DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

Advanced Biofuels and Bioproducts Process Development Unit (ABPDU) Operations, Lawrence Berkeley National Laboratory (LBNL)

04/05/2023

Conversion Team

Deepti Tanjore

Lawrence Berkeley National Laboratory

ABPDU

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview: ABPDU AOP

The ABPDU was initiated by American Recovery and Reinvestment Act funds in 2010 to scale-up technologies with a bioenergy focus.

The total investment to date has been ~$49M ($17.7M ARRA and $31M BETO funds)

Timeline

White Paper submitted in	2009
ARRA funds, Construction, Installation, and Commissioning	2010 - 2012
Operational since	2012
Worked with all three BRCs	2014
Focus shifted to Industrial Collaborators and Bioproducts along with Biofuels	since 2015

In 2011: "*The objective of the ABPDU is to provide the industry and DOE with a Process Development Unit (PDU) capable of demonstration production of advanced biofuels at small scale. Additionally, this facility will provide a means to translate the technologies from laboratory scale to commercial operation created by DOE Researchers (e.g., DOE Bioenergy Research Centers (BRCs)), U.S. industry, and non-profit organizations.*"

ABPDU

Project Overview: Worked with over 75 companies

2021

Biofuels & Biomass

Recology WASTE ZERO
praj
TOTAL COMMITTED TO BETTER ENERGY
SylvateX
RHO Renewables, Inc.
Microvi BIOTECHNOLOGIES
AFINGEN
AFATER
amyris
AEMETIS
HelioBioSys, Inc.
CinderBio
Oobli
NATURAL FIBER WELDING
california almonds Almond Board of California
brightseed
ILLIUM TECHNOLOGIES
UNITED CATALYST
Aequor Antibiofilm Antifouling
INDUSTRIAL MICROBES

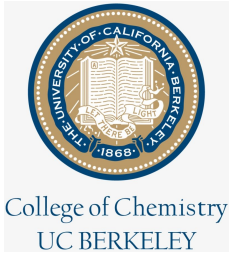
Materials & Chemicals

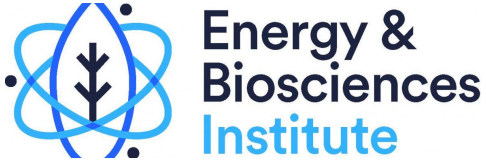
Mosaic Materials
ardra
Enduro Genetics
Pareto Biotechnologies
Kiverdi
INDIE BIO
POW.BIO INTELLIGENT FERMENTATION
TIERRA BIOSCIENCES
KALION, INC.
X-THERMA Biomimetic Nanotech
GreenLight BIOSCIENCES™
LYGOS
CHECKERSPOT
Bolt Threads
zymergen
VISOLIS CARBON NEGATIVE MATERIALS
MANGOMATERIALS
MicroByre
teselagen BIOTECHNOLOGY
ZYMOCHEM
GORE
GINKGO BIOWORKS™ THE ORGANISM COMPANY
MYCOWORKS
INVIZYNE TECHNOLOGIES
DMC
huue.
Aralez Bio
C16 Biosciences

Food, Health, & Ag

Perfect Day
ripple Dairy-Free. As It Should Be.
Hampton Creek
NOVOME BIOTECHNOLOGIES
Boston Bioprocess
BOOST BIOMES
RUBY BIO
Es BioSolutions, Inc.
PURISSIMA
SWIFTSCALE BIOLOGICS
Geltor
EVERY
AMB ALLIED MICROBIOTA
Antheia
assembly bio
NAMUH
KOCH BIOLOGICAL SOLUTIONS
COSPR
BCD BIOSCIENCE BETTER CARBOHYDRATE DESIGN
DIGESTIVA Solving Protein Digestion
Circe.
PSYBIO THERAPEUTICS
concentric THE PHYTO-MICROBIOME COMPANY

Project Overview: Worked with academic collaborators as well





Approach
Task 1 - Scope of the ABPDU Operations

1. ABPDU Operations (FY22-24 $2,500,000)

1.1 Developing Public-Private Partnerships in Service to the BETO Mission (850K/ year): supports staffing time and activities to bring increasing partner usage

- 1.1.1. Outreach Coordination (400K/ year)
- 1.1.2. Technical scope development and internal coordination (450K/ year)

1.2 Operations (1,650K/ year):
ensures facility readiness to execute on collaboration projects

- 1.2.1. Facility Readiness (1,100K/ year)
- 1.2.2. Safety Management (300K/ year)
- 1.2.3 Workforce Development (250K/ year)

No variance or scope change has occurred in the past two years

Approach
Task 2 - Scope of the Technical Task

2. Learning from Data for Predictive Scale-up of Biofuel Technologies (FY23-24 $250,000) PI: Deepti Tanjore

2.1. Agile AI and ML methods for Unanticipated Events

i. Analyze images of microbial hosts from bioreactors under various process conditions
ii. Apply third-wave AI/ML algorithms developed at LBNL and UC Berkeley and train with process knowledge generated at the ABPDU over the past 8 years.

2.2. Rule-based Decision Making for Anticipated Events with Three-Levels of Hierarchy

i. Fall back option to the AI/ML approach
ii. Consolidate knowledge at the ABPDU in the form of multi-layered decision trees

No variance or scope change has occurred in the past two years

Approach
Task 3 - Scope of the Technical Task

3. Biomanufacturing Using Gaseous Feedstocks (FY23-24 $250,000)
PI: Eric Sundstrom

3.1. Development of intensified fermentation capabilities for aerobic gas fermentations

i. Direct conversion of hydrogen and methane gases to energy-dense products
ii. Comparison of serum bottle and bioreactor cultivations for existing engineered strains available at Berkeley Lab
iii. Reflective of broader challenges surrounding extractive fermentation for direct autotrophic synthesis of diesel and SAF

3.2. Documentation of best practices for safe and effective scale-up and scale-down

iv. Best practices for process development and scale-up of gas fermentations currently not available
v. Guidelines for safe fermentation are a primary concern
vi. Addressing cultivation and safety challenges through publication of set of best practices

No variance or scope change has occurred in the past two years

Approach
Task 1 - Project Risks

Name	Target Completion	Severity	Response	Description
Communication efficacy	9/30/ 2022	L	ABPDU will benchmark its communications channels over time to seek out improvement opportunities and focus outreach & online content for optimal efficacy.	ABPDU's track record suggests that its communication tactics are effective. But future outreach may not yield the same level of collaborations.
Facilities readiness	9/30/2024	H	Facilities engineer and other FTEs will be trained to perform or oversee preventive and responsive maintenance for equipment, coordinating with service providers as necessary. Resources including service contracts will be made available.	Unplanned downtime from periodic equipment and utility failure

