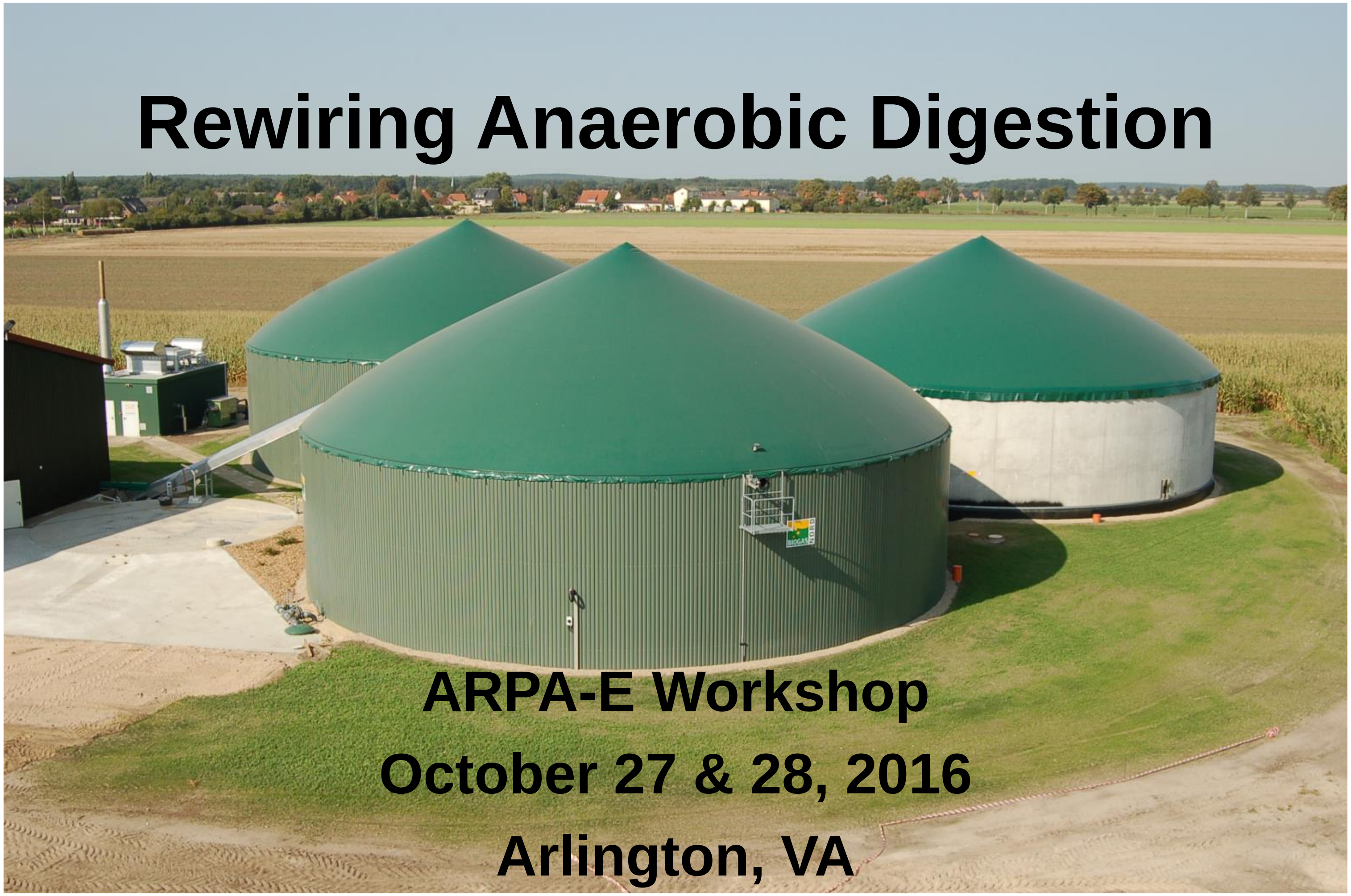
CHANGING WHAT'S POSSIBLE



Rewiring Anaerobic Digestion

ARPA-E Workshop

October 27 & 28, 2016

Arlington, VA

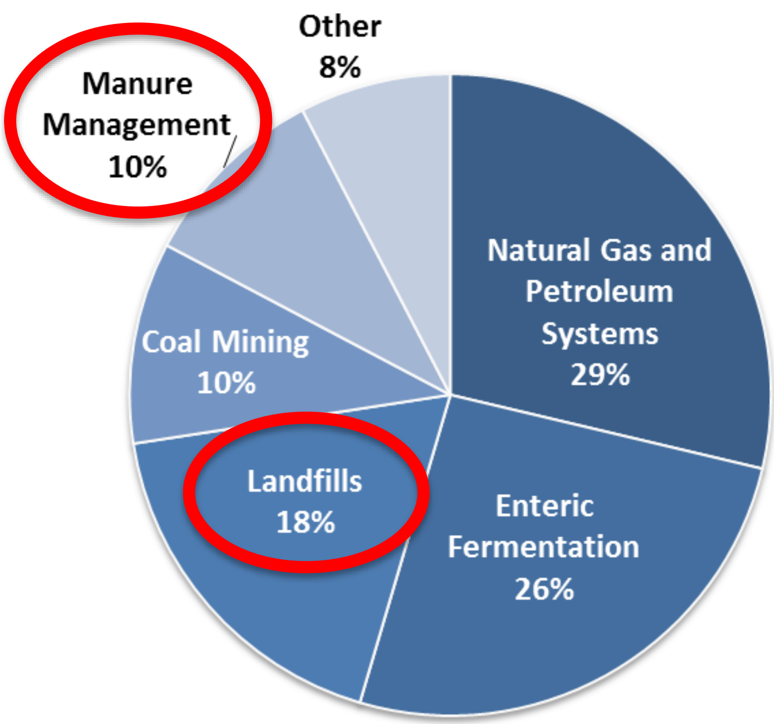
The 3 WHYs?

- Why Rewiring Anaerobic Digestion?
- Why now?
- Why ARPA-E?

Reducing GHG Emissions

- **Manure management** responsible for about 10% of US methane emissions
- **Landfills** emitted another 18% of US methane emissions
- Globally, agriculture sector is primary source of CH_4 emissions

2013 US Methane Emissions:
234.5 $MMTCO_2Eq$



10% of total US GHG Emissions

Source: US EPA

Converting Waste into Renewable Energy

US Methane Gas Potential

Source	Methane Potential (tonnes/yr)
Wastewater Treatment Sludge	2,339,339
Landfills	2,454,974
Animal manure	1,905,253
Industrial and commercial organic waste	1,157,883
Total	**7,857,449**

(~0.431 Quads)

Additional Methane Opportunities

- **~0.4 Quads from 36 Million tons of food waste from MSW**
- **~4.3 Quads from crop waste and energy crops (maximum from all biomass)**

Data from NREL, 2013 & US EPA

Operational vs. Potential

Currently Operational and Potential Biogas Systems in the United States				
	Livestock Manure	Landfill Gas	Water Resource Recovery Facilities	Total
Currently Operational Biogas Systems	239[xi]	636[xii]	1,241[xiii]	2,116
Total Potential Number of Biogas Systems	8,241[xiv]	1,086[xv]	3,681[xvi]	13,008

Figure 5 - Currently Operational and Potential Biogas Systems in the United States Creating Energy

