Electrode-Driven Microbial CO_2 Utilization

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U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
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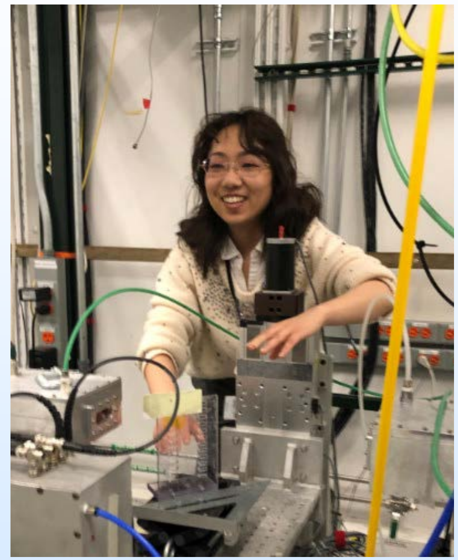
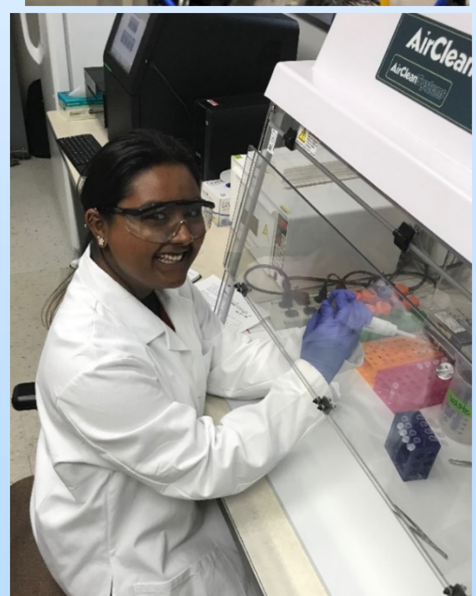
Presentation Outline

- Overview FY17
  - Research Team
  - Task Goals and Structure
- Technical Status
- Lessons Learned
- Project Summary
- Synergistic Opportunities
- Accomplishments to Date

FY2019 Research Team

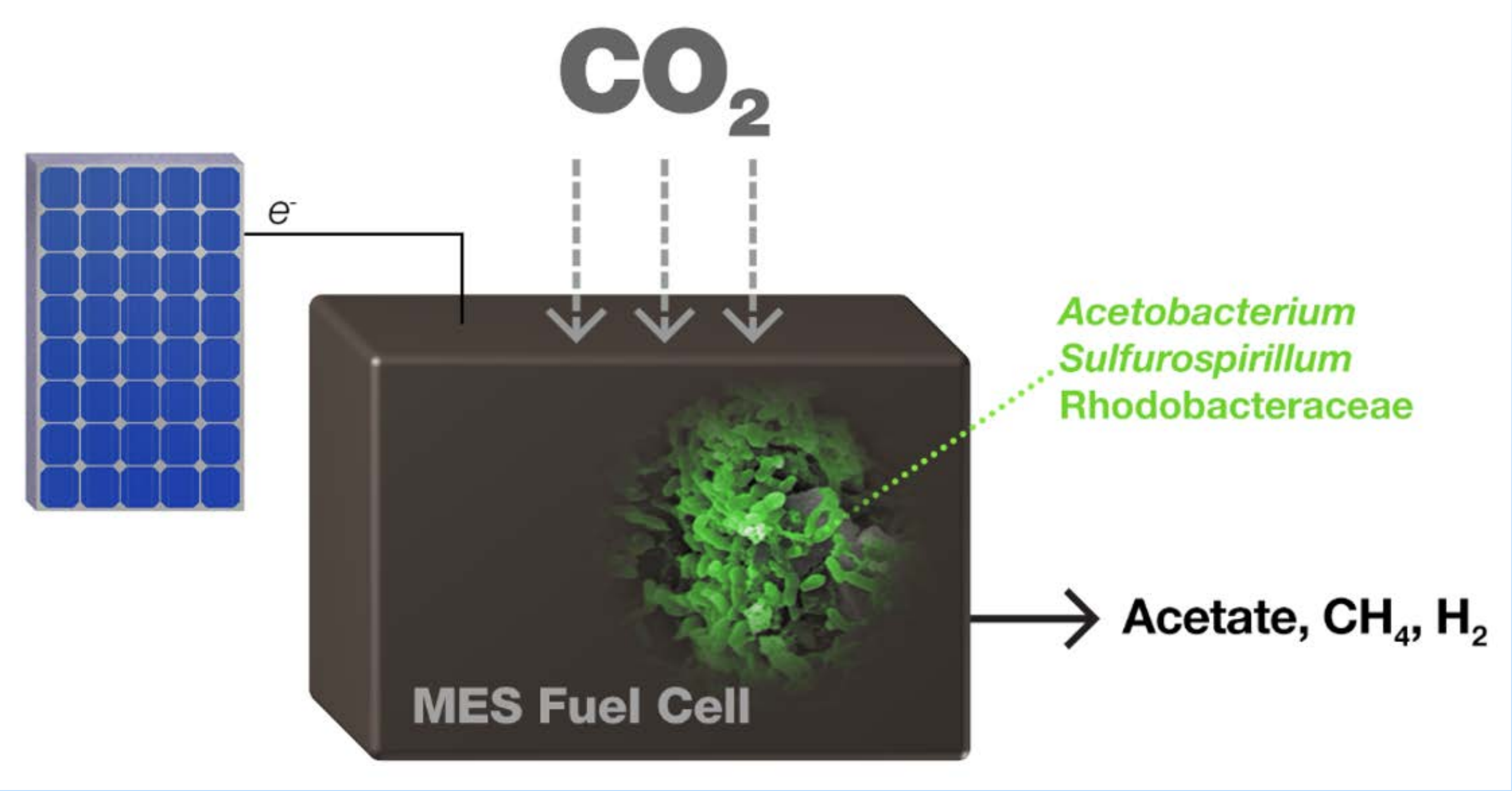
- Dan Ross, Leidos-RIC
- Mengling Stuckman, Leidos-NETL
- Chris Marshall, Marquette University
- Kara Tinker, ORISE
- Preom Sarkar, ORISE
- Joe Moore, ORISE
- Ashley Miles, ORISE



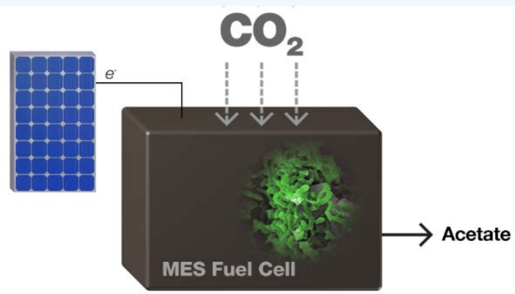
Task 3 (FY19): Biological CO_2 Utilization Goals

Grow a novel microbial community capable of converting CO_2 to value-added products. This microbial community (the biocatalyst) will be used to (1) optimize CO_2-to-acetate conversion rates, and (2) further upgrade CO_2-derived intermediate products such as acetate, carbon monoxide, and formate.



