World Congress on Industrial Biotechnology

The Unified Field Studies of the Algae Testbed Public Private Partnership: What did we learn and where are we going?

Tuesday July 25, 2017 2:30 PM - 4:00 PM
Feedstocks, Agriculture Crop Technologies and Biomass Supply

One little cell, a world of possibilities.

ATP3 Algae Testbed Public-Private Partnership

U.S. DEPARTMENT OF ENERGY

ASU Arizona State University

AzCATI Arizona Center for Algae Technology and Innovation

World Congress on Industrial Biotechnology

ATP3 Algae Testbed Public-Private Partnership

Dr. John McGowen: Director of Operations and Program Management for ATP3
Arizona State University's AzCATI

AzCATI Arizona Center for Algae Technology and Innovation

Dr. Edward Wolfrum: Data Management Lead for ATP3
National Renewable Energy Laboratories

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Dr. Lieve Laurens: Analytical Lead for ATP3
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Valerie Harmon: Experimental Design Lead for ATP3
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ATP3 Algae Testbed
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ATP3 partners

AzCATI
Arizona Center for Algae Technology and Innovation

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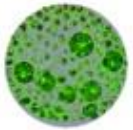
Sandia National Laboratories


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

CAL POLY
SAN LUIS OBISPO

Georgia Tech

cellana
algae-based products for a sustainable future

FLORIDA ALGAE, LLC

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COMMERCIAL ALGAE PROFESSIONALS
From Concept to Commercialization

Litree立升

evodos
DYNAMIC SETTLERS

ASU LightWorks

ASU IRA A. FULTON SCHOOLS OF engineering
ARIZONA STATE UNIVERSITY


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ASU Undergrads
Shaylin Mcghee
Daniel Breyfogle
Levi Bunker
Thomas Chengattu
Delaney DeHertogh
Mark Ford
Riley Greer
Dilon Hurley
Kevin Lawson
Shelby Lui
Carlos Luna
Miguel Martinez
Joe Palaski
Casey Peterson
Jeremy Poet
Alexandra Prassas
Sherry Saethao
Jay Tenison
Jessica Vaughn
Wyatt Western
Mykal Ybarra

GT Undergrads
Fariha Hassan
Jerry Duncan
Frazier Woodruff
Shusuke Doi
Hao Fu
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Allison Dunbar
Allison Carr
Sichoon Park
Priya Pradeep
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Christine Yi

CP Undergrads
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Gulce Ozturk
Kaitlyn Jones
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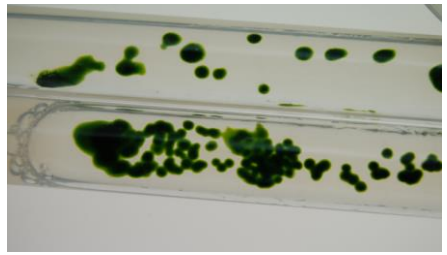
Soroush Aboutalebi
Lauren Miller
Samantha Lui
Michele Hendrickson
Gabriella Campos
Will Briles
Letty Thottathil

Arizona Center for Algae Technology and Innovation

The Arizona Center for Algae Technology and Innovation (AzCATI) was formed in 2010 through federal stimulus funding designated by the Science Foundation of Arizona to serve as a hub for research, testing, and commercialization of algae-based technologies and products.



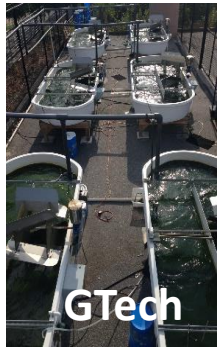
- **Connect**
  - Strain development for multiple applications
  - Carbon capture and bioremediation from industrial/municipal/Ag sources
- **Advance**
  - Development of next generation algal mass culture systems and processes
  - System scale-up and systems/processes integration
- **Collaborate**
  - Evaluation of algae products/co-products
- **Educate**
  - LCA and techno-economical assessment of algae-based biotechnologies
- **Launch**
  - Development of State/National test bed facilities

ATP³ national "open" test bed

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.

Provide increased stakeholder access to algae facilities, expertise, and high quality services across the country.

Perform long term cultivation trials provide high impact data for technoeconomic and life cycle assessments.



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

Goal Statement

Establish a **sustainable network of regional testbeds** that empowers **knowledge creation** and **dissemination** within the algal R&D community, **facilitates innovation**, and **accelerates growth** of the nascent algal biofuels and bioproducts industry.