What's the problem?

From: Biogas Opportunities Roadmap, USDA 8-1-2014

Economics of Anaerobic Digestion

- Biogas Production (Capital Cost): ~$8-10/mmBTU
- Clean up Cost (to CNG level): ~$5-10/mmBTU
- RIN (D5 Advanced Biofuels, only available if used for vehicles): ~$7/mmBTU
- **Total Cost : ~$6-$13/mmBTU** (with RIN)
  ~$13-$20/mmBTU (without RIN)

- **Compare to natural gas cost ~ $3 - 4/mmBTU**

Strategies to increase return from anaerobic digestion

- Increase volumetric productivity of anaerobic digester, thus, reducing capital cost
- Increase methane concentration in biogas (reducing purification cost)
- **Change product portfolio to higher value, more transportable products**

Maximizing the biological route to Direct Air Capture of CO_2

- Plants, terrestrial and marine (macroalgae), annually fix 210 GT of carbon as CO_2 from air
- Much of it as carbohydrates, which can be converted to fuels via fermentation.
- However, fermentation of carbohydrates to methane or ethanol leads to loss of >1/3 of carbon as CO_2 :

  $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

  $C_6H_{12}O_6 \rightarrow 3\ CH_4 + 3\ CO_2$

- Alternatively, produce organic acids and then reduce them electrochemically:

  $C_6H_{12}O_6 \rightarrow 3\ C_2H_4O_2$

  $C_2H_4O_2 + 2\ e^- + 4\ H^+ \rightarrow C_2H_5OH + H_2O$

  - This will increase carbon efficiency by 50 to 100%, and increasing fuel yield per acre correspondingly.