Task 3 (FY19): Biological CO_2 Utilization Goals

MES

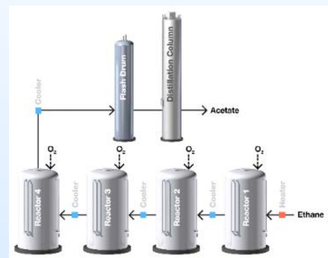


Cost: $1.79/kg

Methanol Carbonylation

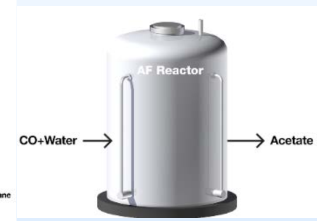
Cost: $0.32/kg

Ethane Direct Oxidation



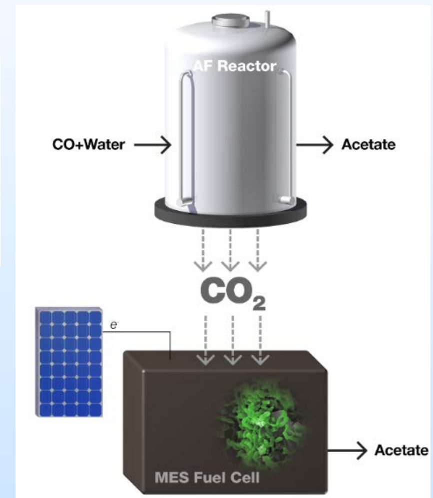
Cost: $0.14/kg

AF



Cost: $5.13/kg

AF+MES



Cost: $0.30/kg

Acetic Acid selling price: $0.60/kg

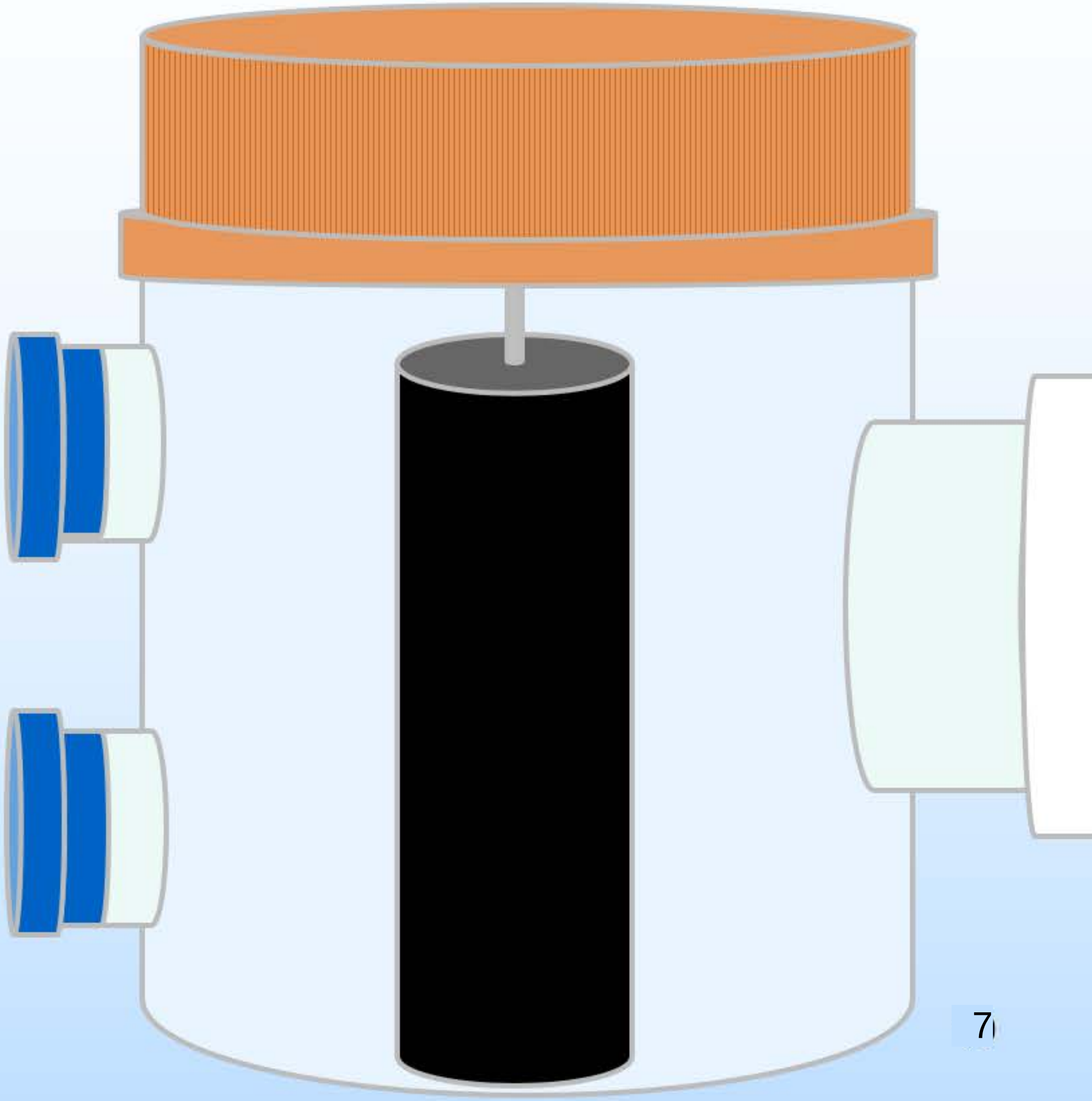
Takeaway Points

- MES may already be cost competitive if designed to be integrated in other systems
- Stand alone MES will be more competitive with increased acetic acid production or with other value-added commodity production
- MES may be more efficient at CO_2 conversion with a concentrated CO_2 input stream compared to photosynthetic processes

Task 3 (FY19): Biological CO_2 Utilization Goals

- **Subtask 3.1 Biological Electro-Synthesis Technologies (BEST)**
  - Growth of biocatalyst from new samples capable of 50% CO_2 and H_2 conversion to acetic acid.
  - Demonstrate CO_2 conversion with newly grown biocatalyst in bench-scale electrochemical reactor
- **Subtask 3.2 Biological Upgrading of CO_2 Derived Chemical Intermediates**
  - Biocatalyze CO_2-derived intermediates, such as acetate and carbon monoxide, into longer chain carbon molecules such as ethanol, butyrate, and/or butanol.

