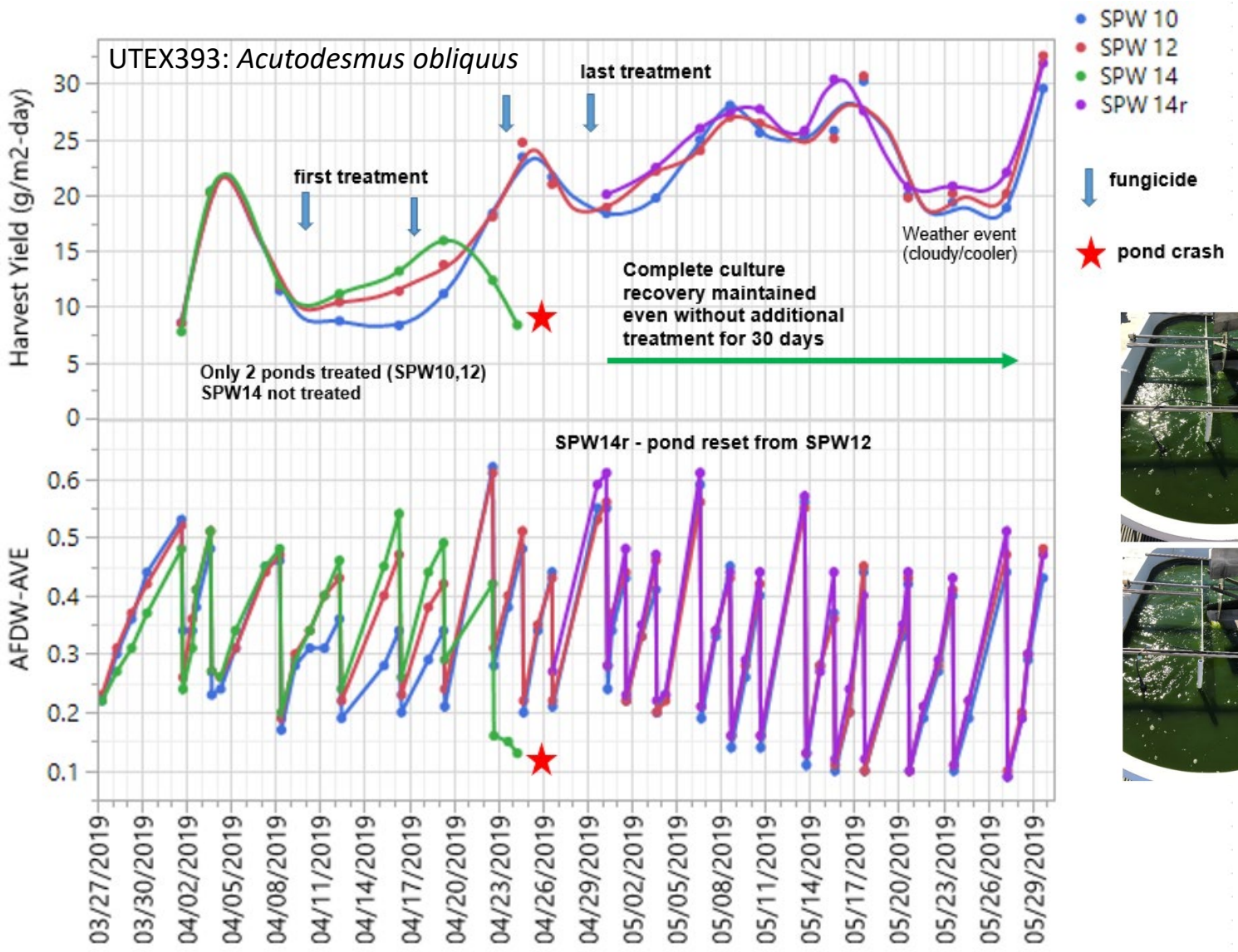
★ - ponds crashed

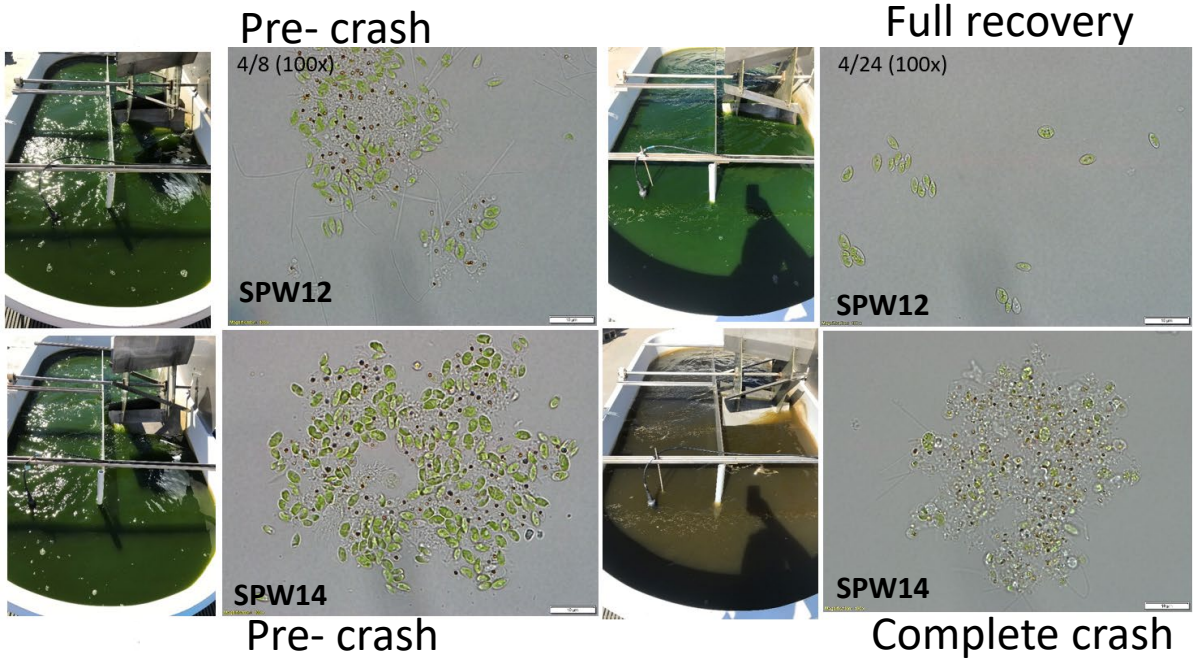




What's (one of) the solutions?

Narrator: "finding ways to *NOT* have things keep killing your cultures…"





Estimating the Achievable Productivities in Mesa, AZ

Challenge

- Reach the DOE-BETO target annual productivity of 25 g/m^2/day by 2030

- In temperate locations, the cold-season (late Fall, Winter, early Spring) is a major challenge in further improving average annual biomass productivities.

- Two primary limiting factors for achieving high biomass productivities in temperate locations during the cold-season:
  1. **Reduced total photons: shorter daylength, lower light intensity.**
  2. **Temperatures are below optimal for many strains (*e.g.*, <15 °C*)***

- *Thought experiment to address the challenge:*
  Assuming *we can find cold-hardy strains and therefore photons are the primary limiting factor*, what productivities can we estimate for the winter season in Mesa, AZ given the average daily light flux?*

  **Also assuming no culture crashes due to contamination or mechanical failures*

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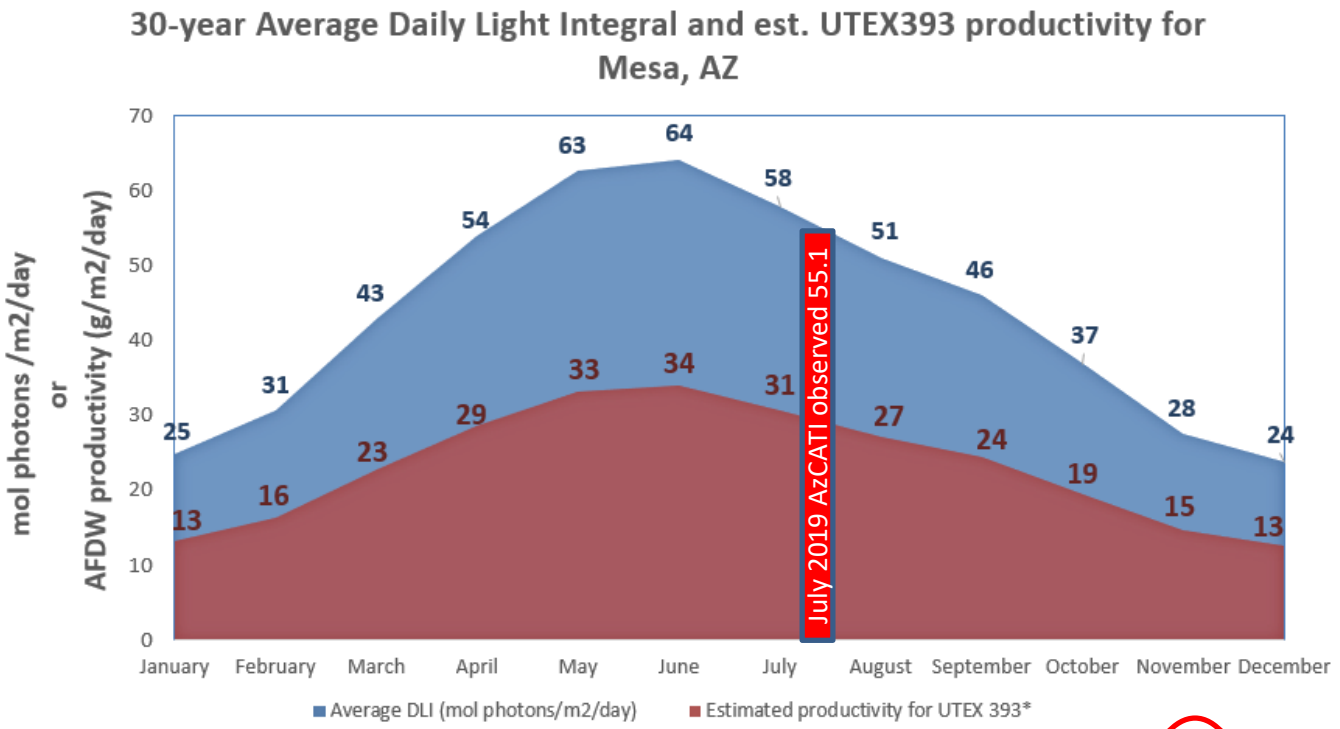
Estimating the Achievable Productivities in Mesa, AZ