Approach
Task 2 - Project Risks

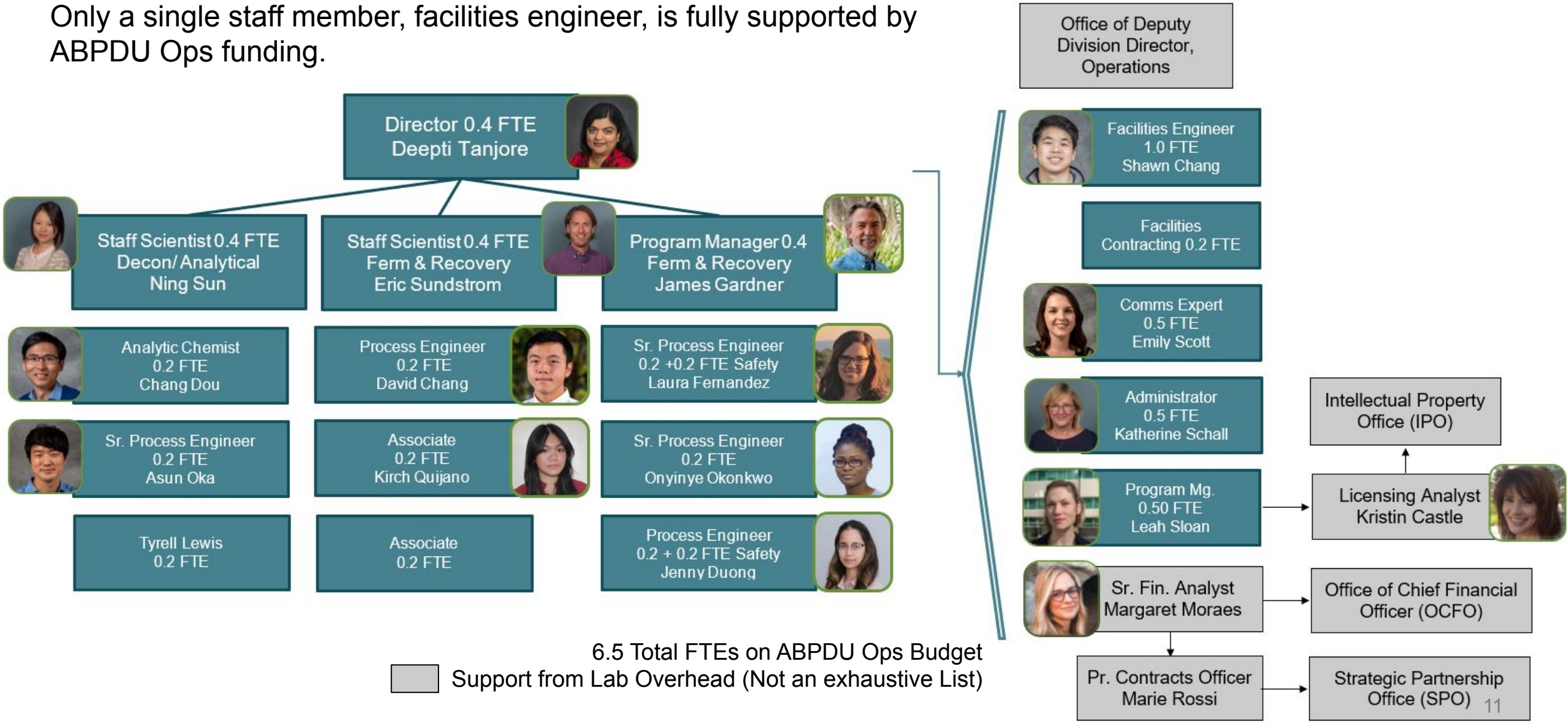
Name	Target Completion	Severity	Response	Description
Real-time variable	9/30/ 2023	L	The imaging work pursued alongside fermentations conducted for the ABF consortium will help us counter this risk. Cell morphology, especially cell wall response to its surroundings will be representative of real- time culture conditions.	While off-gas analysis can be highly representative of real-time bioreactor conditions, in task 1, it may not provide sufficient data and the other process measurements could be delayed in representing culture behavior.
Non- intuitive predictions	9/30/2024	H	The rule-based approach is our fallback approach to the AI/ML task, in case the algorithms do not predict any useful causal relationships.	The AI/ML approach may not lead to any non-intuitive predictions.

Approach
Task 3 - Project Risk

Name	Target Completion	Severity	Response	Description
Gas fermentation safety	9/30/ 2024	M	Build in multiple redundancies for safe operation, including headspace dilution, automated reactor shutdown, gas sensors, and operation in the fume hood. Initiate work with multiple prospective gas streams to create additional process options.	Certain gas streams may prove too flammable or hazardous for safe operation of intensified gas conversions at ABPDU.

Progress and Outcomes
Task 1 - ABPDU Org Chart

Only a single staff member, facilities engineer, is fully supported by ABPDU Ops funding.



6.5 Total FTEs on ABPDU Ops Budget

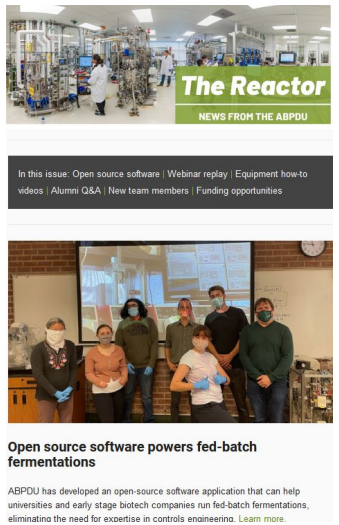
Support from Lab Overhead (Not an exhaustive List)

Progress and Outcomes

Task 1.1 - Developing Public-Private Partnerships in Service to the BETO Mission

MILESTONES:

A. Publish four newsletters every year with information on technologies being developed at the ABPDU.



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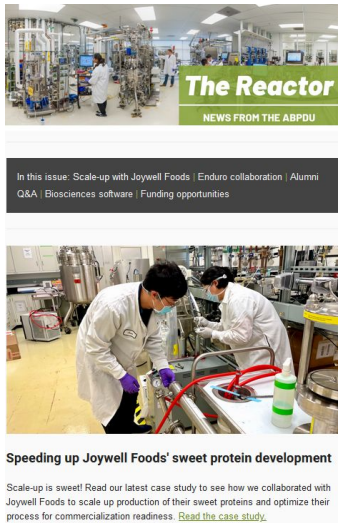
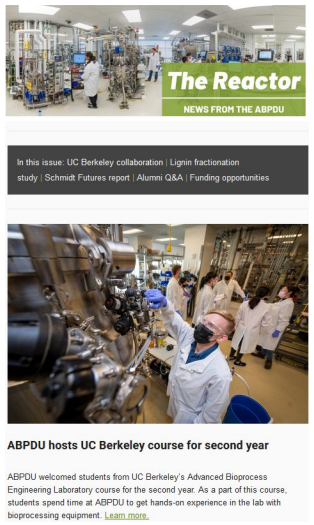


03/09/2022



06/06/2022

08/15/2002

B. Document at least one commercialization effort every year in BETO Conversion mission space.

Project Risk Avoided: Low Communication Efficacy

AIChE The Global Home of Chemical Engineers

RAFT® Recent Advances in Fermentation Technology

SIMB

synbiobeta

CIB COMMERCIALIZING INDUSTRIAL BIOTECHNOLOGY

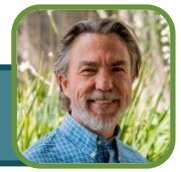
SBFC Symposium on Biotechnology for Fuels and Chemicals

