



Advanced Biofuels Process Demonstration Unit

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Biochemical Conversion Platform

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Goals / Objectives of the ABPDU team

The ABPDU will strongly enable and support the commercialization of industry-, academic- and DOE-driven biofuels and bio-products by providing a key technical resource and an agile, flexible team for process development and demonstration.

The project aims to have at least one industry sponsor per year commercially launch a biofuel / bio-product and secure private funding based on data generated at the ABPDU.

Quad Chart Overview

Timeline

- Project start date: 2010
- Project end date: 2018
- Percent complete: ~80%

Project was most recently merit-reviewed in FY15. Anticipate next merit review in FY18.

Budget

	Total Costs FY 10–FY 14	FY 15 Costs	FY 16 Costs	Total Planned Funding FY 16–18
DOE Funds*	\$30.4 M	\$3.9 M	\$2.75 M	\$7.75 M (\$2.5 M per year in FY17-18)

*Includes \$17M in ARRA funding

Barriers addressed

- Bt-B, Biomass Variability
- Bt-D, Pretreatment Chemistry
- Bt-E, Pretreatment Costs
- Bt-G, Cellulase Enzyme Loading
- Bt-I, Cleanup / Separation
- Bt-K, Biological Process Integration

Partners

- 29 Industry partners over FY14-17, including 26 US small businesses
- 2 academic / not-for-profit partnerships with UCSF and Woods Hole.
- AOP subcontracts for process development and analytical chemistry with SNL and INL
- Formal AOP Lab partnerships as part of Agile BioFoundry, Separations Consortium, co-OPTIMA, Feedstock Conversion Interface

1 – Project Overview

ABPDU enabling biofuel/product commercialization

- 15,000 square foot Demonstration Lab established by American Recovery and Reinvestment Act funds in 2009
- Managed by DOE EERE from the BioEnergy Technologies Office (BETO)



- A bio-process research incubator / accelerator – industry-friendly IP rights, cost-recovery project fee structure, experienced team, and Bay Area location

Engaged with 29 industry partners over past 3 years (incl. 26 US small businesses)



Biofuels & biomass

Materials & chemicals

Food & health

Waste & water



Completed projects

Ongoing



Providing a critical resource and direct support of several DOE / EERE / BETO programs and consortia



cyclotronroad



co-OPTIMA



Feedstock Conversion Interface Consortium

BETO Small Business Lab Calls and Industrial Seedlings



Small Business Vouchers Pilot
ENERGIZING THE CLEAN ECONOMY



Working with industry partners via other agency programs



2 – Management approach

Project development in close concert with IPO / OCFO



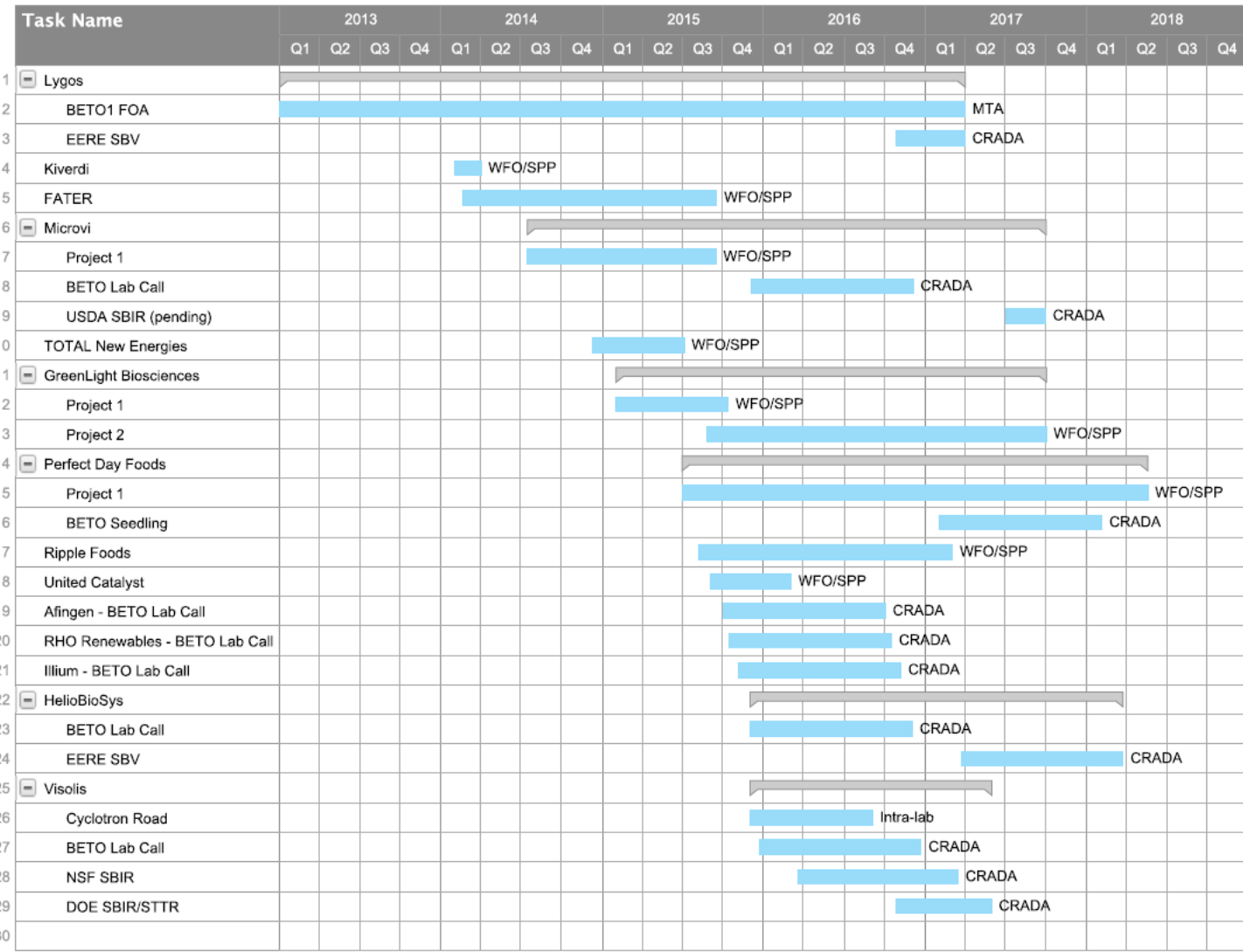
ABPDU Mission:
Partner with researchers
from industry, the National
Labs, and academia to
optimize and scale
technologies for bio-based
chemicals / materials / fuels
commercialization.