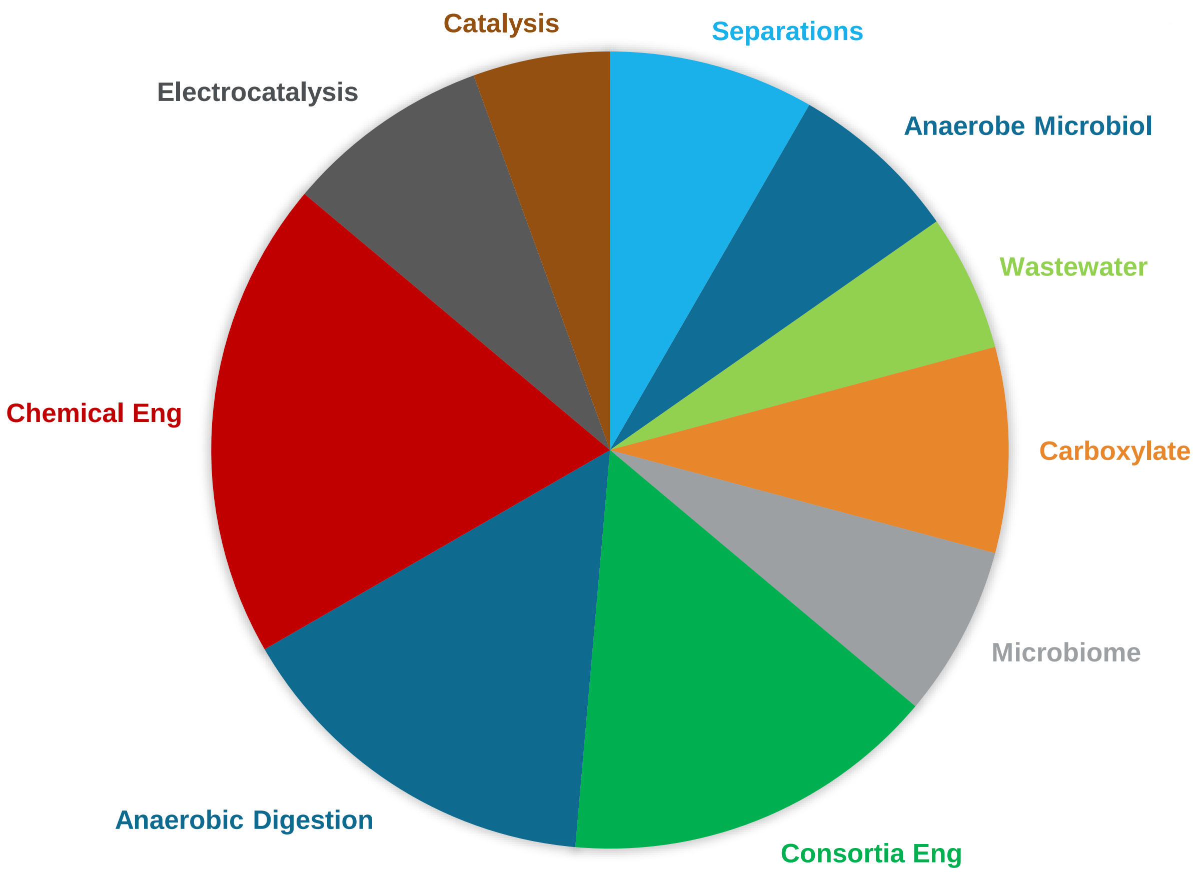
Why now?

- Ever increasing need for technologies that can reduce GHG emissions.
- Significant advances in the areas of
  - Microbiome analysis and engineering
  - Electrocatalysis
  - Separation Sciences

Why ARPA-E?

- Large Renewable Fuel Opportunity
- Multi-disciplinary approach needed
- High risk / high reward project