Outcomes:

- **Increased stakeholder access** to high quality, outdoor cultivation and laboratory facilities
  - Over 40 different testbed clients and >60 completed projects in 4+yrs.
  - Mix of national lab, academic and industrial stakeholders
  - 12 education/training workshops held at 3 ATP^3 sites and 2 additional sites
- **Support DOE**'s techno-economic, sustainability, and resource modeling activities and **close critical knowledge gaps** and inform robust analyses of the **state of technology** for producing algal biofuels and bioproducts
  - ATP^3 cultivation data **the prime source** for 2015, 2016, and 2017 BETO SOT
  - ATP^3 has set high data quality standards with 3+ yrs of cultivation data that is completely available to the public
  - Data already seeing use beyond ATP^3 teams and BETO SOT

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

Approach: Project Timeline

Phase 1 M1-12

Major Milestones

- ATP organization, **systems and processes established**
- Methodologies **harmonized**
- Initial cultivation trial and **detailed experimental planning completed**

Critical Success Factor:
Network established and experimental framework validated demonstrating readiness to proceed with the long term cultivation trails

Successful Go/No Go February 2014

Phase 2 M13-36

Major Milestones

- Cultivation trials **complete**
- Data made **widely available**
- **State of algal biofuels technology design report** completed (2015)

Critical Success Factor:
Capability of testbed network to **serve stakeholder community** demonstrated

Successful Go/No Go March 2016 (with scope change to extend multisite cultivation trials into Phase 3)

Phase 3 M37-60

Major Milestones

- State of algal biofuels technology **design report updated (2016 and 2017)**

Critical Success Factor:

- Value proposition validated and funding secured to **sustain network** in out years
- Requires a robust algal industry seeking access to user facilities and expertise
- **CONTINUED, ROBUST FEDERAL SUPPORT NEEDED**

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ATP3 Video

ATP³: Open for Business

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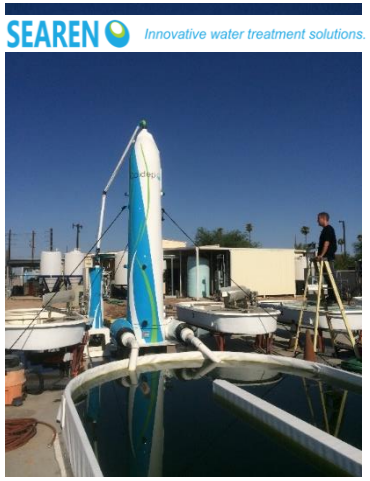
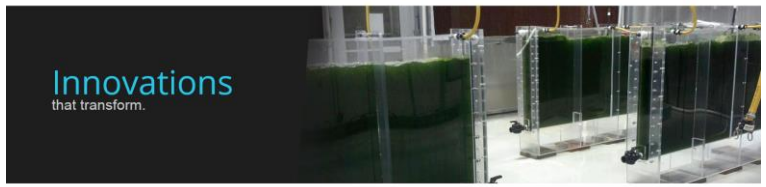
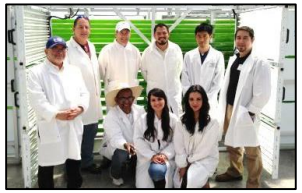
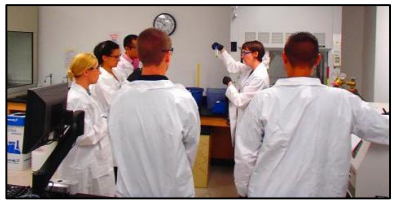
- ***Project Activities***:
  - ✓ biomass supply (1-100's kg)
  - ✓ equipment testing
  - ✓ analytical testing
  - ✓ Culture maintenance and scale up
  - ✓ genetically engineered algae field trials
  - ✓ Education and Training Workshops
- ***Project Benefits***: access to facilities to drive technology R&D, de-risk and validate technological innovations
- ***>40 individual clients to date***
- ***>60 completed projects***
- ***>$800K in additional TB revenue***





Education and Training





Demographics of Participants

By Discipline	Count
Academic	59
Industry	50
Government/Labs	16

By Geography	Count
Local	10
US national	71
International	44

Approximately 50% of the participants were students and educators - the majority of these have engineering backgrounds