Innovation and Partnerships Office

Bringing you Berkeley Lab's pioneering research and inventions

Robust management systems to implement projects and balance / schedule resource utilization

Industry partnerships initiated FY13-FY15

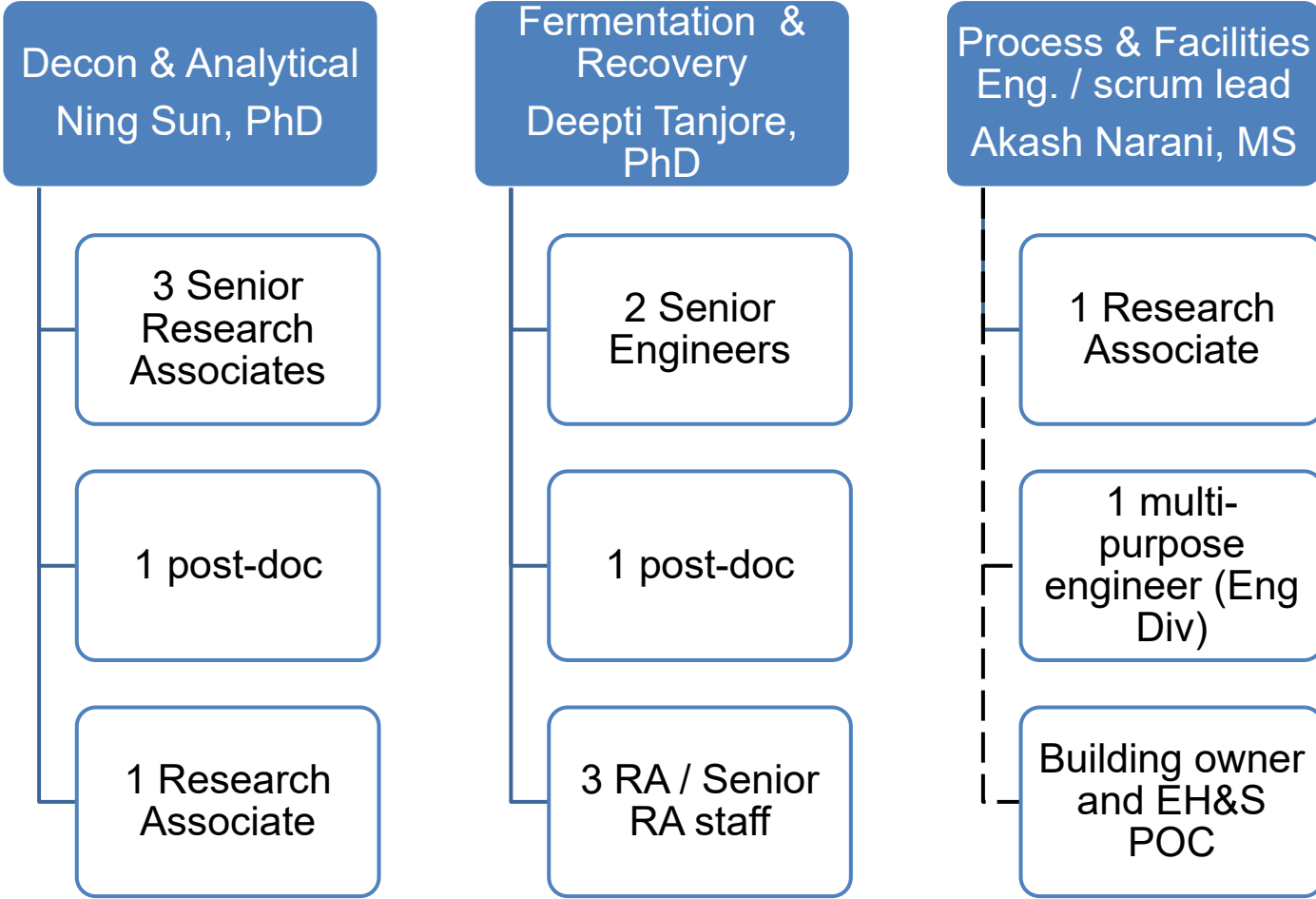


Robust management systems to implement projects and balance / schedule resource utilization

Industry partnerships initiated FY16-FY17

Task Name	2013				2014				2015				2016				2017				2018				
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
31 Pareto - BETO Lab Call													[Light Blue Bar]				CRADA								
32 <input type="checkbox"/> Sylvatex													[Grey Bar]												
33 Project 1													[Light Blue Bar]				WFO/SPP								
34 BETO Seedling																	[Light Blue Bar]				CRADA				
35 Clara Foods													[Light Blue Bar]				WFO/SPP								
36 Geltor													[Light Blue Bar]								WFO/SPP				
37 Hampton Creek													[Light Blue Bar]				WFO/SPP								
38 Ardra Bio													[Light Blue Bar]				WFO/SPP								
39 Ginkgo Bioworks													[Light Blue Bar]				WFO/SPP								
40 ES Biosolutions													[Light Blue Bar]				WFO/SPP								
41 <input type="checkbox"/> Mango Materials																	[Grey Bar]								
42 Project 1													[Light Blue Bar]				WFO/SPP								
43 EERE SBV																	[Light Blue Bar]				CRADA				
44 Mosaic Materials - Cyclotron Road																	[Light Blue Bar]				Intra-lab				
45 Kalion - BETO Seedling																	[Light Blue Bar]				CRADA				
46 Zymochem EERE SBV																	[Light Blue Bar]				CRADA				
47 Checkerspot - BETO Seedling																	[Light Blue Bar]				CRADA				
48 Recology																	[Light Blue Bar]				WFO/SPP				
49 Aequor - BETO Seedling (pending)																	[Light Blue Bar]				CRADA				
50																									