Background



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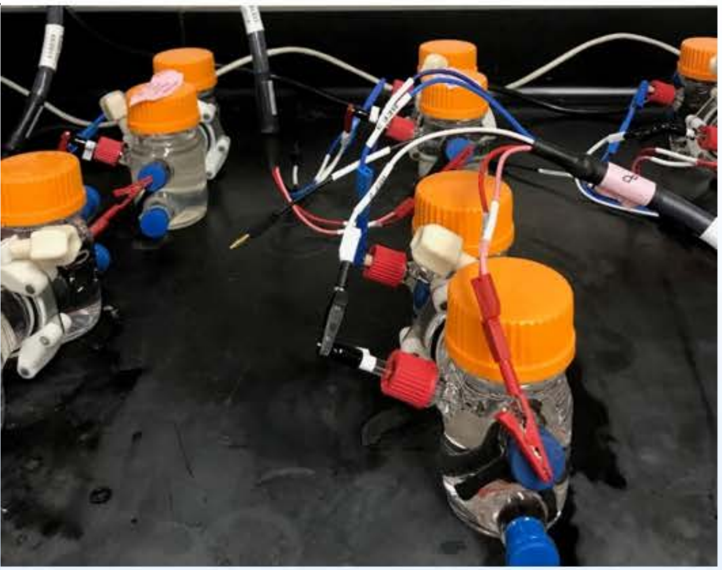