Workshop Participant Mix



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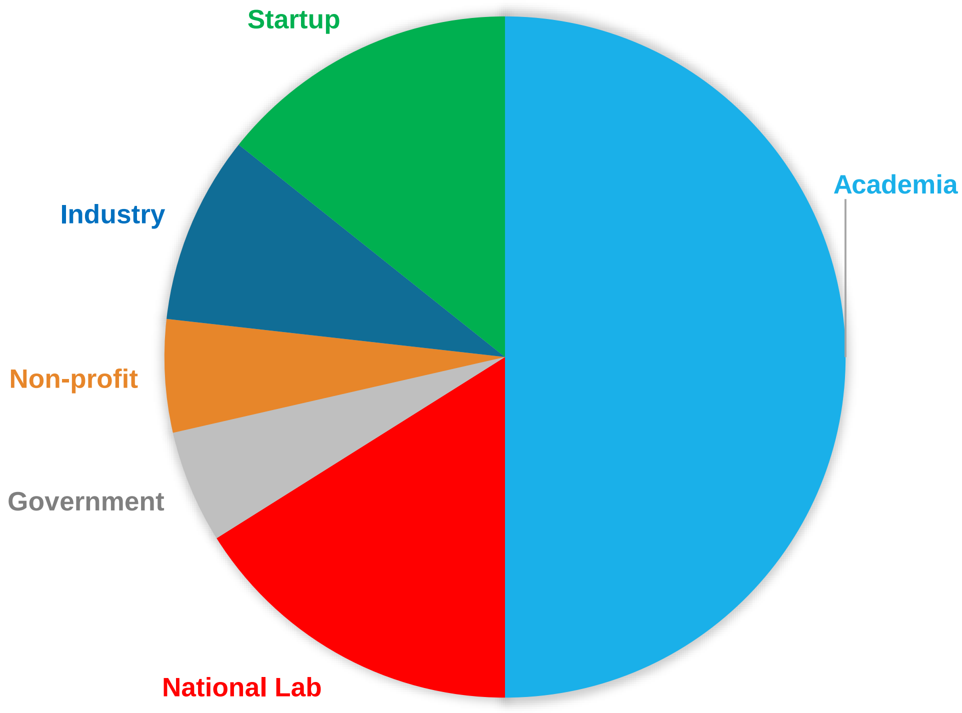
Workshop Participant Mix



ARPA-E Goals for Workshop

- Validate that **this technology matters, if it works**.
- Identify the critical questions/topics on which to focus to put this technology on a path towards commercial viability.
- Catalyze new connections between various disciplines to help in the formation of innovative teams.
- Establish meaningful targets metrics for a potential FOA.

Workshop Guidelines

- GOOD QUESTIONS are more important than answers

- Consensus is NOT required

Schedule - Morning

Time	Session/Speaker	Topic/Comments
8:00 am	Registration w/ coffee	
8:30 am	Dr. Eric Rohlfing	Welcome and introduction to ARPA-E
8:45 am	Marc von Keitz	Workshop motivation and goals
9:05 am	Dr. Luca Zullo	*Anaerobic digestion industry overview and opportunities for process intensification*
9:30 am	Dr. David Chynoweth	*Anaerobic digestion feedstocks and opportunities for macroalgae conversion*
9:50 am	MvK	Breakout #1 instructions
10:00 am	Coffee break	Migrate to breakout rooms
10:15 am	**Breakout Session #1**	**Challenges and opportunities for intensification of the AD process**
11:45 pm	Lunch & Breakout Session #1 report out	

Let’s dig in…

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Morning Presentations

Schedule - Afternoon

Time	Session/Speaker	Topic/Comments
12:50 pm	Dr. Jang Kim	*Macro algae cultivation in Korea/Asia – emerging technology trends*
1:15 pm	MvK	ARPA-E perspective of new tech opportunities & Breakout #2 instructions
1:30 pm	**Breakout session #2**	**Advanced tools & Strategies to approach challenges to scale**
2:45 pm	Coffee break	
3:00 pm	Breakout Session #2 read out & Instructions for Breakout Session #3	
3:30 pm	Erick Ask	*A US Seaweed Industry – View from the largest US market for seaweed*
4:00 pm	Bren Smith	*Greenwave – Opportunities for distributed, sustainable ocean farming*
4:15 pm	**Breakout session #3**	**Macro Algae Products – revenue, business models & processing**
5:15 pm	Breakout Session #3 read out	
5:45 pm	Day 1 closing remarks	
6:30 pm	No host dinner options	Informally coordinated

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Breakout Session 4:

Potential ARPA-E Funding Opportunity – Focus, Metrics, Scale, Feedstock

ARPA-E Focused Programs

- ~$30-35 Million
- 7-12 projects
- 2-4 years

Parameters

- Focus Area
- Metrics
- Scale & Feedstocks

Focus Area – Guiding Questions

- Which key problems need to be addressed to lower the cost of/intensify the anaerobic digestion process?
- Which key problems do we need to address to make rewiring anaerobic digestion a meaningful alternative process?
- Which problems can we tackle with the resources/time frame ARPA-E can offer?
- **If we succeed, does it matter?**

Metrics – How do we measure success?

- Target metrics – Defining success
- Benchmarking relative to existing technologies (either commercial or under development)
- Enabling technical and economic viability
- Need to be quantitative
- Stretch goal

Scale and Feedstock

- Big enough to derisk technology
- Still manageable considering time & money
- Feedstocks that offer opportunity to “earn to learn”, but also are abundant enough to matter, if they work

Some closing thoughts

(Potential) Next Steps

- Request for Information (RFI)
- Internal Pitch
- Teaming List
- Funding Opportunity Announcement (FOA) –start of silent period
- Project Selection
- Project Start

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Thank you!