Multi-disciplinary and cross-trained team



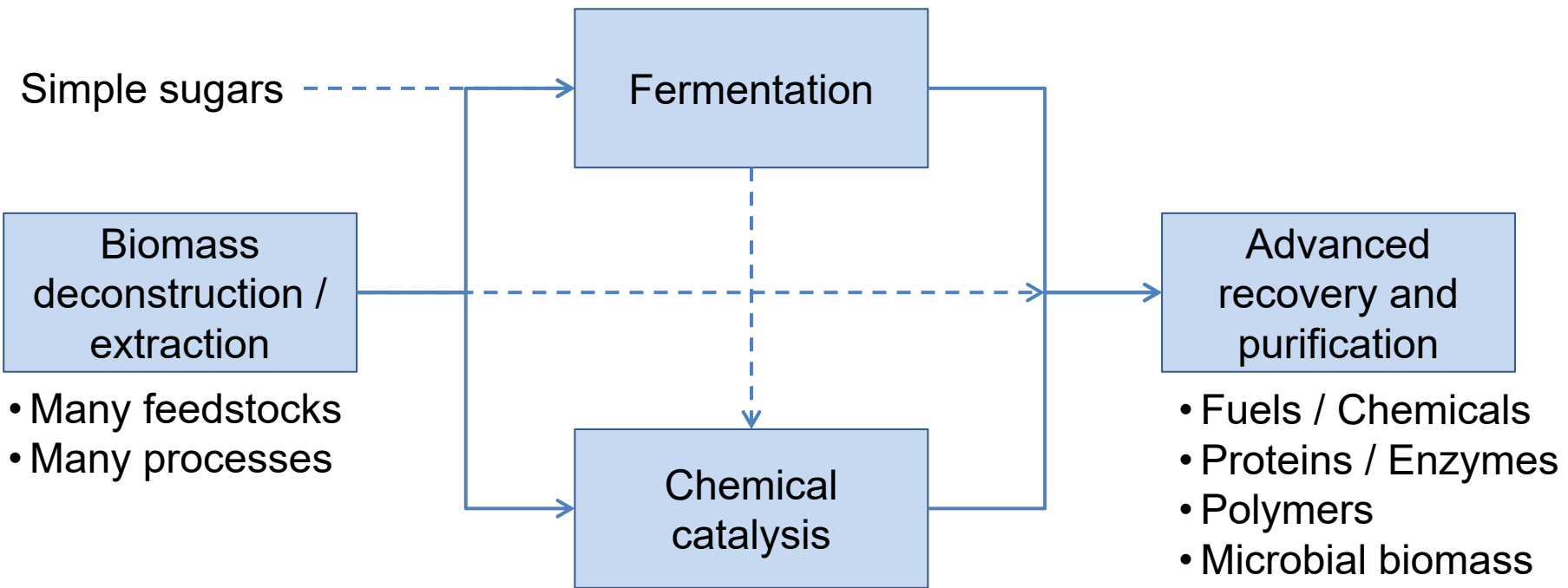
Agile Project Management employed for day-to-day Ops on the process floor

Workforce development via internships a key activity - DOE CCI & SULI, UC Berkeley Manufacturing-to-Market

2 – Technical approach

Bench-scale & pre-pilot prototyping, benchmarking and cross-training prior to partner process execution

- Process demonstration, integration and techno-economic analysis across varied bio-process configurations, feedstocks and products

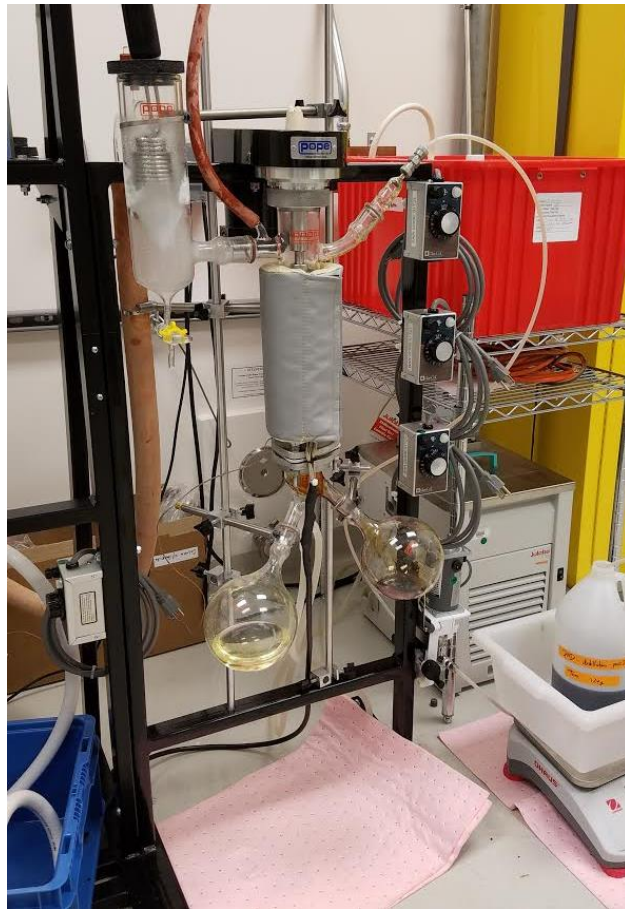


- Can focus on individual unit operations or several processes in succession

Facility at a glance – from bench-to-pilot scale



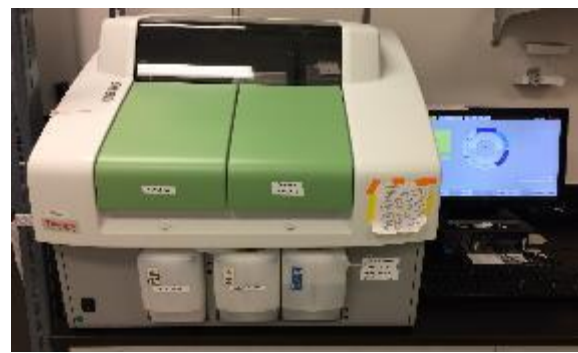
Key capability upgrades over past 2 years