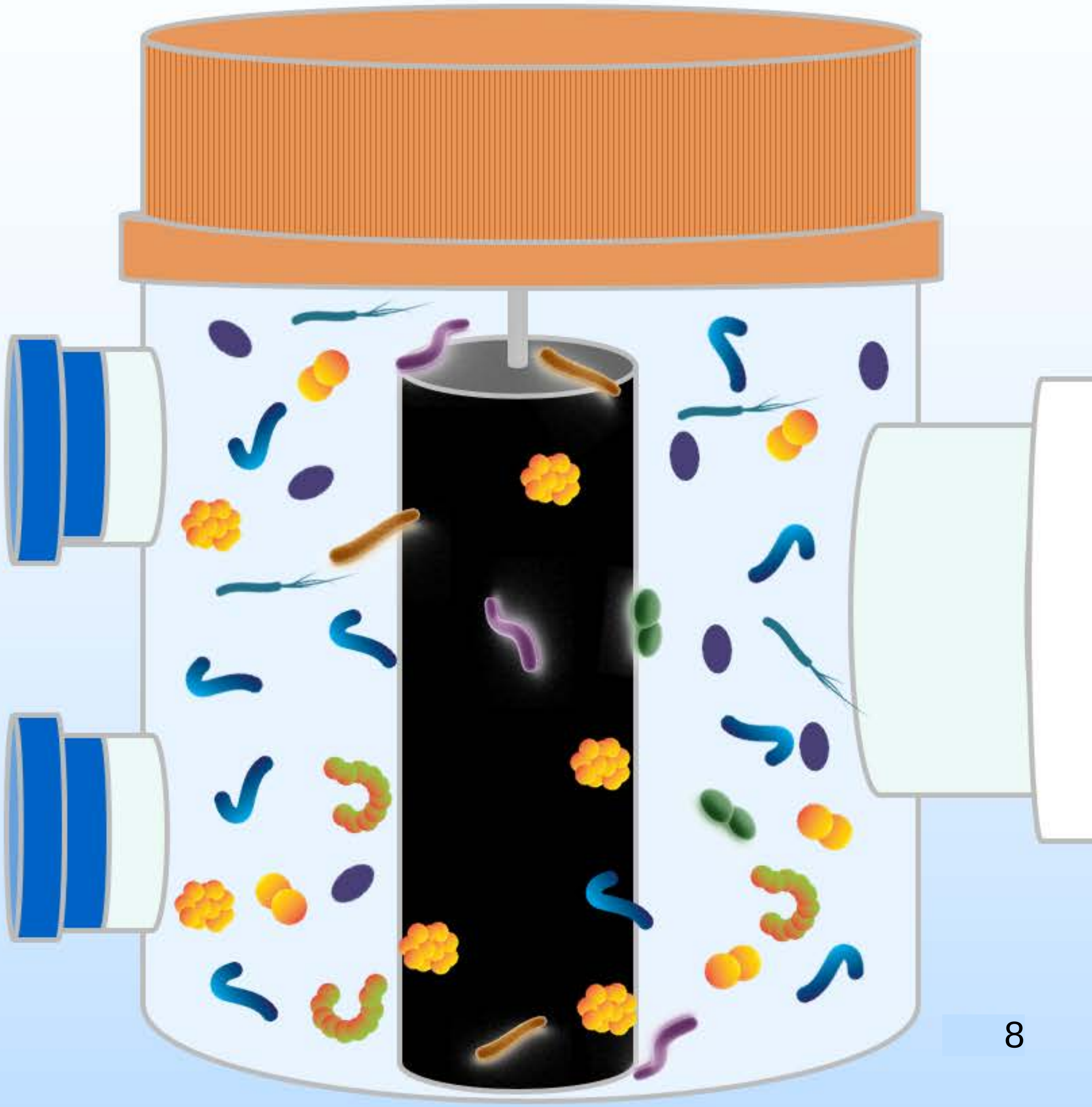

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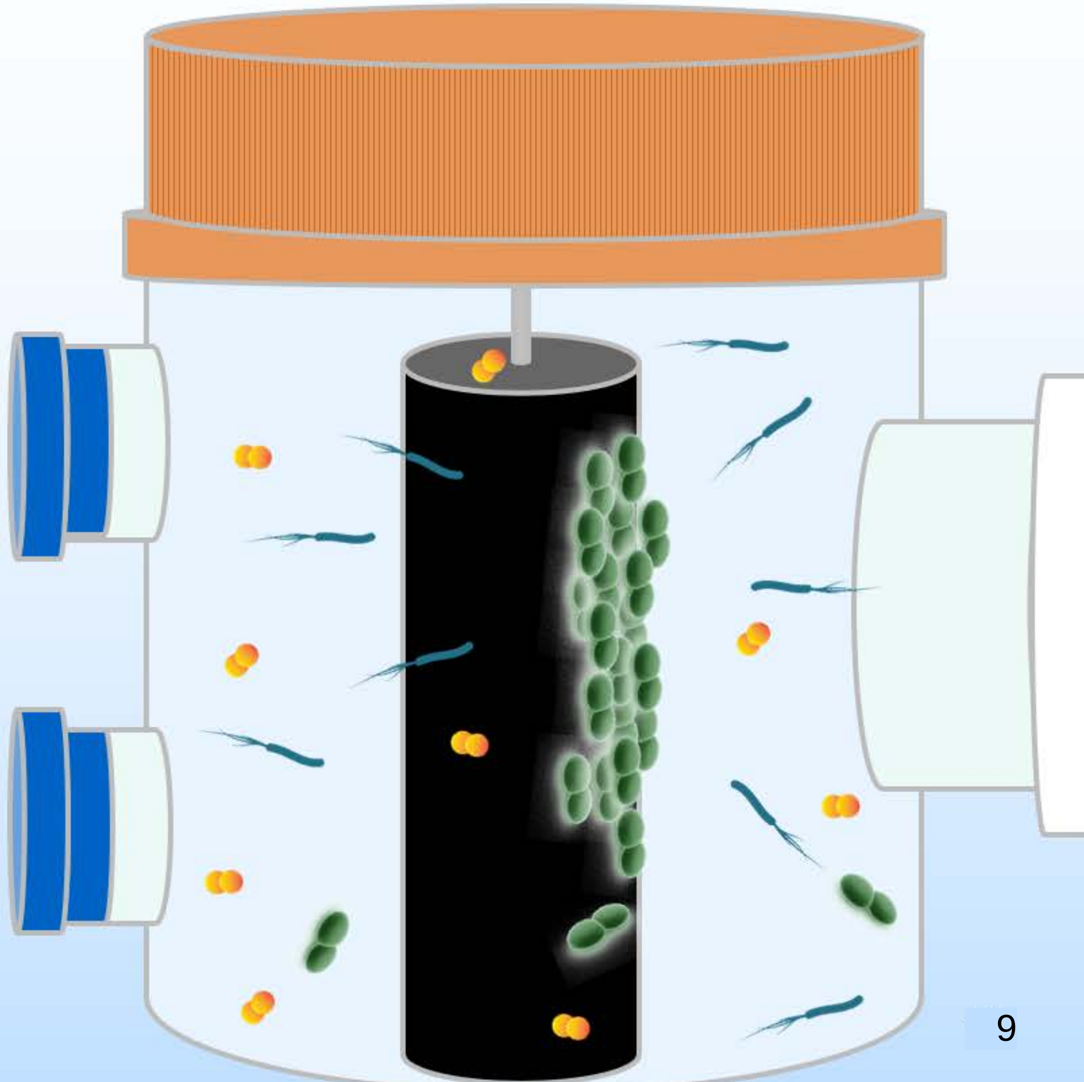
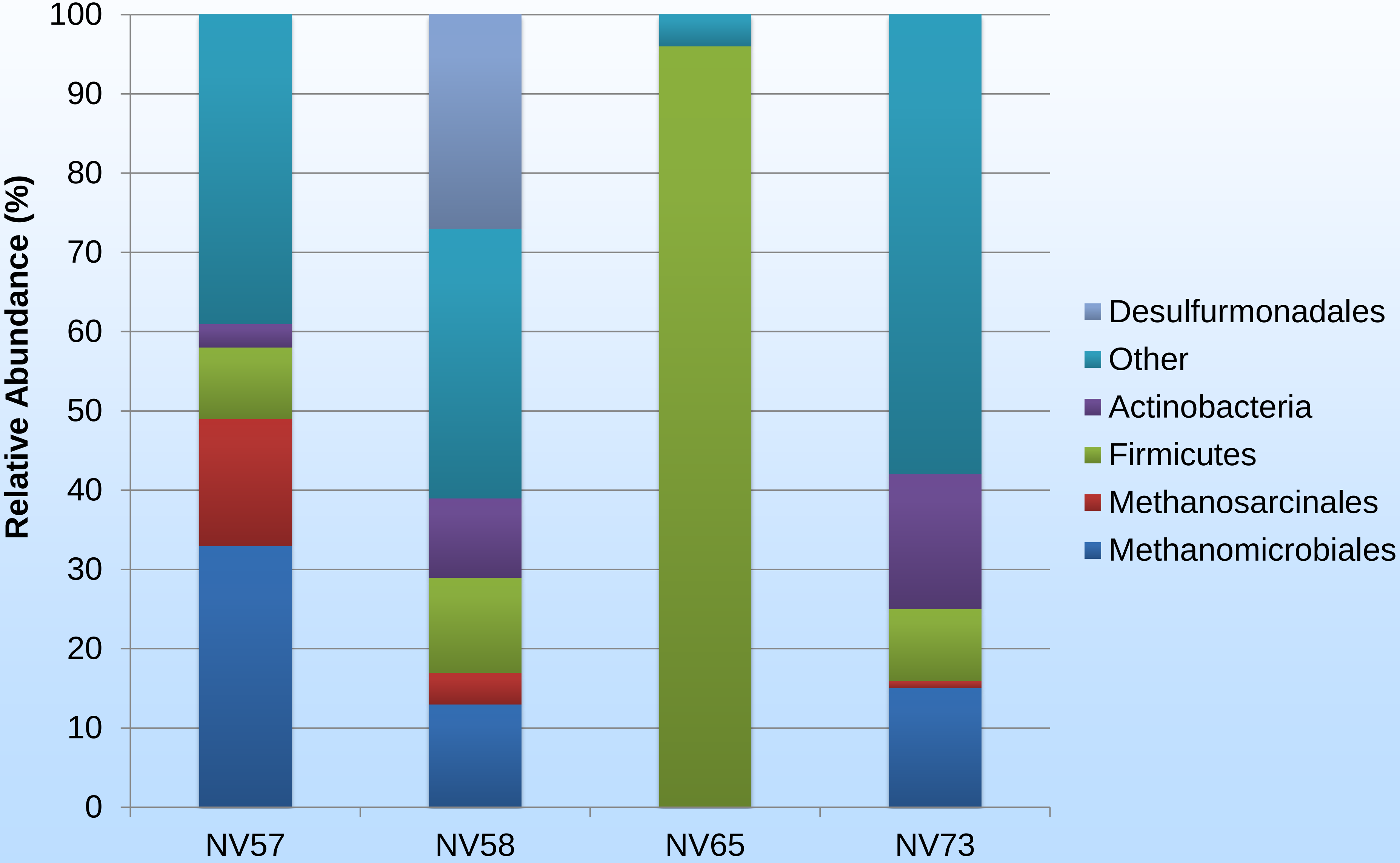