Communications Expert
Emily Scott

Staff Scientist
Ning Sun

Scientist
Eric Sundstrom

Program Mg.,
James Gardner



Partnership Development
Leah Sloan

Director, ABPDU
Deepti Tanjore

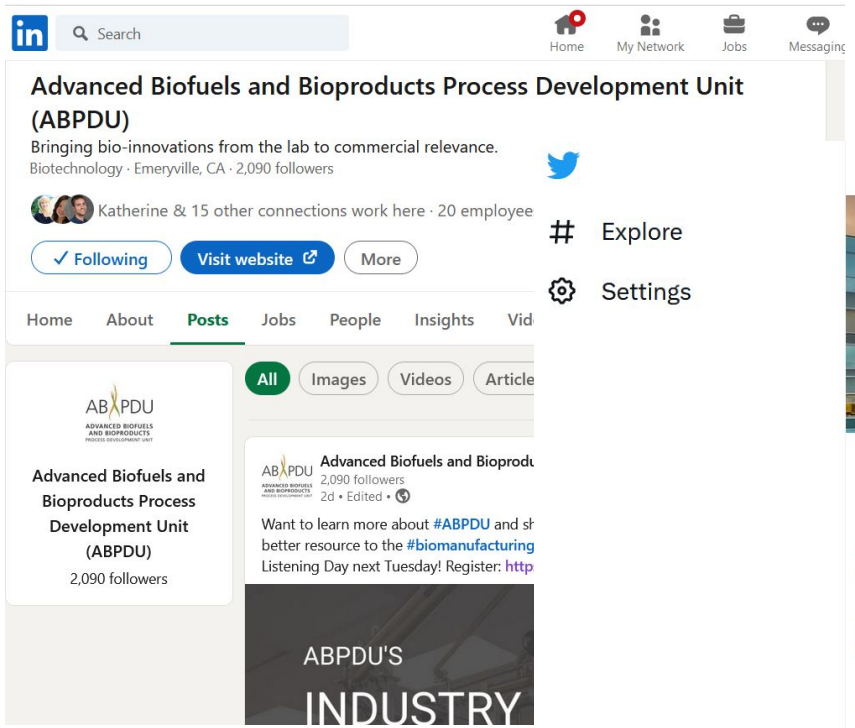
Sr. Administrator
Katherine Schall

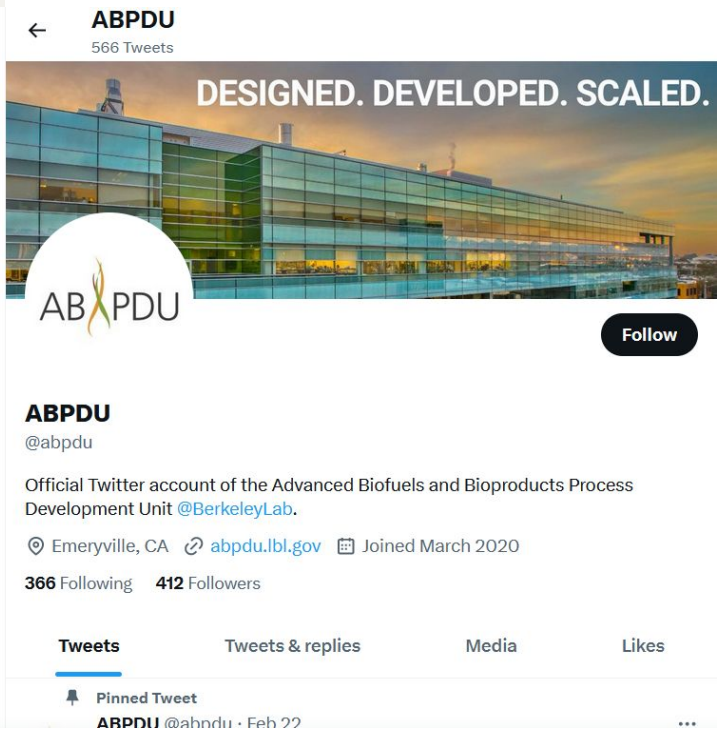
ABPDU

Progress and Outcomes
Task 1.1.1 – Outreach Coordination

Peer Review Comment: It would be good to have a strategic plan on how to reach out to external collaborators, besides word of mouth and personal connections, in order to maximize the impact of the ABPDU.
Response: We are now reaching to general audience through (i) Social Media, (ii) Newsletter, and (iii) Videos.

Regular Communications via Linked In and Twitter





Quarterly Newsletter

Progress and Outcomes

Task 1.1.1 – Outreach Coordination (Industry Listening Day - ILD)

41 entities, including 28 companies attended the Second ILD on March 7th, 2023 with ABPDU & DOE on zoom. The first ILD was conducted in-person (pic below) in October 2019 with 24 companies attending the event.

Progress and Outcomes

Task 1.1.1 – Feedback on Outreach from ILD 2019: More Information on Capabilities and Contracting needed

Knowing ABPDU's capabilities ahead of time will be helpful. What kind of organisms have you worked with, what can you help us with in terms of advising, etc. - Tina Boville, CEO Aralez Bio

What is an example of substantial contribution by ABPDU staff members for them to be listed as inventors on IP - Ouwei Wang, Co-Founder and CTO of Pow Bio

ABPDU

Progress and Outcomes
Task 1.1.1 – More Information on Capabilities needed: Case Studies

Over 10 case studies authored. Many more in preparation

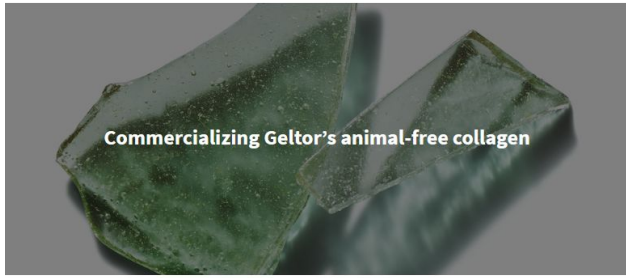
Checkerspot

Checkerspot is a high-performance materials company that designs materials at a molecular level.

ZymoChem

ZymoChem is re-imagining the microbe, one that is designed to eliminate — or substantially reduce — carbon loss during the production of chemicals.

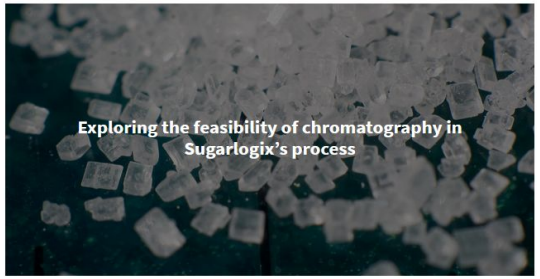
Geltor



Geltor is a Bay Area startup creating biodesigned protein ingredients.

As Geltor's first hire, Monica Bhatia was faced with a difficult task: turn the company's concept bioprocess into a commercially scalable technology in a short amount of time.

Sugarlogix



Sugarlogix is a biotech startup developing yeast-based technologies to produce a key component in infant formula.

Recology

Recology is an employee-owned resource recovery company headquartered in S

Collecting and managing waste is tricky business. Recology knows that firstha

Digestiva

tion combats

Huue

Huue uses biotechr

Speeding up Joywell Foods' Sweet Protein Development

March 02, 2022 | By Emily Nelson

ABPDU's Gas Capture Capability Enables Production of Sustainable Aviation Fuel Molecule

February 06, 2023 | By ABPDU

Making the Case for Repurposing Leftover Almond Shells as Plastic Reinforcing Agents