Pope hybrid wiped-film evaporator / fractional distillation skid



Seg-Flow® 4800 Automated On-line Sampling System



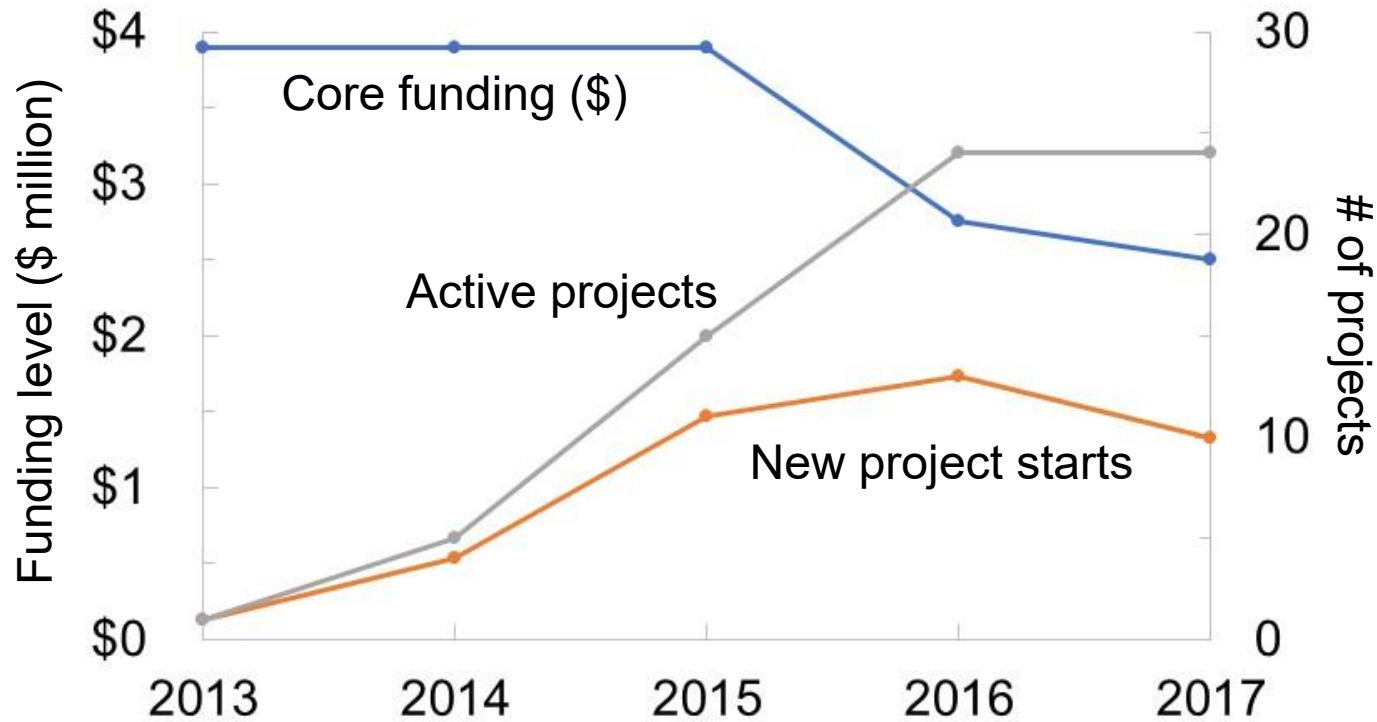
Gallery™ Automated Photometric Analyzer



Using custom controls, automation and data acquisition with almost every campaign

3 – Technical Accomplishments/ Progress/Results

Reducing dependence on BETO ABPDU core funding while growing impact with industry



*FY 2017 project numbers to-date

Major technical outcomes

- 3 patent applications filed / in process – flexible pre-treatment reactor design, MSW to fermentable sugars, algae to bio-materials
- Supported commercial product launch of a low GHG dairy alternative (Ripple Foods) via initial process scale-up demonstration and commercial scale-down prototyping
- Implemented pre-commercial process prototyping and troubleshooting for companies focused on commodities and specialty chemicals (Ginkgo Bioworks and GreenLight Biosciences) and bio-materials (Mango Materials)
- Supported and developed capabilities required to meet milestones in other BETO projects presenting at peer review (FCIC, SepCon, ABF, co-OPTIMA)

Task D: Translate plate metrics to pilot scale metrics

3rd party validation of final project metrics was performed at the ABPDU (50-liter scale)

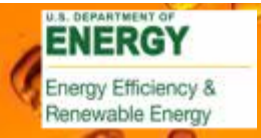


- Problems were encountered obtaining cellulosic sugars within allowed budget, limiting fermentation scale
- Demonstrated successful scaleup of fermentation process with real-world cellulosic sugars*

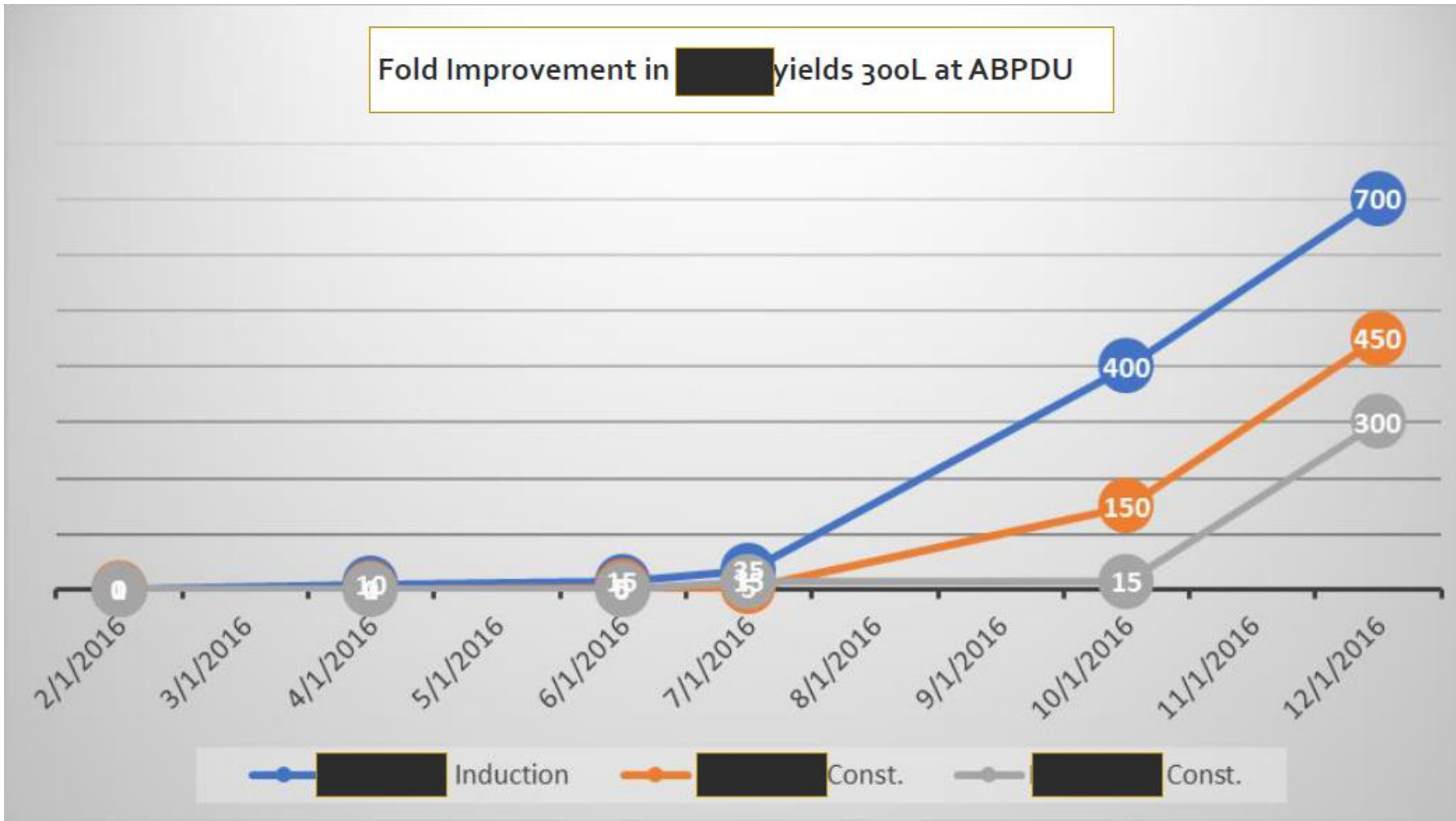
Parameter	As % of Control Fermentations
Yield	120%
Titer	99%
Productivity	99%