Less than 30% of participants had exposure to basic lab techniques

- ATP^3 has hosted 12 educational workshops to date (~3/yr)
- Over 125 participants
  - add'l~150 engaged through mini-workshops at PSA
- Week-long workshops
  - Over 30 lecture modules
  - Over 15 hands-on field site and laboratory activities
- Demonstrated ability to go **"on the road"**
  - Multiple ATP^3 sites (AzCATI/UTEX/NREL) as well as other collaborator sites (LANL/SFCC) utilized
  - Important for future expansion of the E&T program – we can partner with new sites

thealgaefoundation

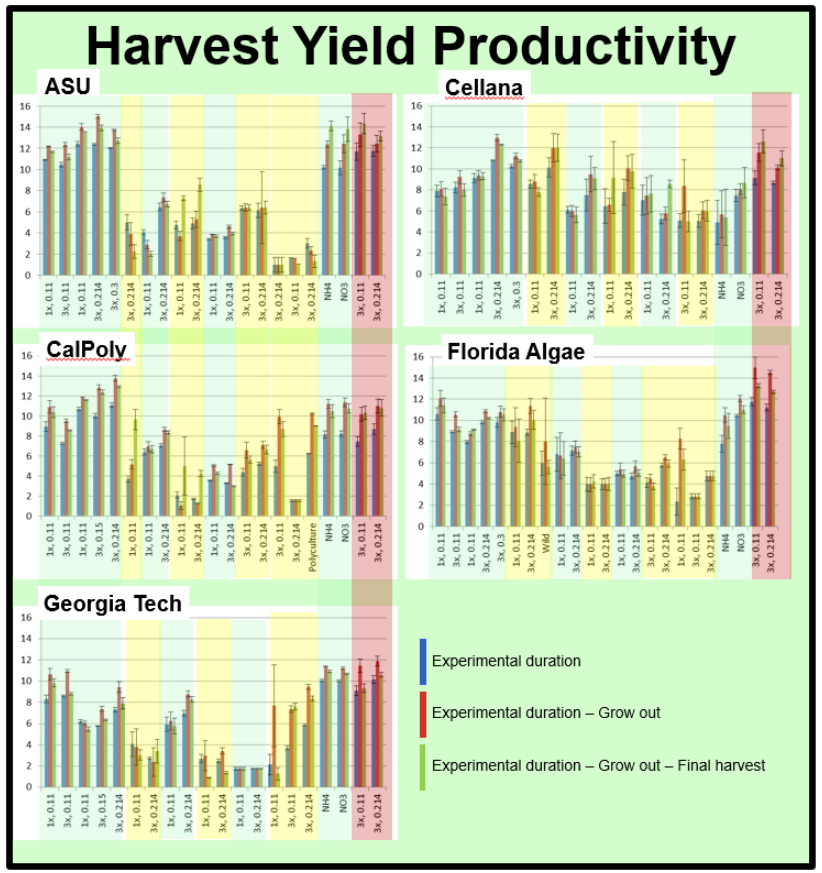
ATEC | ALGAE TECHNOLOGY EDUCATIONAL CONSORTIUM

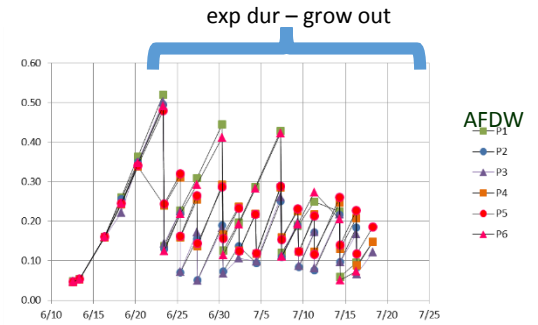
High Impact Data:
Long Term Algal Cultivation Trials

ATP^3 set standards and conducted 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
- Our **Scientific Data Management** System and validated, harmonized SOP's for analytical and production processes ensured **data integrity** across all sites
- Our protocols and data from the UFS and AFS are publicly available and provide a critical resource to TEA and LCA analysis yielding **high impact, validated data** http://en.openei.org/wiki/ATP3

Unified Field Study Productivity: Informing Current State of Technology

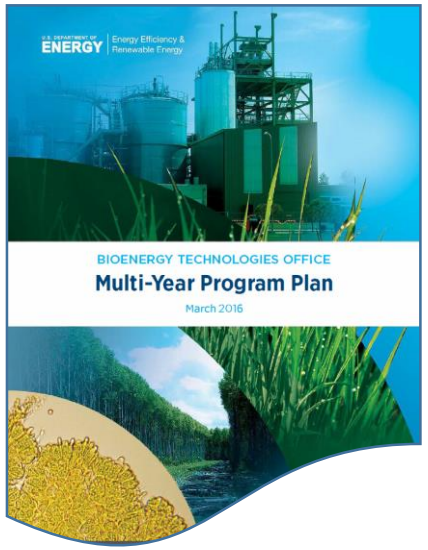




Season	2015 SOT (ATP³)	2016 SOT (ATP³)	2016 SOT (ABY1 Performer)	2020 Projection	2022 Design Case
Summer	10.9	13.3	17.5	27.4	35.0
Spring	11.4	11.1	13.0	22.9	28.5
Fall	6.8	7.0	7.8	19.6	24.9
Winter	5.0	5.0	4.8	9.1	11.7
Average	**8.5**	**9.1**	**10.8**	**19.7**	**25.0**
Max variability	**2.3:1**	**2.7:1**	**3.6:1**	**3:1**	**3:1**
MBSP ($/ton, 2014$)	**$1,227**	**$1,171**	**$1,031**	**$598**	**$494**