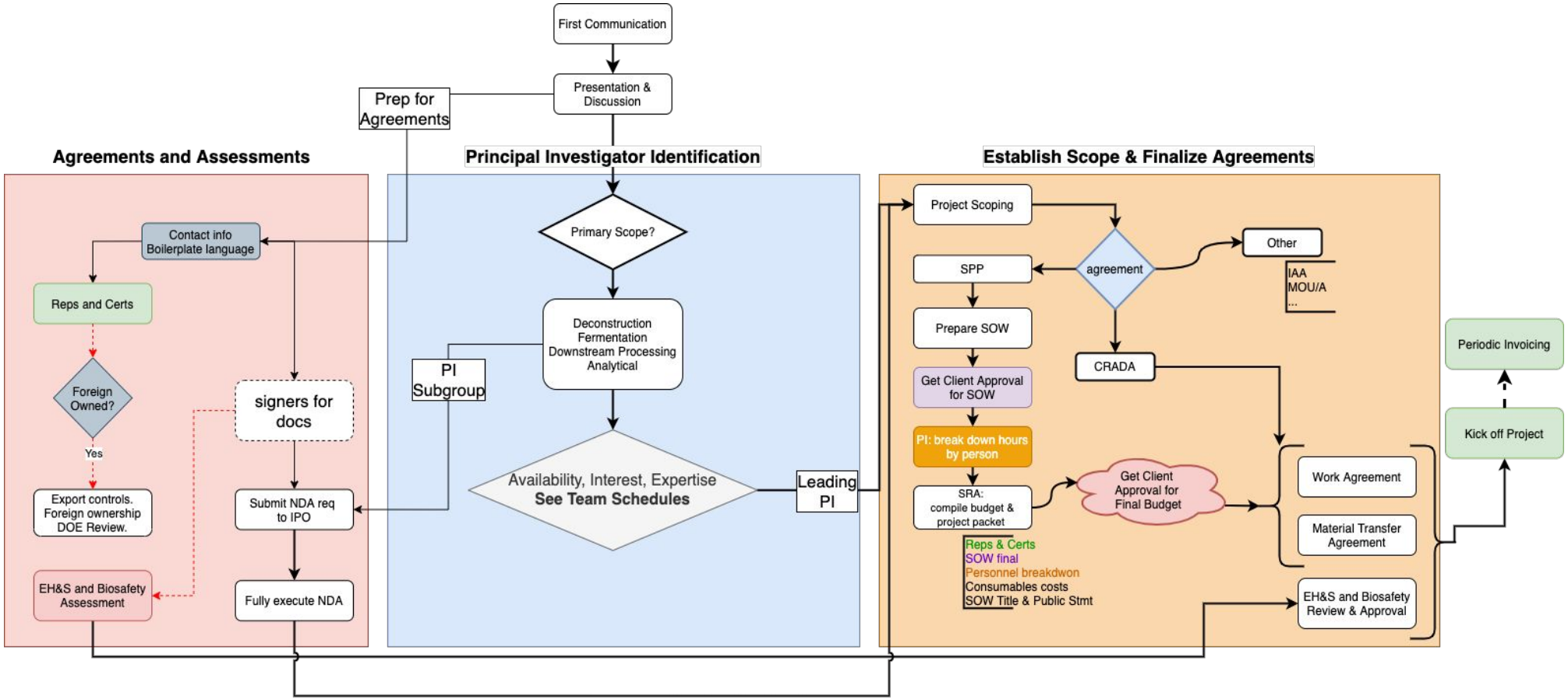
February 21, 2023 | By Emily Nelson

ABPDU

2 – Progress and Outcomes

Task 1.1.2 – Technical Scope Development and Internal Coordination

To establish a collaboration via a contract with LBNL, we follow the Workflow given below to ensure that we can deliver on the 12-week timeline for Strategic Partnership Program (SPP) contracts. Co-operative Research And Development Agreements (CRADA) and other contracts can take longer depending on the review of contract terms by the collaborators. Industrial collaborators prefer SPP contracts due to favorable IP terms.



2 – Progress and Outcomes

Task 1.1.2 – Technical Scope Development and Internal Coordination

After an initial phone call or email contact from a potential collaborator, PM Leah Sloan sends out a standard email with the overview video given below and option to process an NDA. This is followed by a meeting to answer any specific questions from the prospective collaborator and initiate scoping with an ABPDU PI, who is the expert on the topic.

https://www.youtube.com/watch?v=zJ_m0N7aTb8

In FY21-22, we met with 123 companies

Typical Questions from Potential Collaborators

Can you execute on *this* project?
The PI discusses the scope of the project in this first meeting to answer the question.

How much will it cost?
Cost varies drastically from campaign to campaign and is calculated based on staff hours required for a given project. SOW draft shared with clients after the meeting elucidates the # of hours needed to execute the project.

When can we start?
We suggest a 12-week timeline and initiate Reps and Certs, etc. immediately after the first meeting.

Progress and Outcomes
Task 1.2 - Operations

MILESTONES:

A. Complete purchase and commissioning of at least two new equipment as suggested by industry collaborators (during Industry Listening Day 2019)
  - Completed procuring, installation and commissioning of Gas Fermentation reactors and a Flow Cytometer
  - In the process of procuring (1) 4 X 2L bioreactors, and (2) Ceramic Filtration Unit
  - Waiting on Boiler Installation and Commissioning in mid-May

B. Conduct four safety workshops every year

C. Train at least four SULI, CCI, GEM interns every year and Host at least four high school student interns in 3-year period
  - Met high-school student intern milestone but missed SULI, CCI, GEM intern milestone in FY 21 due to COVID restrictions
  - Resumed internships in Spring of 2022 and met all milestones in FY22

Project Risk Avoided: Unplanned Downtime

Facilities Engineer
Shawn Chang

Sr. Process Engineer &
Safety Liaison
Laura Fernandez

Sr. Process Engineer &
Safety Support
Jenny Duong

Student Interns

All Principal Investigators and Many Sr. Engineers

Progress and Outcomes
Task 1.2.1 – Facility Readiness

Primary responsibilities of Facilities Engineer:

- Provide multi-support to ensure equipment and utilities are serviced and maintained well, to minimize downtime.
- Serve as point of contact and ABPDU's liaison with external vendors, building owners, Laboratory Division Facilities, Transportation and Engineering personnel.
- Manage subcontracts with a broad range of vendors for the utilities, equipment, instruments, and services.
- Prepare the sub-contractor job hazard analysis (sJHA) and work with LBNL facilities and electrical safety groups to make sure all hazards are reviewed and documented.
- Schedule Preventative Maintenance services, upgrades, and repairs for all utilities and equipment.
- Inform ABPDU teams with facility/equipment related updates (weekly SCRUM, lab update emails).

Maintenance and On-Call Response to emergency alarms from:

Waste Treatment Unit

- Steam boilers and steam traps
- Chillers/Process Chilled Water
- Air compressor
- Reverse Osmosis Deionized (RODI) Water System
- Clean Steam generator

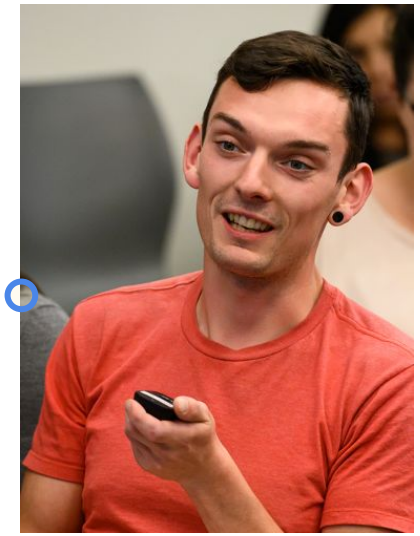
Responsibilities associated with Lab spaces:

- Maintenance
- Cleaning
- Shipping and Receiving and Mid-week Task Requests
- Chemical and Waste Management

ABPDU

Progress and Outcomes
Task 1.2.1 – Out-of-House Training (Feedback from ILD 2019)

Out of house training of equipment to company affiliates, before a project campaign. This can help with turnover issues - Bryan Dalton, Production and Process Development Scientist, BioPlastech. Previously at Mango Materials

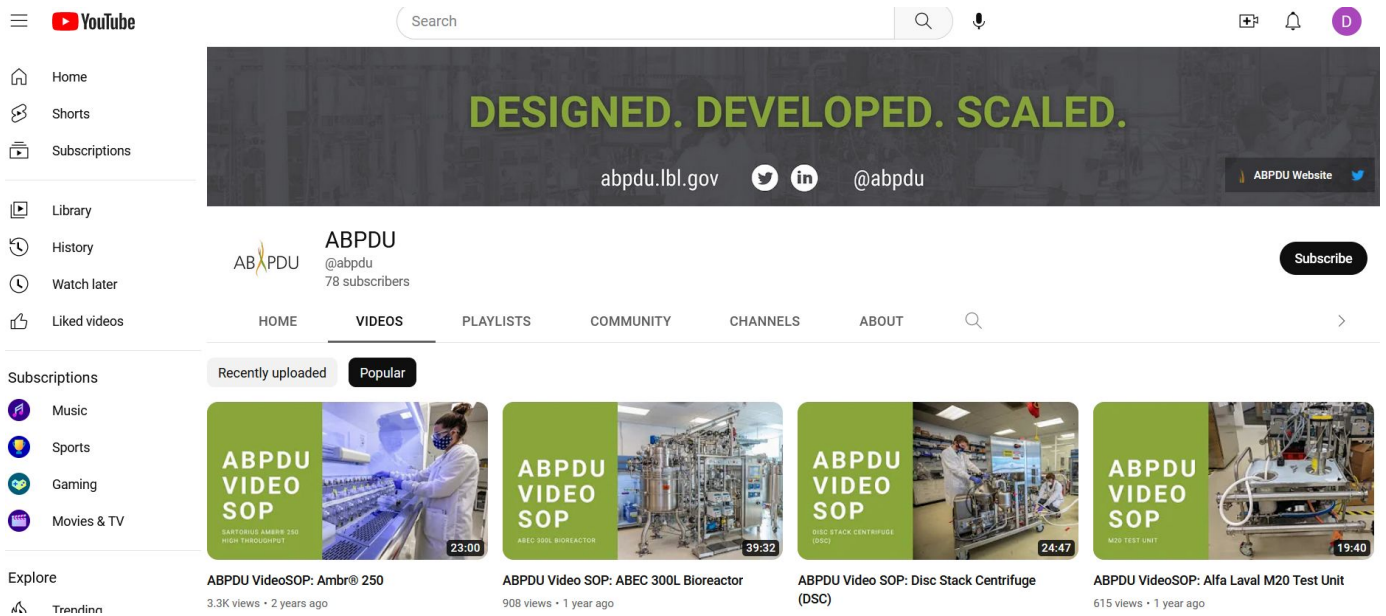


Training our team members can be very valuable. Information is super valuable, especially around safety (gas fermentation). Developing the training materials can be very helpful - Noah Helman, Founder and President, Industrial Microbes