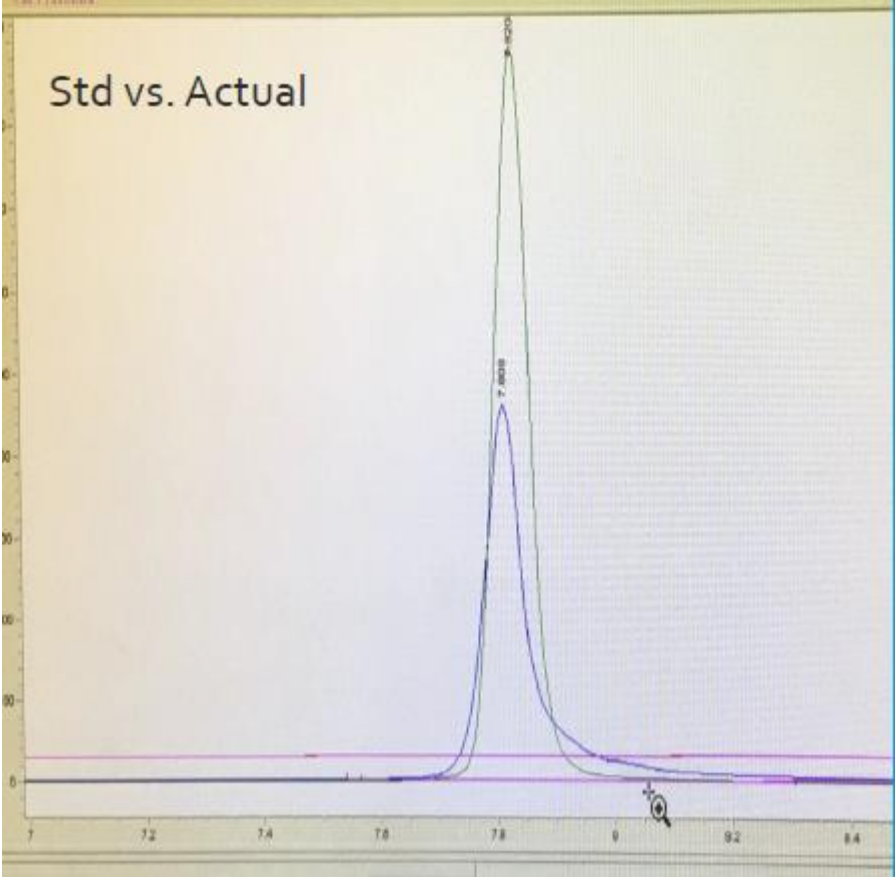
* Confidential commercial provider



Enabling advances in scalable protein production at commercially relevant quality with industry partner



Enabling advances in scalable protein production at commercially relevant quality (cont.)



Translating basic scientific discoveries from BRCs into more applied and scaled demonstrations

Green Chemistry

PAPER

[View Article Online](#)

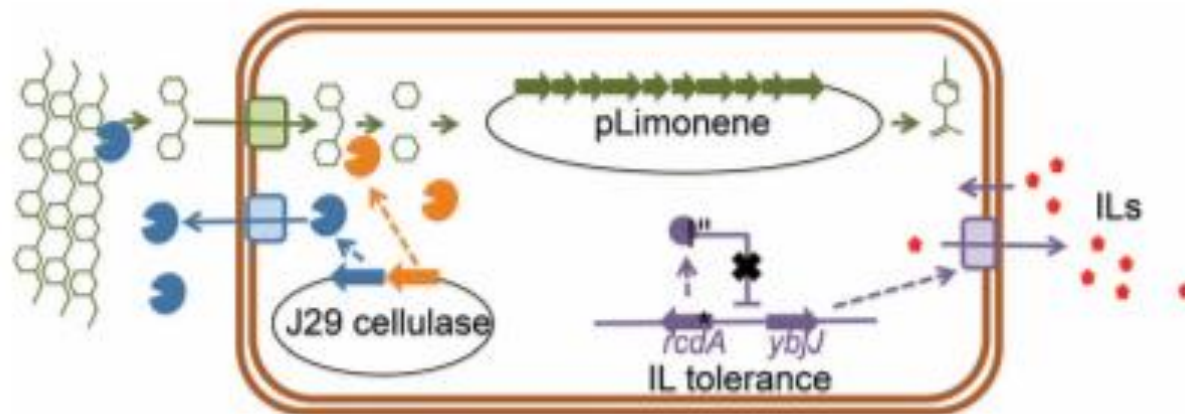
[View Journal](#) | [View Issue](#)