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

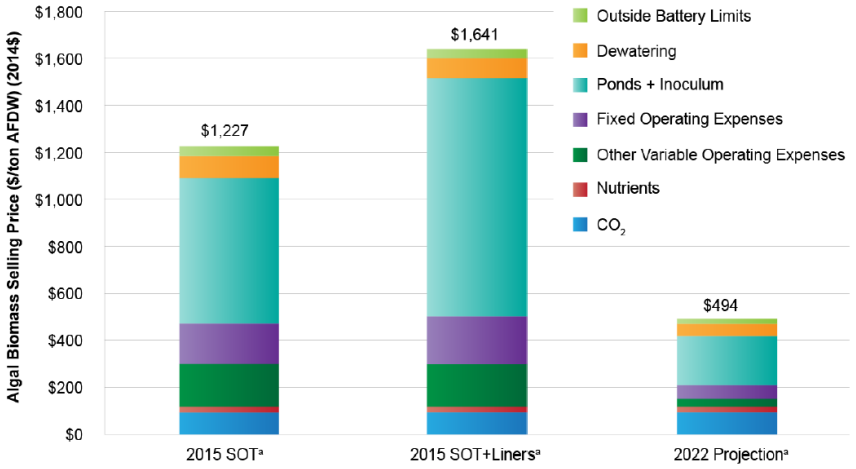
High Impact Data: Informing Current State of Technology



http://www.energy.gov/sites/prod/files/2016/07/f33/mypp_march2016.pdf

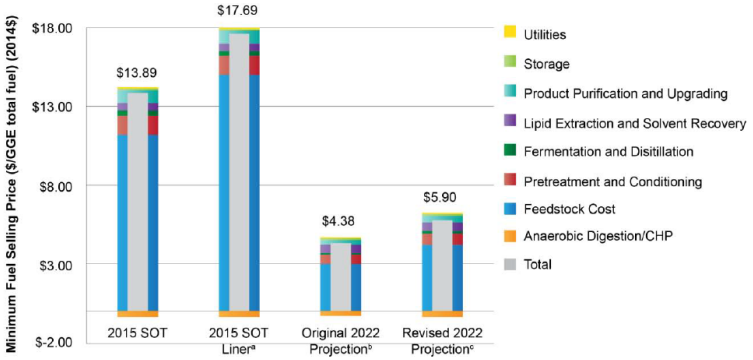
Table A-2: Unit Operation Cost Contribution Estimates (2014$) and Technical Projections for Algae Farm[2]

Processing Area Cost Contributions & Key Technical Parameters	Metric	2015 SOT [a]	2015 SOT (Fully Lined) [a]	2022 Projection
Biomass Selling Price	$/ton AFDW	$1227	$1641	$494
Production Cost	$/ton AFDW	$1069	$1483	$409
Harvest/Dewatering Cost	$/ton AFDW	$116	$116	$64
Other Cost (Facility Circulation, Storage)	$/ton AFDW	$42	$42	$21
Gross Biomass Production Yield	ton AFDW/acre-year	12.4	12.4	37.5
Total Farm Power Demand	KWh/ton AFDW	860	860	407
Production				
Total Cost Contribution	$/ton AFDW	$1069	$1483	$409
Capital Cost Contribution	$/ton AFDW	$629	$1015	$213
Operating Cost Contribution	$/ton AFDW	$440	$468	$196
Cultivation Productivity (Annual Average)	g/m^2/day AFDW	8.5	8.5	25
Max Seasonal Production Variability	max:min productivity	2.3:1	2.3:1	3:1
Lipid Content	dry wt% as FAME	27.4%	27.4%	27.4%
N Content	AFDW wt%	1.8%	1.8%	1.8%
CO_2 Utilization Efficiency	% utilized for biomass	90%	90%	90%
Gross CO_2 + Nutrient Cost Contributions[b]	$/ton AFDW	$124	$124	$120
Operating Days Per Year	days/year	330	330	330
Biomass Concentration at Harvest	g/L AFDW	0.27	0.27	0.5
Dewatering				
Total Cost Contribution	$/ton AFDW	$116	$116	$64
Capital Cost Contribution	$/ton AFDW	$93	$93	$52
Operating Cost Contribution	$/ton AFDW	$23	$23	$12
Gross Dewatering Efficiency [c]	%	87%	87%	87%
Net Dewatering Efficiency [c]	%	99%	99%	99%
Final Concentration of Dewatered Biomass	g/L AFDW	200	200	200
Dewatering CAPEX	$/MGD from cultivation	$18	$18	$6