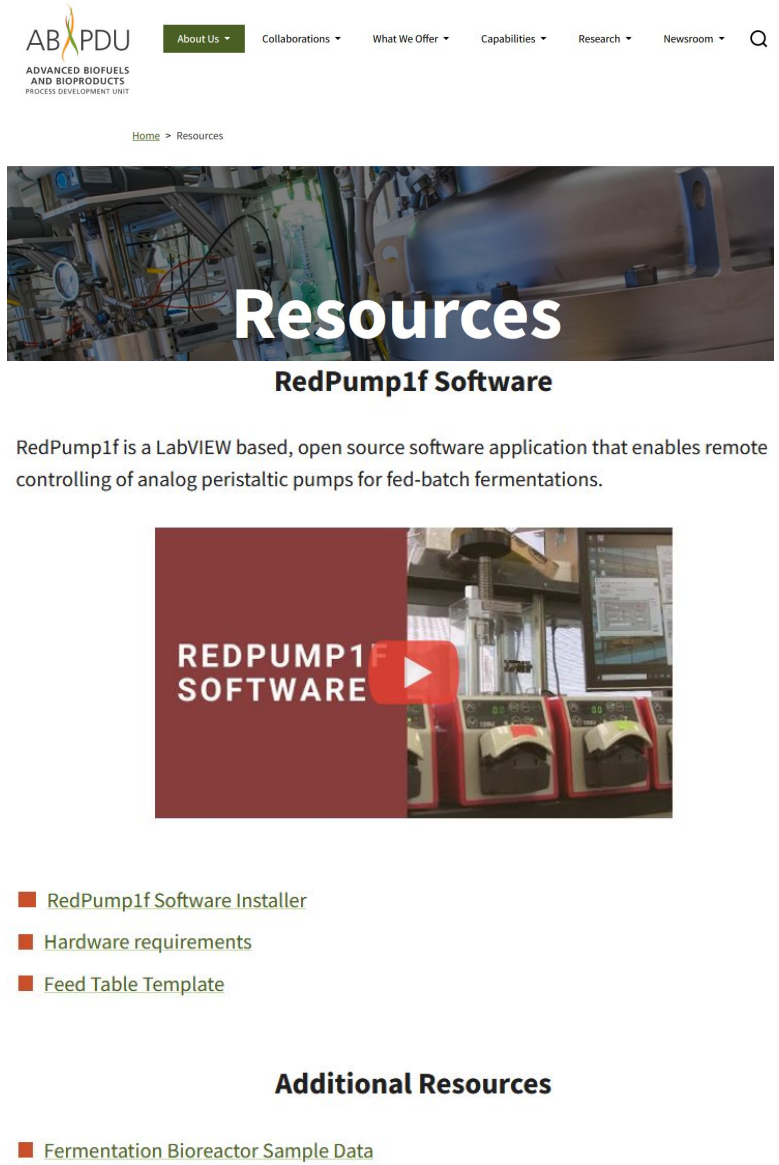
ABPDU

Progress and Outcomes
Task 1.2.1 – Out-of-House Training; RESPONSE: Video Safe Operating Protocols