Cite this: *Green Chem.*, 2016, 18, 4189

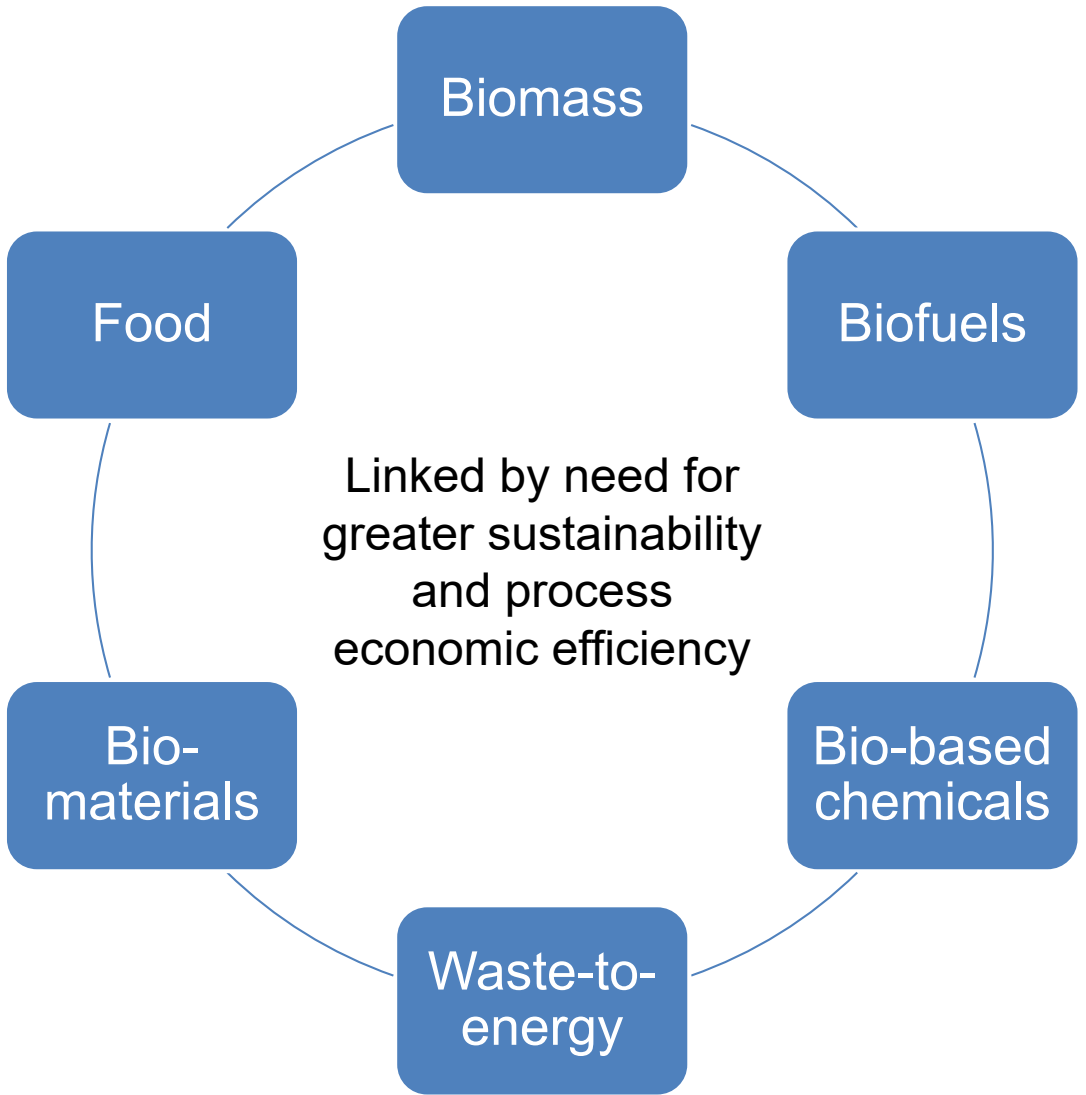
Development of an *E. coli* strain for one-pot biofuel production from ionic liquid pretreated cellulose and switchgrass†

Marijke Frederix,^{a,b} Florence Mingardon,^c Matthew Hu,^{a,b} Ning Sun,^{b,d} Todd Pray,^{b,d} Seema Singh,^{a,b,e} Blake A. Simmons,^{a,b,e} Jay D. Keasling^{a,b,f,g} and Aindrita Mukhopadhyay^{*a,b}



4 - Relevance

Driving innovation across several sectors of bioeconomy



Key outcomes for private sector collaborators

- Several competitive awards as preludes or follow-ons to sponsored projects



- Numerous partners have set up their own labs or pilot plants and secured private financing while / after working with ABPDU



RIPPLE FOODS

- Product launches and commercial / pre-commercial scale-up & scale-down



RIPPLE FOODS



<http://www.biofuelsdigest.com/bdigest/2016/12/14/chief-pilot-the-abpdu-where-the-elite-meet-to-defeat-petroleum/>

Critical resource and capability for other BETO projects and Labs

- AOP project subcontracts for analytical and process demonstration support



- Key player in process development, benchmarking and prototyping across several National Lab BETO consortia



Feedstock Conversion Interface Consortium

5 – Future Work

Growth along new partnerships and technologies

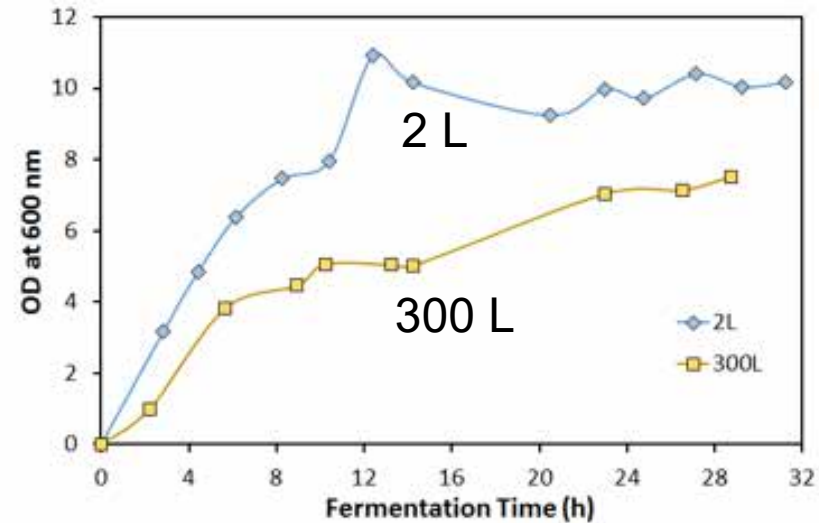
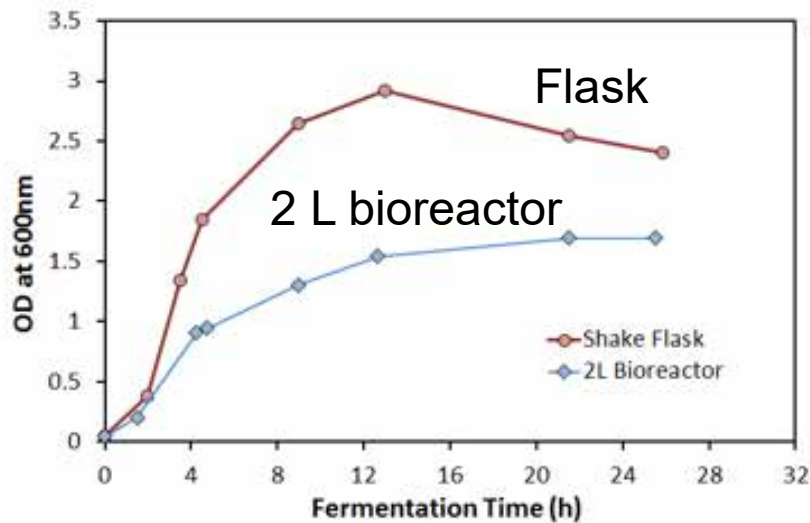
- Complete RFI with BETO on industry technical needs, and potentially deploy:
 - HTST skid and additional bench-scale bioreactor capacity
 - continuous chemical reactor capability at bench / pre-pilot scale
- Develop more incubator / accelerator and academic / university collaborations and project proposals