[a] 2015 MBSP projections are derived using cultivation data from the ATP[3] test-bed consortium with 2015 Algae Farm design report assumptions.

Figure 2-16: Cost contribution for algal biomass selling price by process area



[a] 2015 MBSP projections are derived using cultivation data from the ATP[3] test-bed consortium with 2015 Algae Farm design report and 2014 ALU design case assumptions.
[b] Original 2022 projection based on 2014 ALU design report (assumed biomass feedstock)[48]
[c] Revised 2022 projection based on modified ALU design case (modeled biomass feedstock)[49]

Figure 2-17: Cost contribution by process area for CAP Pathway

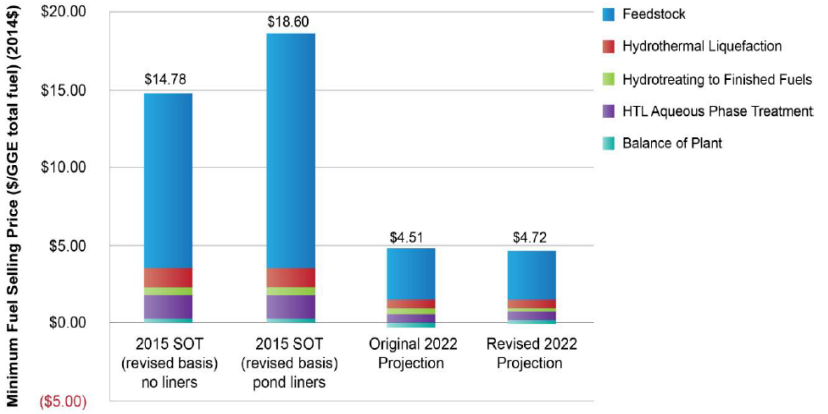


Figure 2-18: Cost contribution by feedstock and conversion process area for HTL Pathway

[44] ATP[3] Algae Testbed Public-Private Partnership, http://en.openei.org/wiki/ATP3.
[45] R. Davis, et al. (2015), *Process Design and Economics for the Production of Algal Biomass: Algal Biomass Production in Open Pond Systems and Processing Through Dewatering for Downstream Conversion*, National Renewable Energy Laboratory, NREL/TP-5100-64772, http://www.nrel.gov/docs/fy16osti/64772.pdf.

[50] Jones et al. (2014), *Process Design and Economics for the Conversion of Algal Biomass to Hydrocarbons: Whole Algae Hydrothermal Liquefaction and Upgrading*, Pacific Northwest National Laboratory, PNNL- 23227, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23227.pdf

ATP^3 Summary

- From 2013 through December 2016, over 75 individual experiments have been conducted across the network with an average duration of at least 40 days
- Major outcomes:
  - Standardized, validated methods with an emphasis on continuous improvement
  - 10 strains utilized in outdoor cultivation experiments with the majority of multi-season data coming from 3 strains with average run time of >40 days
  - Data and experimental protocols for the UFS (Fall 2013 through Summer of 2015) curated and posted on ATP^3's OpenEI.org web portal. http://openei.org/wiki/atp3
  - Advanced field study data sets currently under curation and will be loaded by Q4 2017.
  - ATP^3 generated productivity data **were the primary data sets** supplied to the DOE sponsored SOT reports for 2015, 2016 and will be again for 2017
  - Data beginning to be used by outside groups (2 publications submitted by researchers not affiliated with ATP3 to date)
  - Strong E&T program that is well recognized as a key resource to the stakeholder community
- Novel platforms for pond ecology monitoring and real-time monitoring of culture density and health, demonstrating ATP^3's capability for deploying new technology into an active R&D pilot facility
- Novel methodology developed to quantify pond reliability metrics - a nascent idea in the research community but key to long term deployment and viability
- While overall customer base remains challenging for sustainably supporting a test bed network without ongoing federal support – ATP^3 has demonstrated the ability to work collaboratively across the algal value chain

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