12 Video Safe Operating Protocols (Vidoe SOPs) online on ABPDU Youtube Channel: https://www.youtube.com/@abpdu/videos

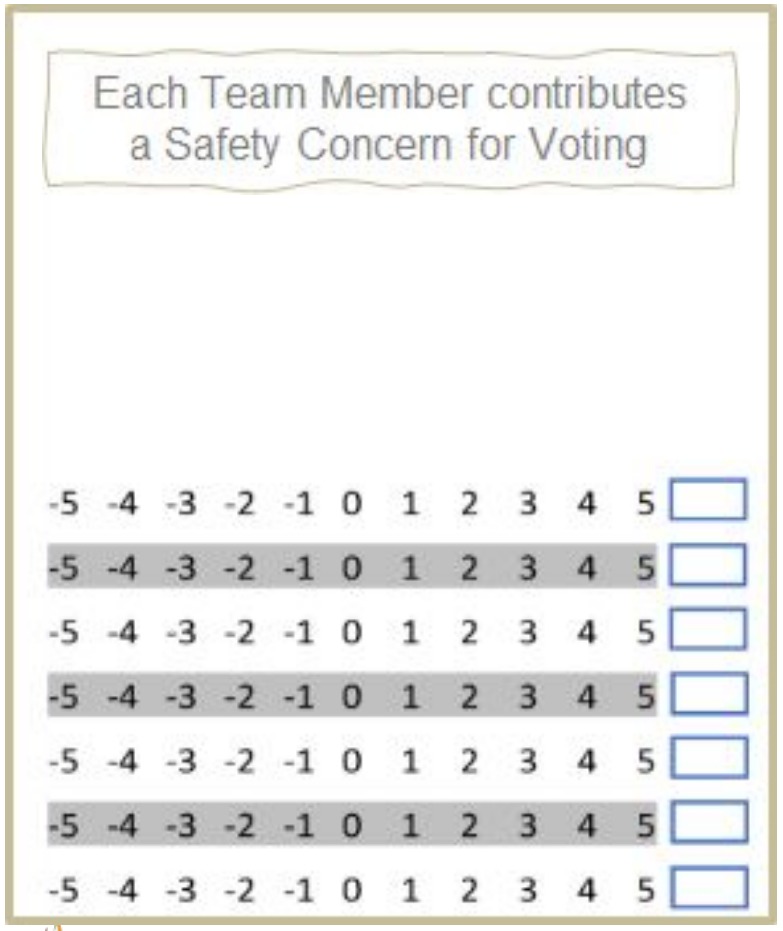


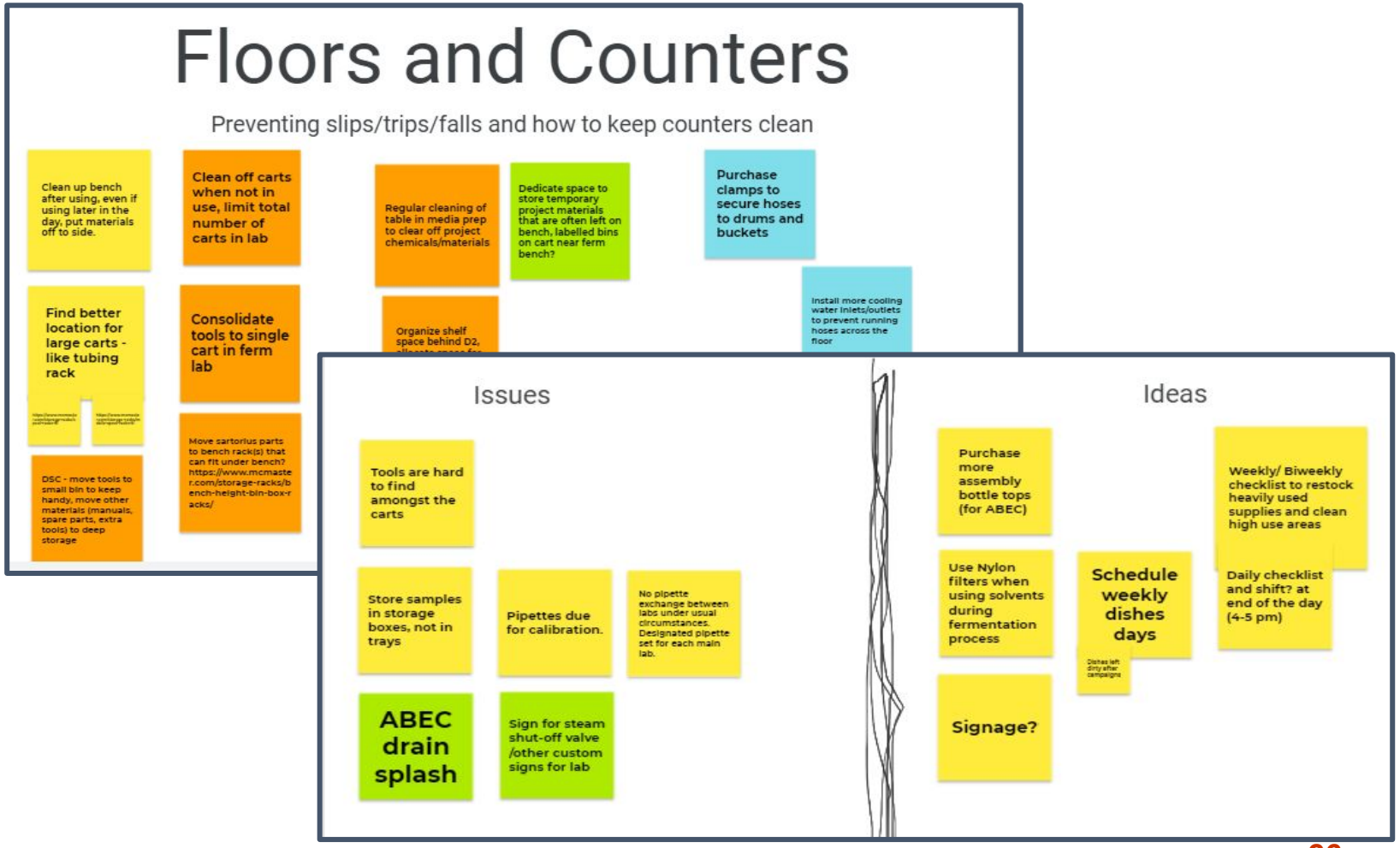
Software and Data made available on ABPDU Resources webpage: https://abpdu.lbl.gov/resources/



Progress and Outcomes
Task 1.2.2 – Safety Management

We converted our Safety Meetings into Workshops and applied Design Thinking approach to be more Proactive than Reactive to safety concerns.





Progress and Outcomes
Task 1.2.2 – Safety Management

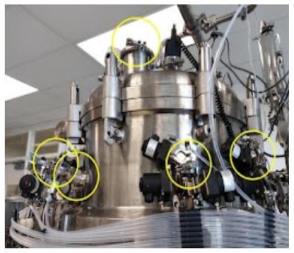
Prototype/ Test Proactive Solutions: Safety Checklists for High Hazard Operations

Fermenter

Confirm each of these statements are true

☐ Filters have been removed and replaced with housing caps

☐ Additional port hose barbs have been replaced with blanks



☐ Tri-clamps on hoses and fermenter are tightened; Hand valves on the

☐ CIP spool has been installed in place of sample assembly

Andritz Safety Checklist

Confirm the items below are true BEFORE OPERATING the Andritz Reactor

- ☐ Temperature Control Unit is operational (check oil level, pressures, and for leaks)
- ☐ The motor is running
- ☐ Nitrogen cylinder outlet pressures are correct
- ☐ Put valves in correct configuration (water supply vs loop)
- ☐ Release valve is operational and closed
- ☐ Vessel is not hot already

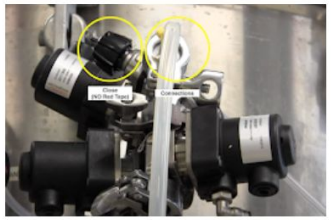
Please confirm the items below are true BEFORE OPENING the Andritz Reactor

- ☐ Vessel is not pressurized
- ☐ Agitator is not on or moving
- ☐ Bolts are loosened using STAR/opposites pattern
- ☐ Vessel is not heating and the surface is not hot

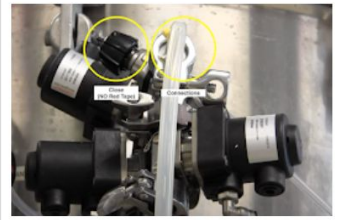
SIP Safety Checklist

Confirm each of these actions have been done

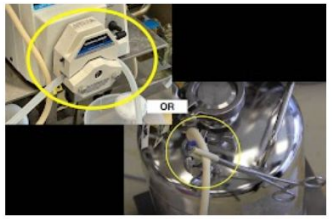
☐ Tighten all tri-clamps on headplate, vessel and skid; All the hand valves for PSA should be closed



☐ All hand valves are closed and in the correct orientation



☐ Acid and/or base has been connected



☐ Lines are clamped (if not in pumps)

Progress and Outcomes
Task 1.2.2 – Safety Management

Prototype/ Test Solutions: Ergonomically Optimized Glucose Batching

Pouring the glucose buckets from above shoulder height into the holding tank led to arm/ shoulder discomfort, bending toward the tank

Initiated use of a platform over the ladder, a funnel extender, and smaller buckets with 5 kg capacity

Progress and Outcomes
Task 1.2.3 – Workforce Development: Feedback from ILD 2019 - Turnover

Turnover at the ABPDU affects us. Rehiring, re-establishing relationships, and building knowledge takes time. Schedules were delayed. - Ritu Bansal, , Sr. Director, Process Research and Development, Zymochem. Previously at Mycoworks

RESPONSE: We hired a program manager to free up PIs so they can spend more time with their team members and focus on their training and invest in their careers. We are engaging in many workforce development activities to create opportunities to hire skilled team members, e.g. UC Berkeley MBPE program.

I echo the comment on turnover. Can you raise salaries? - Jill Fuss, Managing Director, Activate Berkeley. Previously at Cinder Bio

ABPDU

Progress and Outcomes
Task 1.2.3 – UCB Masters in Bioprocess Engineering Lab Course at the ABPDU

Berkeley College of Chemistry

Bioprocess Engineering Program Description

PROFESSIONAL MASTERS DEGREE IN BIOPROCESS ENGINEERING

- **Program Description**
- Application Process
- Degree Requirements
- Tuition & Fees
- Info Sessions

PROGRAM DESCRIPTION

The Master of Bioprocess Engineering (MBPE) degree will provide graduates upon completion of a 9-month program with an understanding and ability to apply Bioprocess Engineering to a number of key technological needs spanning multiple industries. These include methods to produce biofuels, bio-based

MBPE Info Session Webinar

Complete our interest form to download the MBPE Info Session Webinar.

Apply Online

Applications for the 2023-24 academic year have now closed. If you are interested in applying late, please email: mbpe@berkeley.edu

https://chemistry.berkeley.edu/grad/cbe/bioprocess-engineering/program-description