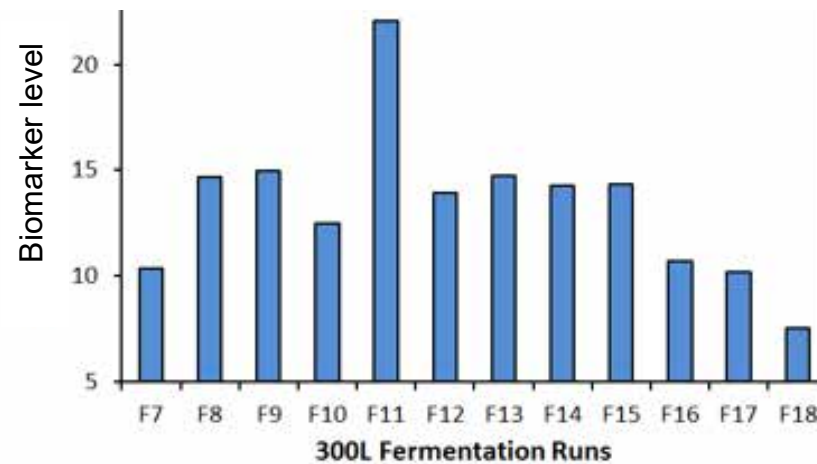
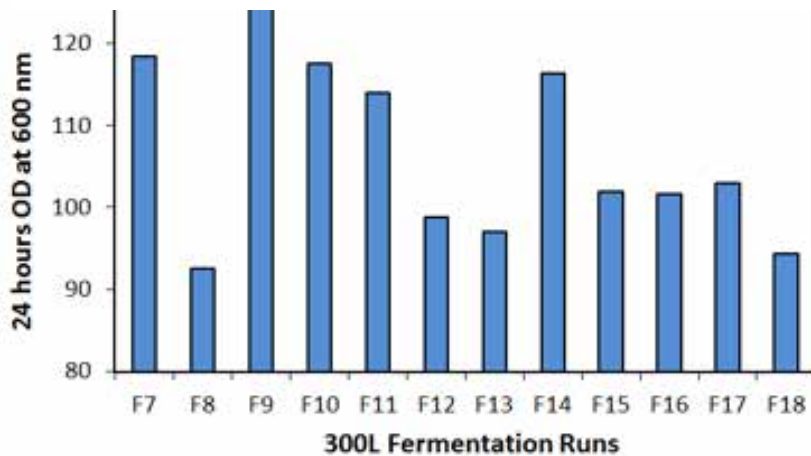
- Augment US small business projects with larger company alliances
- Develop and implement Masters in Bioprocess Engineering Program with UC Berkeley: <http://chemistry.berkeley.edu/grad/cbe/bioprocess-engineering>
- Continue meeting milestones around project occupancy, publications, new project starts, and presentations / outreach

Working to make partners' scale-up more predictable

Reduced culture growth periodically observed during scale-up



Inter-campaign variability pointed to need for greater process robustness



Summary

Enabling bio-economy and BETO partners to succeed

- Have become a key resource for industry, BETO and DOE consortia, as well as other Federal agency projects, even while reducing core operating expenses by over 35% and working to keep project costs and overhead in a manageable range for sponsors such as small businesses and other National Labs and academic groups.
- Keen focus and success in working with US small businesses for technical support and IP development, as well as in workforce development with DOE and other internship programs
- Driving innovation in process development, demonstration and scale-up / scale-down for prototyping and commercialization

Additional slides

Responses to Previous Reviewers' Comments

Major comments from FY15 review

- The ABPDU is a terrific resource that has clearly improved since the last peer review. Although significant progress has been made toward self-sufficiency, it is important that project leadership focus on methods to grow industrial application and move away from BETO funding rapidly. The plan to maintain cutting-edge status by continuously upgrading is admirable; be sure to focus on upgrading in a direction that attracts industry.
- The ABPDU needs to become self-sustaining in the very near term.
- The ABPDU represents a state-of-the-art, flexible small pilot-scale facility. The project has facilitated a number of studies for others and appears positioned to increase collaborative work. As most small entities could not afford to develop such a capability on their own, this facility plays a vital role in scale up

The ABPDU has dramatically grown its technical capability and industry user base and reduced dependence on core BETO funding from \$4 million per year to \$2.5 million. Further reduction in core funding would reduce industry impact by increasing overhead and project costs to industry and Lab partners.

Go / no-go decision point - ABPDU mission adjustments

- Decision point – 3/31/2017
- Description
 - Demonstrate performance that matches BETO mission goals, including bioeconomy-relevant industry projects as well as milestones on other BETO projects at the ABPDU.
- Criteria
 - Complete RFI with BETO and develop plan forward based on ABPDU performance, needs identified in RFI, and industry feedback and documented project outcomes on WFO and CRADA projects completed to date.