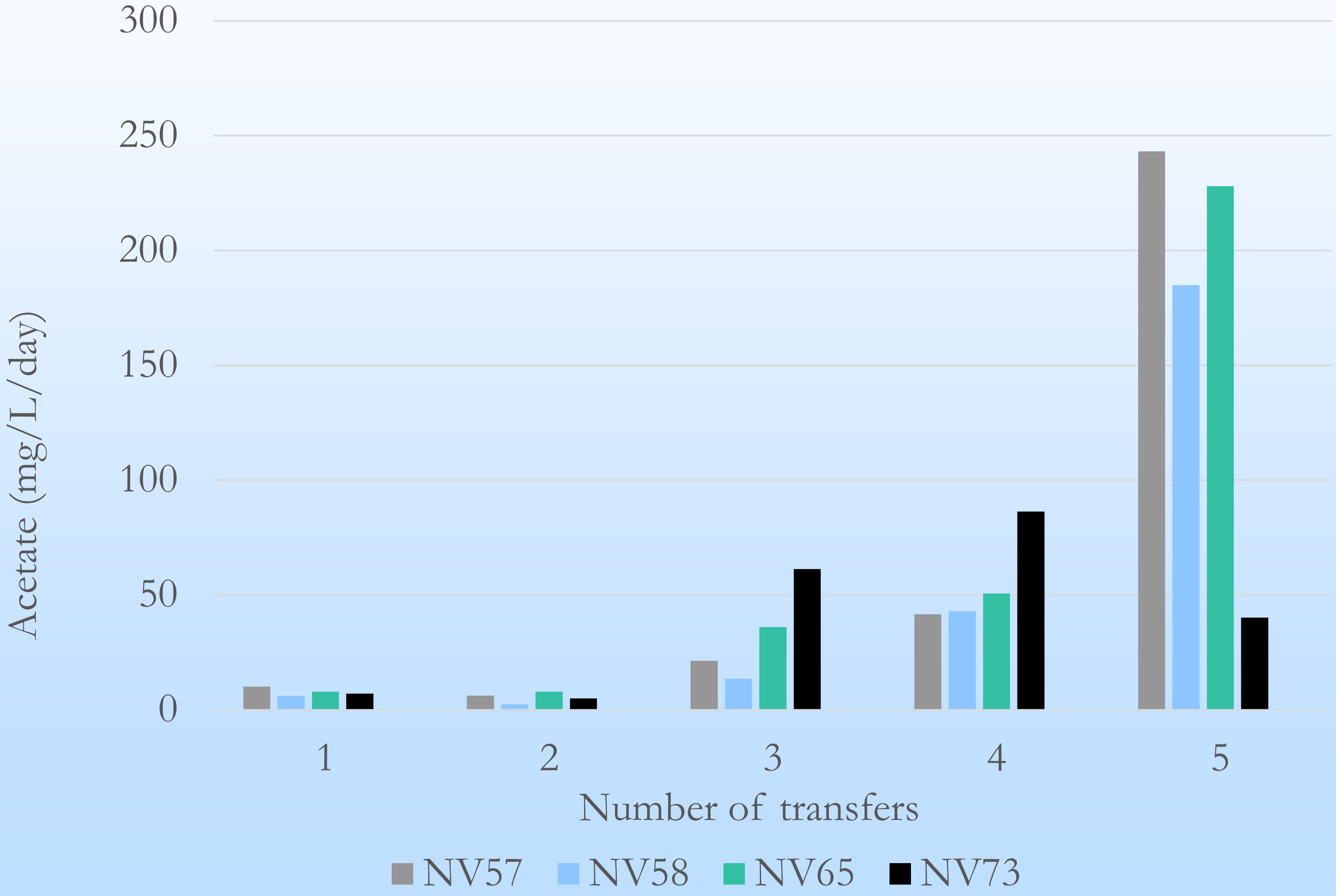
Technical Status

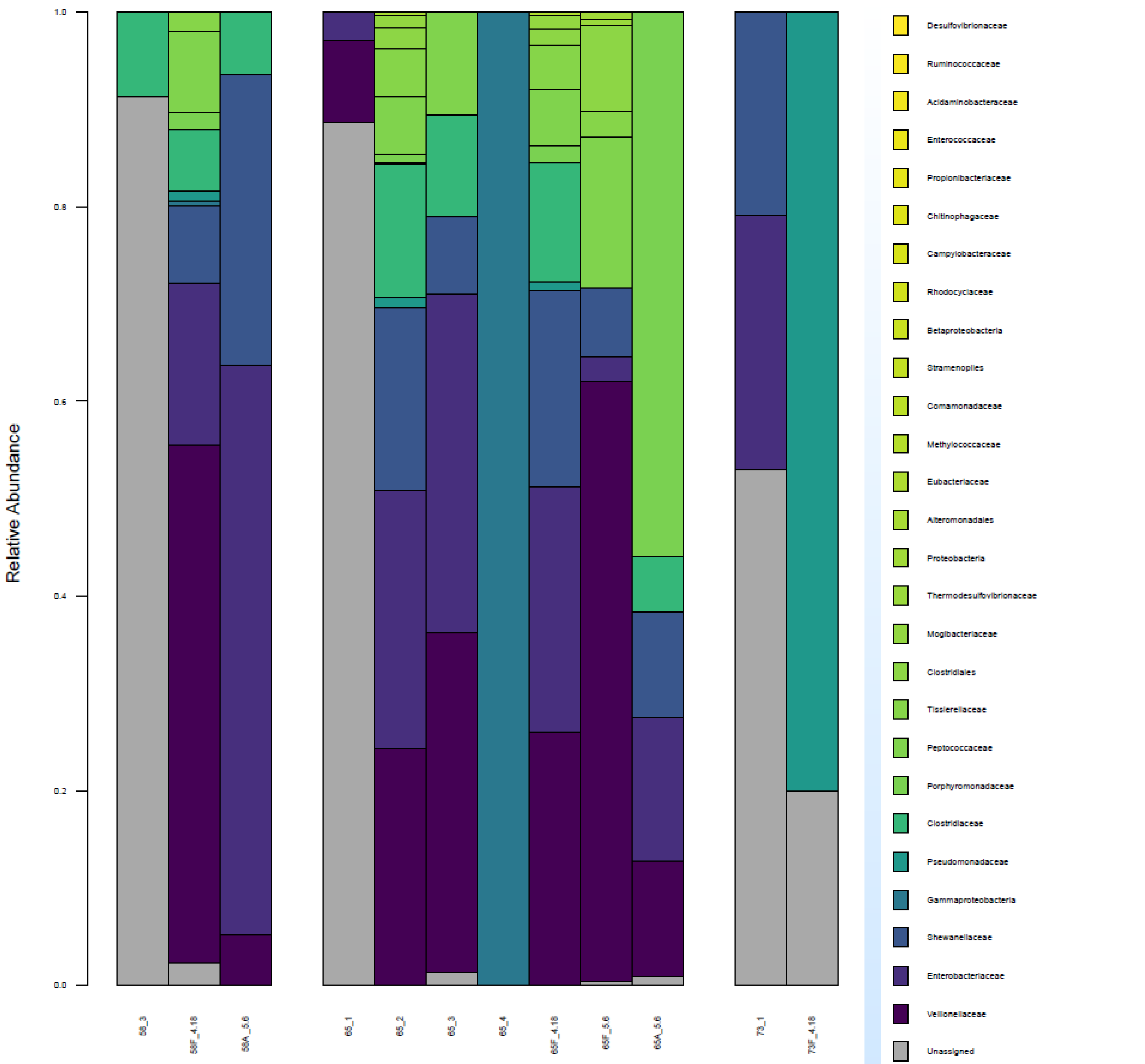
Initial microbial communities were recovered from unconventional oil and gas reservoirs and coalbeds