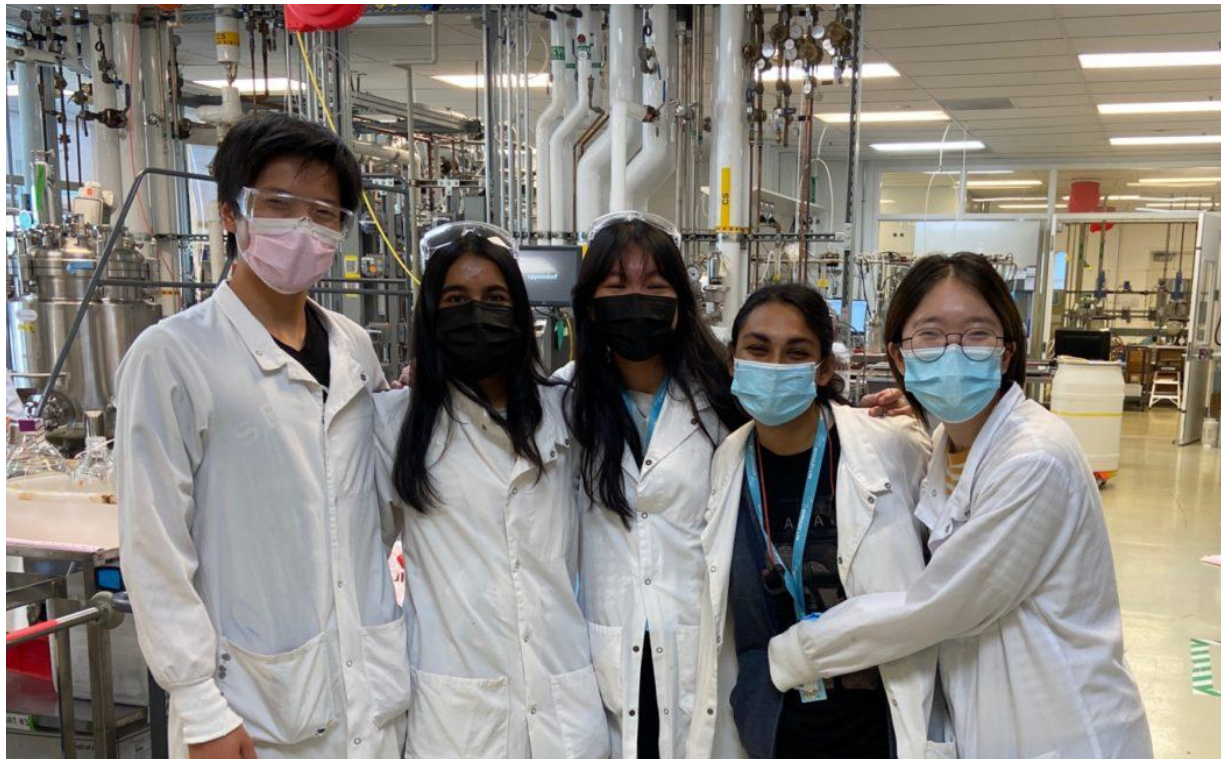


James Gardner (PI), Laura Fernandez and Asun Oka (Instructors)


David Chang and Kirch Czarina Quijano, Graduates of the MBPE program and Process Engineers at the ABPDU

ABPDU

Progress and Outcomes
Task 1.2.3 – Internship Programs



Since 2021, as part of the Pilot City internship program, ABPDU has hosted six high school student interns yet to apply to college and decide their majors.

https://abpdu.lbl.gov/news/pilot-city-interns-help-improve-abpdu-processes/

Program Manager James Gardner, interns Tyler Pham and Sanjana Rathore, and Postdoctoral Fellow Onyinye Okonkwo

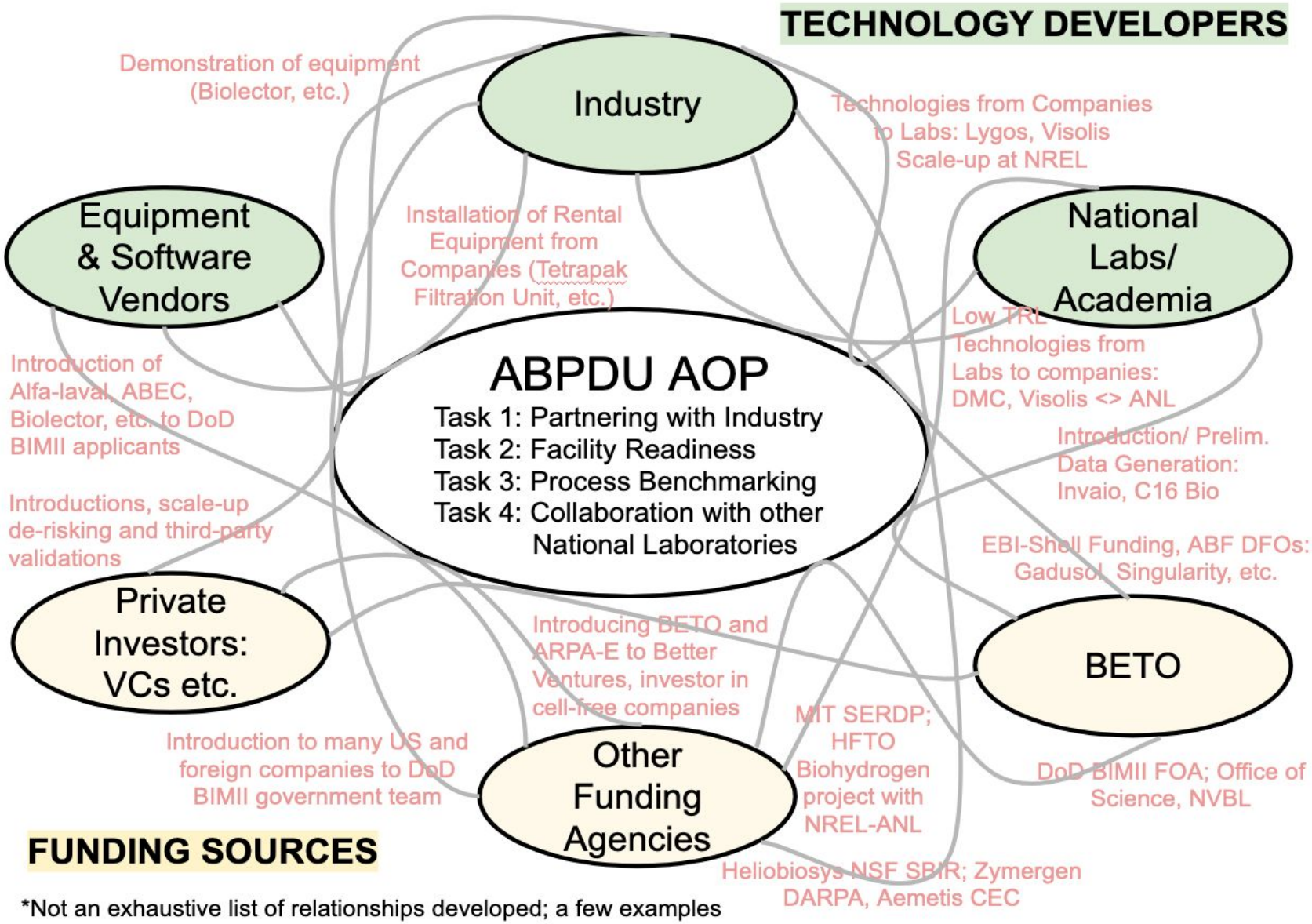
"I liked being able to work in an important area of research" - Rohan Adwankar

"It was my first time working in a lab, and it was cool to see all our interdisciplinary work coming together." - Sanjana Rathore

"The joy I felt when we professionally hosted the scripts for the first time was immense. I can't express my gratitude enough for the generosity of Mark (Kuwalik - IT Manager) and the rest of the Berkeley Lab staff." - Tyler Pham