Patent applications (cumulative)

1. Reactor vessel useful for performing multiple pretreatments. Application number 62/080,968 filed 2014.
2. "Conversion of a soiled post-consumer cellulosic composition." Application number 62/193,701 filed 7/17/2015. International Patent Application Filed in matter "Conversion of post-consumer hygiene cellulosic stream for biorefinery," July 18, 2016. Patent Application Ser. No: PCT/US2016/042863
3. Application drafting in progress related to biomaterial production from algal extract. Target filing end-March.

Publications with partners since FY15 peer review

1. C. Li, D. Tanjore, W. He, J. Wong, J. L. Gardner, V. S. Thompson, N. A. Yancey, K. L. Sale, B. A. Simmons and S. Singh. (2015). Scale-Up of Ionic Liquid-Based Fractionation of Single and Mixed Feedstocks. *BioEnergy Research*, 2015, 1-10.
2. N. Sun, F. Xu, N. Sathitsuksanoh, V. S. Thompson, K. Cafferty, C. Li, D. Tanjore, A. Narani, T. R. Pray, B. A. Simmons and S. Singh (2015). Blending municipal solid waste with corn stover for sugar production using ionic liquid process *Bioresource Technology*, 186, 200-206.
3. J. L. Gardner, C. Li, W. He, J. Wong, K. Sale, B. A. Simmons, S. Singh, and D. Tanjore (2015). Calorimetric Evaluation indicates that Lignin Conversion to Advanced Biofuels is Vital to improving Energy Yields, *RSC Advances*, 5, 51092.
4. Tanjore D and Richard TL (2015). A Systems View of Lignocellulosic Hydrolysis. In *Advances in Bioprocess Technology* (Ed. by R. Pogaku), Springer Series (2015) 387-419.
5. M. Frederix, F. Mingardon, M. Hu, N. Sun, T. R. Pray, S. Singh, B. A. Simmons, J. D. Keasling and A. Mukhopadhyay (2016). Development of an E. coli strain for one-pot biofuel production from ionic liquid pretreated cellulose and switchgrass. *Green Chem.*, 2016,18, 4189-4197
6. C Li , L. Liang, N Sun, VS Thompson , F Xu , A Narani , Q He, D Tanjore, TR Pray , BA Simmons, S Singh (2017) Scale up and process integration of sugar production by acidolysis of municipal solid waste/corn stover blends in ionic liquids. *Biotechnol Biofuels* 10 (1):13.

Currently 5 other articles submitted and under review

Oral presentations since FY15 peer review (pg. 1 of 2)



1. A. Narani, P. Coffman, J. Gardner, N.V.S.N. Murthy Konda, K. L. Kenney, V. Thompson, G. L. Gresham, C. Li, B. Simmons, D. Klein-Marcuschamer, T. Pray, and D. Tanjore. Predictive Modeling Can De-Risk Bio-Based Production. Oral Presentation for **SIMB Symposium on Biotechnology for Fuels and Chemicals**. April 27-April 30, 2015, San Diego, CA.
2. Chenlin. Li; L. Liang, N. Sun, F. Xu, V. S. Thompson, A. Narani, Q. He, T. Luong, D. Tanjore, T. R. Pray, B. A. Simmons, S. Singh. Scale-up and process integration of sugar production by acidolysis of single and mixed feedstocks in ionic liquids. **SIMB Symposium on Biotechnology for Fuels and Chemicals**. April 27-April 30, 2015, San Deigo, CA.
3. Todd R. Pray, Chenlin Li, Ling Liang, Jessica Wong, Qian He, Firehiwot Tachea, Deepti Tanjore, Marcello Somma, Nicola D'Alessio. Integration and Chemical and Fuel Intermediate Production from Post-consumer Municipal Solid Waste. **BIO World Congress on Industrial Biotechnology**. 7/23/2015 Montreal, Canada
4. Todd R. Pray, Bio-process scaling and optimization - from bench to piloting at the DOE Berkeley Lab ABPDU. **SIMB Annual Meeting**. 8/6/2015. Philadelphia, PA.
5. Todd R. Pray, Recent Technical and Commercial Advances for Cellulosic Ethanol and other Bio-products. 9/8/2015. **Univ. Tokyo** invited lecture. Tokyo, Japan
6. Todd R. Pray, ABPDU overview. 9/9/2016. **National Institute for Advanced Industrial Science and Technology (AIST)** - invited lecture. Hiroshima, Japan
7. Todd R. Pray, ABPDU overview, 9/11/2015. **Kobe University** invited lecture Kobe, Japan.

Oral presentations since FY15 peer review (pg. 2 of 2)

8. A. Narani, P. Coffman, F. Tachea, C. Li, T. Pray, and D. Tanjore. Predictive Modeling and Rheological Characterization of Mixed Feedstocks. **2015 AIChE Annual Meeting**. November 8-13, 2015, Salt Lake City, UT.
9. Ling Liang, Ning Sun, Chenlin Li, Qian He, Tina Luong, Feng Xu, Marcello Somma, Nicola D'Alessio, Vicki S. Thompson, Blake A. Simmons, Seema Singh, and Todd R. Pray. Scale-Up and Process Integration of Municipal Solid Waste Conversion Process. **38th Symposium on Biotechnology for Fuels and Chemicals**. April 25-April 28, 2016, Baltimore, MD.
10. Todd R. Pray. Panel moderator for Bioprocess Scaling: Imagining the Microliter to Megaliter Transition. **BIO Annual Meeting**. June 7, 2016. San Francisco, CA.
11. Todd R. Pray. Panel moderator and speaker at **APEC Workshop on the Development of Biomass Energy**. 7/26/2016. Hanoi, Vietnam.
12. Jipeng Yan, L Liang, Q He, T Luong, F Xu, C Li, V S. Thompson, Ee-Been Goh, H R. Beller, B A Simmons, T R Pray, S Singh, and N Sun Conversion of Municipal Solid Waste to Methyl Ketone Using Ionic Liquid Based Process. **2016 AIChE Annual Meeting**, November, 2016, San Francisco, CA.
13. Todd Pray. Developing and Piloting Robust Downstream Processes to Utilize Variable Composition and Blended Biomass Feedstocks. **2016 AIChE Annual Meeting**, November, 2016, San Francisco, CA.
14. Akash Narani, Phil Coffman, Matthew Miller, Firehiwot Tachea, Chyi-Shin Chen, Chenlin Li, Allison E. Ray, Todd Pray and Deepti Tanjore. Predictive Model and Bioconversion of Mixed Feedstocks. **2016 AIChE Annual Meeting**, November, 2016, San Francisco, CA.