Technical Status



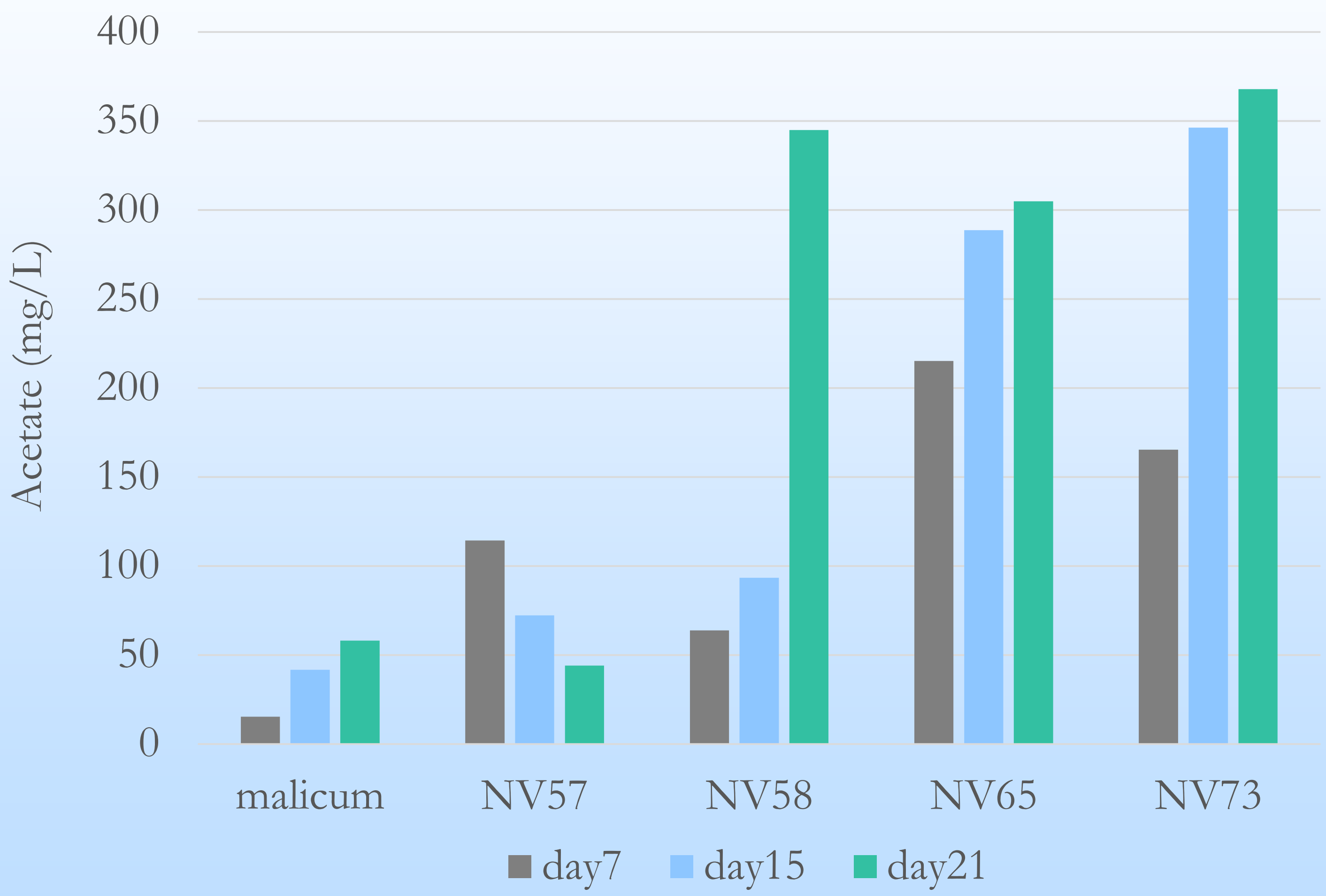
Technical Status: CO_2/H_2



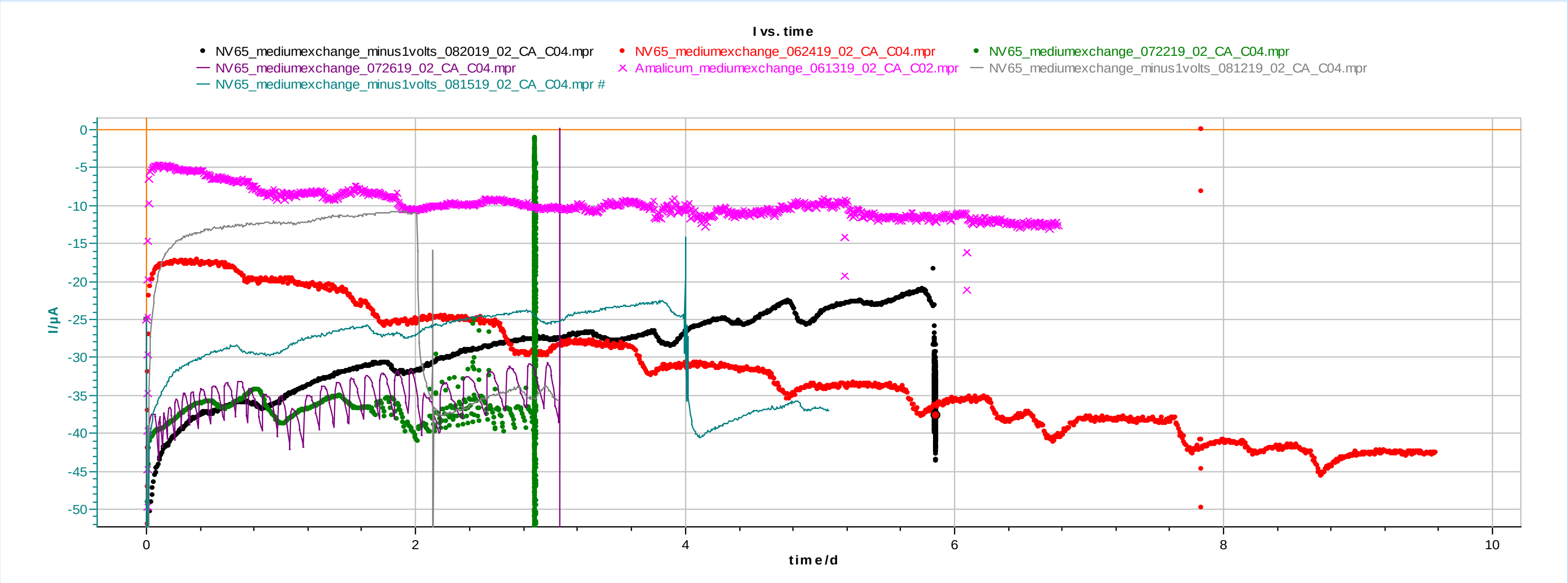


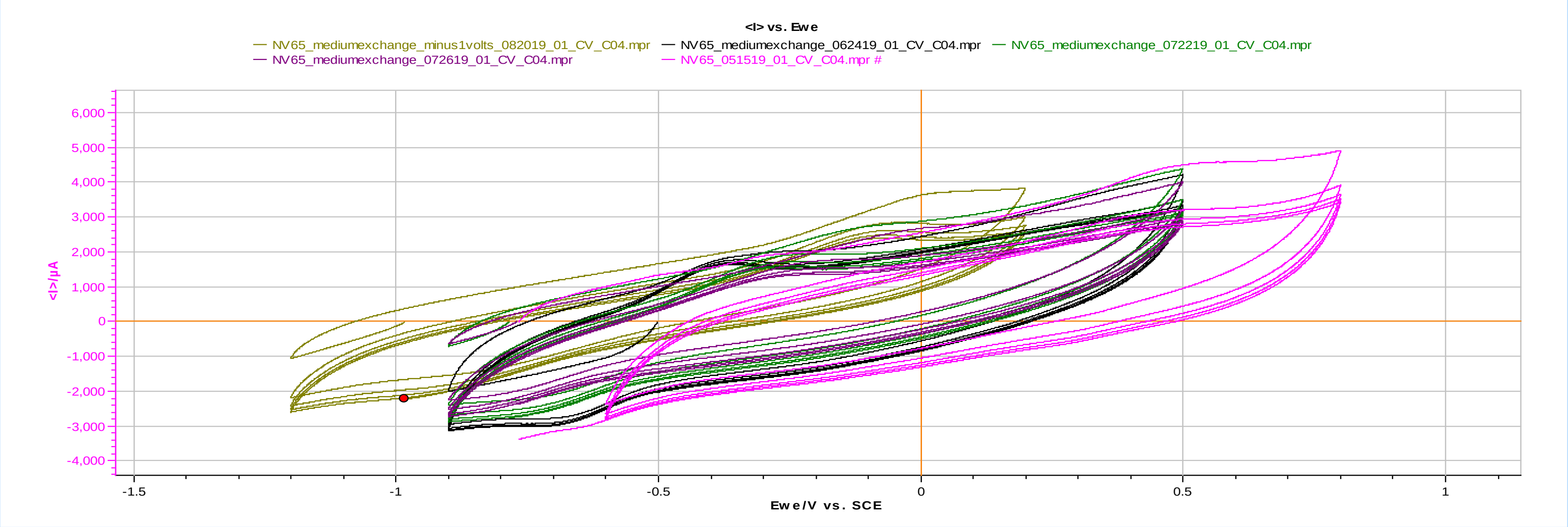
Relative Abundance
1.0
0.8
0.6
0.4
0.2
0.0
58_3
58F_4.18
58A_5.6
65_1
65_2
65_3
65_4
65F_4.18
65F_5.6
65A_5.6
73_1
73F_4.18
Desulfovibrionaceae
Ruminococcaceae
Acidaminobacteraceae
Enterococcaceae
Propionibacteriaceae
Chitinophagaceae
Campylobacteraceae
Rhodocyclaceae
Betaproteobacteria
Stramenopiles
Comamonadaceae
Methylococcaceae
Eubacteriaceae
Alteromonadales
Proteobacteria
Thermodesulfovibrionaceae
Mogibacteriaceae
Clostridiales
Tissierellaceae
Peptococcaceae
Porphyromonadaceae
Clostridiaceae
Pseudomonadaceae
Gammaproteobacteria
Shewanellaceae
Enterobacteriaceae
Veillonellaceae
Unassigned