ANNUAL SUMMARY

	Average DLI	2019 SOT	Est. Prod. (UTEX 393*)	Productivity Gap
January	25	7.0	14	49%
February	31	6.3	17	63%
March	43	11.8	24	50%
April	54	17.7	30	41%
May	63	26.3	35	25%
June	64	26.3	36	26%
July	58	30.6	32	5%
August	51	24.3	28	10%
September	46	10.9	26	57%
October	37	13.5	20	34%
November	28	9.7	15	37%
December	24	5.9	13	55%
Annual Average	44	16.0	24.2	38%

*assuming same conversion efficiency as in summer

Season	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Summer	10.9	13.3	14.1	15.4	27.1	28.5	29.9	31.4	32.9	34.6	36.3
Spring	11.4	11.1	13.2	15.2	18.6	19.5	21.5	23.6	24.8	26.1	27.4
Fall	6.8	7	8.5	8.5	11.4	14.8	17.0	19.6	20.6	21.6	22.7
Winter	5.0	5.0	5.5	7.7	6.4	7.0	8.1	9.3	9.8	10.3	10.8
Average	**8.5**	**9.1**	**10.3**	**11.7**	**15.9**	**17.5**	**19.1**	**21.0**	**22.0**	**23.1**	**24.3**
Year over year (YOY) Improvement	N/A	7%	13%	14%	36%	10%	10%	10%	5%	5%	5%
SOT Improvement since 2015		7%	21%	38%	87%	105%	125%	147%	159%	172%	186%

Disclaimer: I take no credit for this analysis (well – I take credit for productivity data used for the analysis). This is all due to a thought experiment performed and presented to the DISCOVR team by Scott Edmundson **(a true renaissance man of algae!).** And yes…we all understand this has a zillion assumptions….RELAX…its just a thought experiment and **HELPS US KEEP OUR HOPES UP!!!**

Last Thoughts

- ATP^3 established a validated framework for implementing rigorous, long-term multi-site cultivation trials (including GM) and transitioned it into DISCOVR
  - SOT cultivation trials are a crucial activity and resource generating public, open source data sets to formally benchmark progress year over year for BETO and the algae R&D stakeholder community
  - Leveraging BETO AAS investments across the portfolio
- Lot's of progress across the algae R&D community
  - Still a long way to go…
    - (biomass quality/composition, reliability, opex/capex, commercialization, etc., etc.)
  - But we are showing that we are trending in the right direction

Acknowledgements

ASU
Gary Dirks
John McGowen
Thomas Dempster
Pete Lammers
Milt Sommerfeld
William Brandt
Jessica Cheng
Jessica Forrester
Sarran Chinn
Sarah Arrowsmith
Sarah Kempkes
David Cardello
Theresa Rosov
Maria Bautista
Mary Cuevas
Joel Izzet
Richard Malloy
Henri Gerken
Pierre Wensel
Linda Boedeker
Jamie Rock
Sarah Mason
Travis Johnson
Sydney Lines

UTEX
Schonna Manning
Jerry Brand

Valicor Renewables
Kiran Kadam
Brian Goodall

NREL
Phil Pienkos
Lieve Laurens
Eric Knoshaug
Ed Wolfrum
Ryan Davis
Christopher Kinchin
Stefanie Van Wychen

Sandia National Labs
Ron Pate
Todd Lane
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Patricia Gharagozloo
Thomas Reichardt
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Commercial Algae Professionals
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  - Mike Guarnieri
  - Stefanie Van Wychen
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  - Song Gao
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  - Madison Clar, Henri Gerken,
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