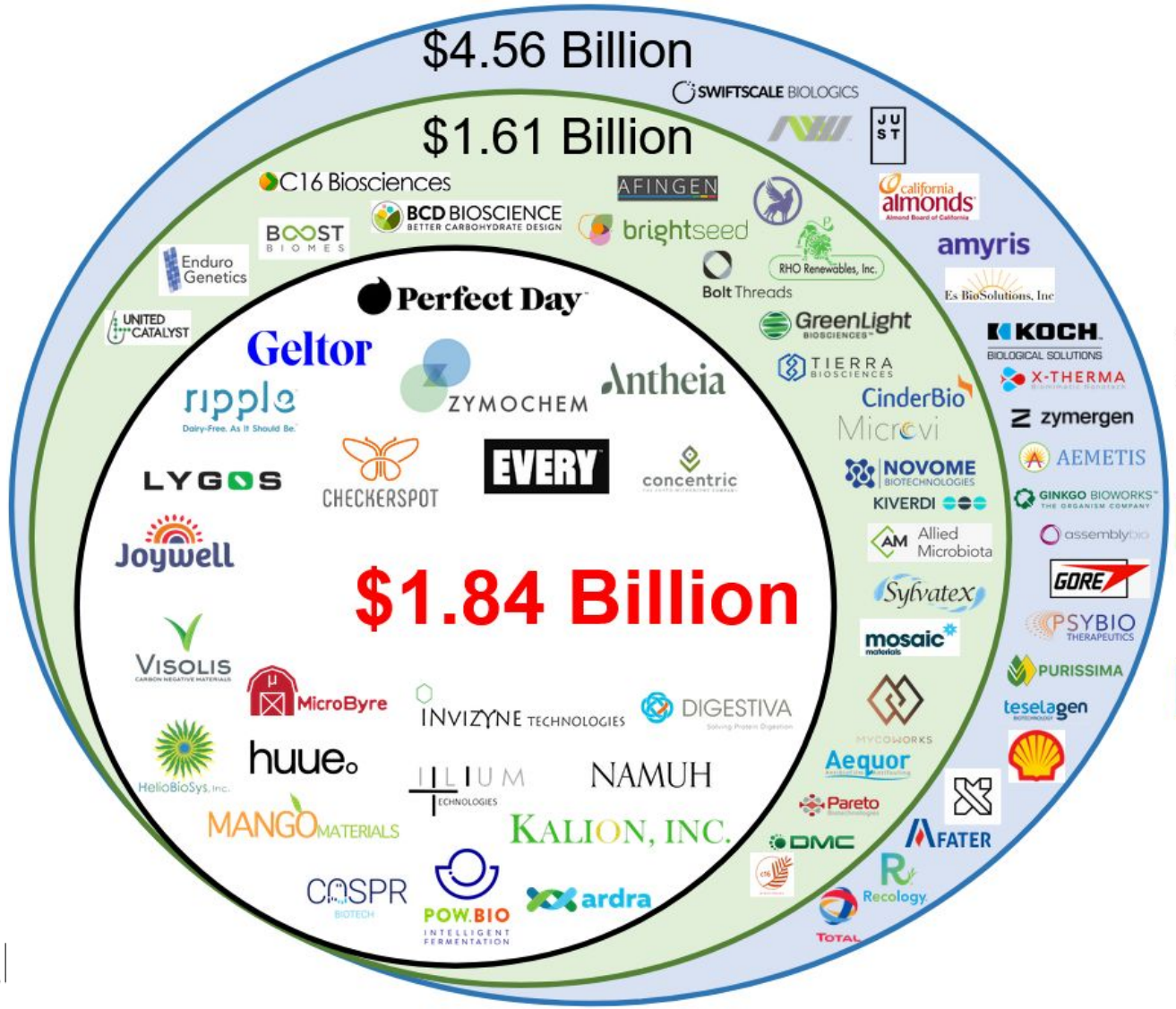
ABPDU

Impact
Disseminating the Experience by Supporting the Budding BioEconomy



*Not an exhaustive list of relationships developed; a few examples

Impact
Helping Companies Grow



Generating prototypes and/ or de-risking technologies at ABPDU improved equity value and accelerated the process of securing private financing for many companies.

- Companies that were enabled by ABPDU in generating prototypes and/ or raising private investments
- Companies that relied on ABPDU to develop and/ or analyze one or more of their processes
- Companies that benefited from ABPDU's expertise and capabilities

*Data from Crunchbase as of 07/01/2022

Impact
Task 1.1.1 – Technical Scope Development and Internal Coordination

What do you like?

- "Love the communication and quality of data that is generated."
- "In addition to videos (i.e., Overview, case studies, SOPs), I like ABPDU's website, which has been improving every year. Highly transparent."

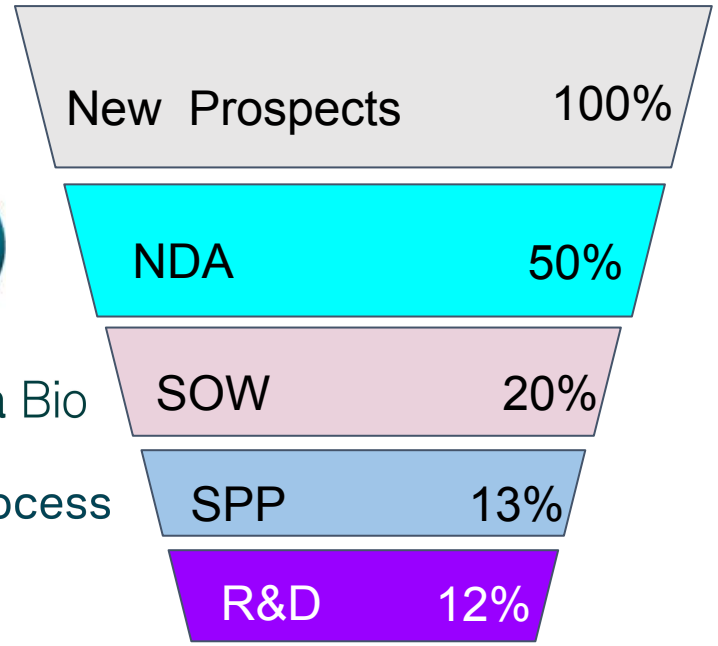
ILD 2023 had 60+ participants from 41 institutes share their thoughts

What changes are needed?

- "Would be better to have a one page summary of IP limitations of the contracts we're working on.."
- "Any possibility of having a viewable calendar to see the available dates?"

Impact
Task 1.1.2 – Technical Scope Development and Internal Coordination

SPP Project Development Pipeline



#s in FY 21 - 22
123
62
24
16
15 + 4 extensions

Total CRADAs in FY 21-22 = 8. CRADA Conversion Rate ~10% and is highly dependent on Funding Opportunity, often from Government Agencies.

Impact
Task 1.2.1 – Facility Readiness

Pressurized Fermentation Capability funded by Berkeley Internal funds: Simulating Manufacturing Scale Aerobic Fermentation in Pressurized Miniature Bioreactors

8 x 500 mL 6 bar pressure fermenter setup

<10% variation from 500mL to 300L across all key metrics

AB PDU

Impact
Task 1.2.2 – Safety Management

Empathize/ Define Problems:

- Polls and surveys enable everyone to contribute to safety workshops
- Serves as assurance to lab members that safety is a top priority
- Venue for sharing lessons learned to prevent repeat mistakes
- Lessons learned shared with Industry Collaborators as well

What do you like?

- "Ability to consult with James and collect lessons learned to assist with our facility development."
- "Research Capacity and Equipment"

What is not working for you?

- "Would like for ABPDU to share more process documents."

What changes are needed?

- "Successful stories and demonstration on how ABPDU can help in process design."
- "The lengthy process to get equipment for testing."

Participants of ILD 2023

Impact

Task 1.2.3 – Disseminating the Experience by training a Strong and Diverse Workforce entering Industry and Academia

100+ Trained Alumni from the ABPDU now working at various Companies and Universities. A complete list provided here: https://abpdu.lbl.gov/about-us/alumni/. Select Profiles listed below:

Aigerim Daniyar
Associate Process Design Engineer, Chevron

Robin Herbert
PhD Student at University of California, Berkeley

Fre Tachea
CTO and Co-Founder at Essential

Chenlin Li
Technology Manager, BETO, DOE

Jipeng Yan
Associate Professor, Beijing Institute of Technology, China

Chyi-Shin Chen
Scientist at Chugai Pharmaceutical Co., Japan

Tyler Pham, Sanjan Rathore, and other high school interns through the Pilot City Program

ABPDU Team


Deepti Tanjore


Ning Sun


Eric Sundstrom


James Gardner


Shawn Chang

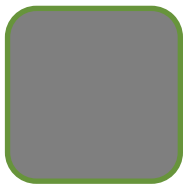

Emily Nelson


Leah Sloan


Katherine Schall


Chang Dou


Asun Oka


Tyrell Lewis


David Chang


Kirch Quijano


Sr. RA


Laura Fernandez


Onyinye Okonkwo


Jenny Duong


Wilian Marcondes


Kristen Hunter-Cevera


Zack Jones


Maria Duran Meneses


Postdoc


Dupeng Liu


Krishna Singh


Xihui Kang


Carolina Araujo Barcelos


Xinyi Zhou


Dylan Song


Sara Tejedor Sanz


Basem Zakaria