Technical Status: Electrochemical Reactor

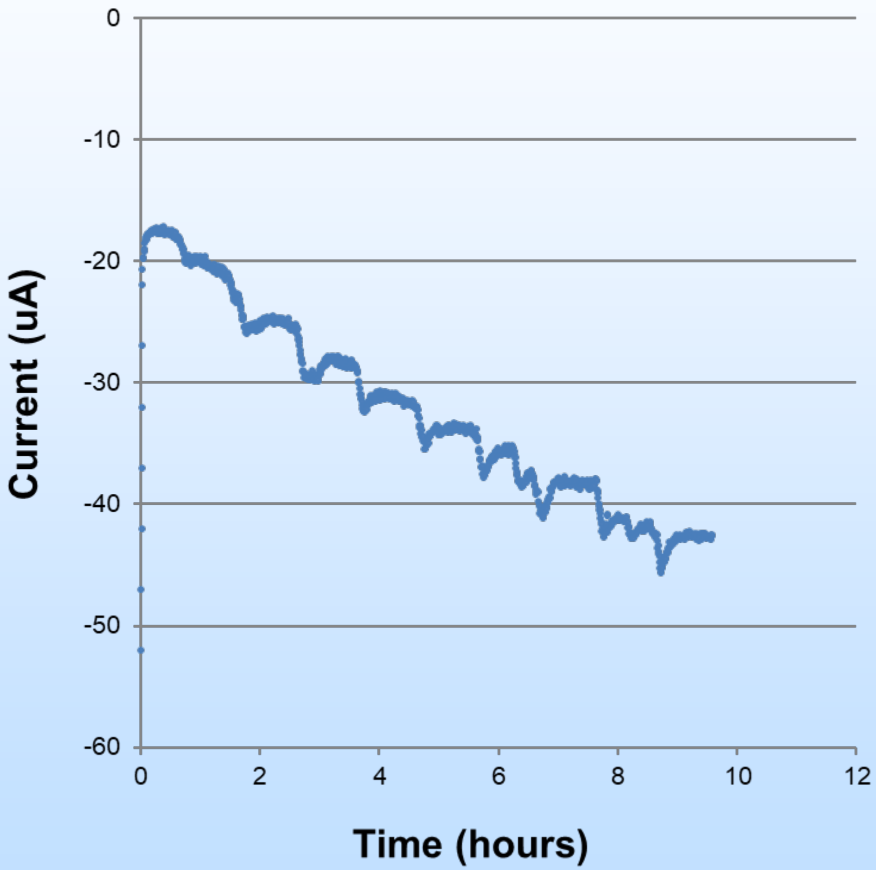


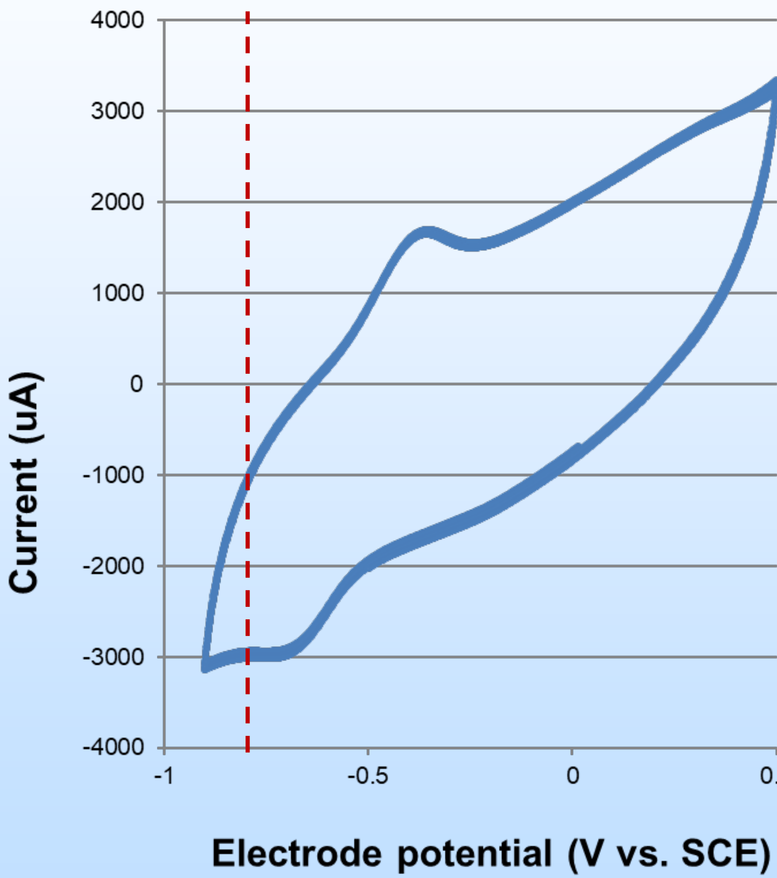
Technical Status: Electrochemical Reactor





Technical Status: Electrochemical Reactor



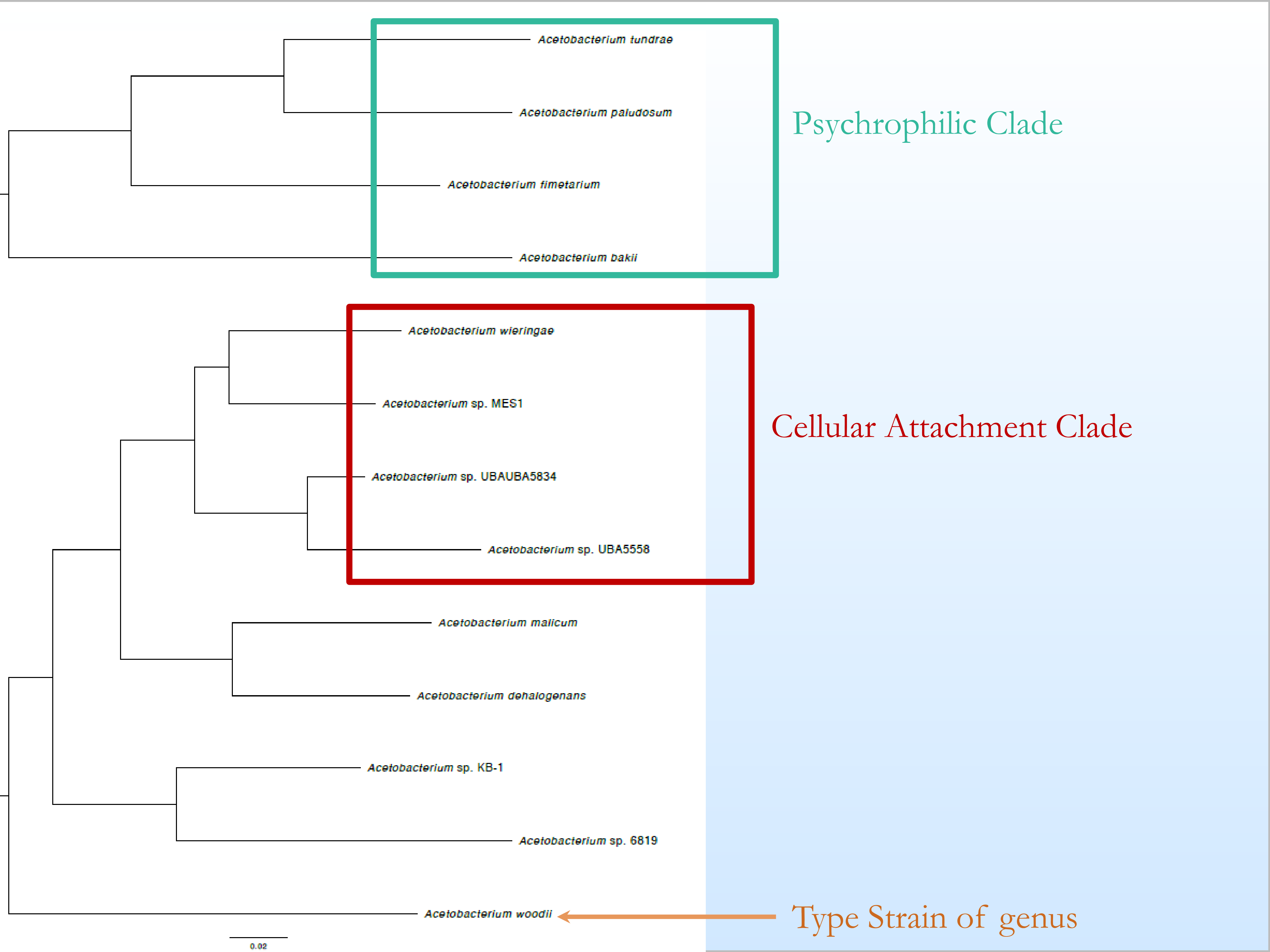


Technical Status: Acetobacterium

AAI

	malicum	dehalogenans	UBA6819	KB-1	MES1	wieringae	UBA5834	UBA5558	fimetarium	bakii	woodii	tundrae	paludosum
Acetobacterium malicum		96	85	86	87	87	73	72	74	74	79	74	74
Acetobacterium dehalogenans	97		85	86	87	87	87	86	74	74	79	74	74
Acetobacterium sp. UBA6819	84	84		99	83	83	83	81	73	72	78	72	72
Acetobacterium sp. KB-1	84	83	99		84	84	83	82	73	74	79	73	73
Acetobacterium sp. MES1	84	84	81	82		97	97	96	74	73	78	73	73
Acetobacterium wieringae	84	84	81	82	97		97	96	73	73	77	73	73
Acetobacterium sp. UBA5834	84	84	81	81	97	97		100	74	73	78	73	73
Acetobacterium sp. UBA5558	84	84	81	81	97	98	100		72	72	77	72	72
Acetobacterium fimetarium	80	79	79	78	78	79	78	78		72	73	80	81
Acetobacterium bakii	80	78	79	80	77	78	77	78	80		72	73	73
Acetobacterium woodii	80	80	79	80	79	79	79	79	78	78		74	74
Acetobacterium tundrae	78	78	78	78	77	77	77	77	81	79	80		94
Acetobacterium paludosum	78	78	78	78	78	78	77	77	81	79	78	95	

ANI


Acetobacterium tundrae
Acetobacterium paludosum
Acetobacterium fimetarium
Acetobacterium bakii
Psychrophilic Clade
Acetobacterium wieringae
Acetobacterium sp. MES1
Acetobacterium sp. UBAUBA5834
Acetobacterium sp. UBA5558
Cellular Attachment Clade
Acetobacterium malicum
Acetobacterium dehalogenans
Acetobacterium sp. KB-1
Acetobacterium sp. 6819
Acetobacterium woodii
Type Strain of genus
0.02

Lessons Learned

– Each biocatalyst is a dynamic system
  - Optimal reactor conditions will be adjusted until equilibrium is reached
  - Sequencing difficulties due to reduced diversity
– Voltammetry does not correspond to acetate production
  - Might be due to production of other constituents
    – CH_4 measurements
  - Might be due to H_2 production
– Early biocatalyst "contenders" are often surpassed by "dark-horses".

Project Summary

- **Subtask 3.1 Biological Electro-Synthesis Technologies (BEST)**
  - Biocatalyst enriched on H_2:CO_2
    - Coalbed microbial communities were most easily enriched on CO_2
    - Highest acetate concentration was 250 mg/L, reaching approximately 52% bioconversion from CO_2.
    - One culture produced butyrate
  - Bioelectrochemical reactors poised at -560 mV vs SHE and produced up to 345 mg/L of acetate.
  - Acetobacteria pan-genome comparison demonstrate conserved Wood Ljungdahl pathway, 2 unique clades, and divergence from type strain
- **Subtask 3.2 Biological Upgrading of CO_2 Derived Chemical Intermediates**
  - Permit modification and ES&H approval completed

Project Summary

Next Steps

- Biocatalysts will continue to develop
- Minor adjustments with potential, electrode, and media
- Reactor optimization
- Taxonomic and metagenomic characterization of biocatalyst
- SEM imaging of electrodes

Synergy Opportunities

- Field sampling efforts
- Comparison with other related subsurface reactions
  - Unconventional resource systems
  - Coal systems
  - Carbon storage systems
- Electrochemistry expertise within NETL
- Communication with outside research groups
- TEA and LCA with Systems Engineering and Analysis
- Integration with Carbon Capture
- Communication with renewable energy experts

FY19 Accomplishments to Date

- FY19 Milestone: Growth of biocatalyst from new samples capable of 50 percent CO_2 and H_2 conversion to acetic acid.
  - Completed. Growth of a new biocatalyst from coalbed fluid was capable of 52% CO_2 conversion to acetic acid
- FY19 Milestone: Demonstrate bio-electrochemical CO_2 conversion with newly grown biocatalyst in bench-scale electrochemical reactor at a faradaic efficiency of at least 20 percent.
  - Ongoing
- FY19 Milestone: Growth of a biocatalyst in the electrochemical reactor with more than 50% faradaic efficiency.
  - Ongoing