Bioelectrochemical Integration of Waste Heat Recovery, Waste-to-Energy Conversion, and Waste-to-Chemical Conversion with Industrial Gas and Chemical Manufacturing Processes

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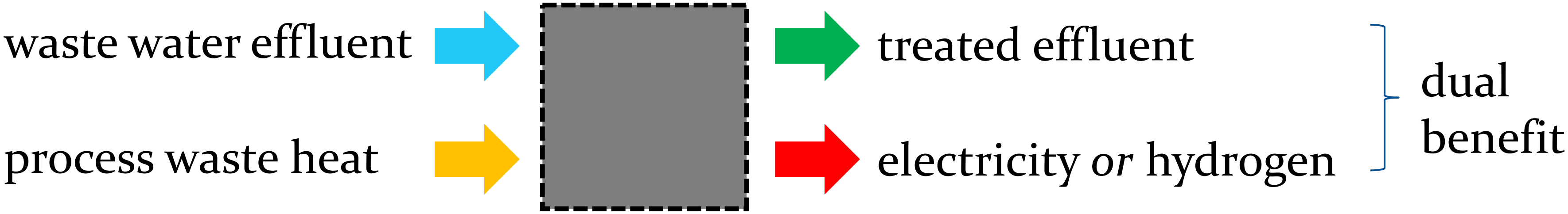
Project Objective

Develop a novel system that produces electricity or hydrogen from waste heat conversion and waste effluent oxidation



Issues with existing, disassociated solutions

1. **Waste Heat to Energy/Hydrogen** (ex: organic Rankine cycle)
   - High installed $/KW capital
   - Low temperature waste heat (<=100C) is not practicable
   - Further efficiency loss in electrolytic conversion to hydrogen
2. **Waste Effluent to Energy/Hydrogen** (ex: anaerobic digester)
   - High installed $/KW capital:
   - Further efficiency loss in reforming conversion to hydrogen

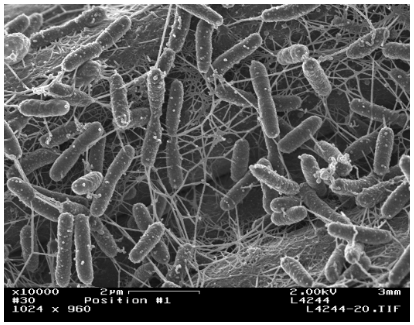
Technical and economic synergies are achieved with dual benefits through a novel, combination of effects

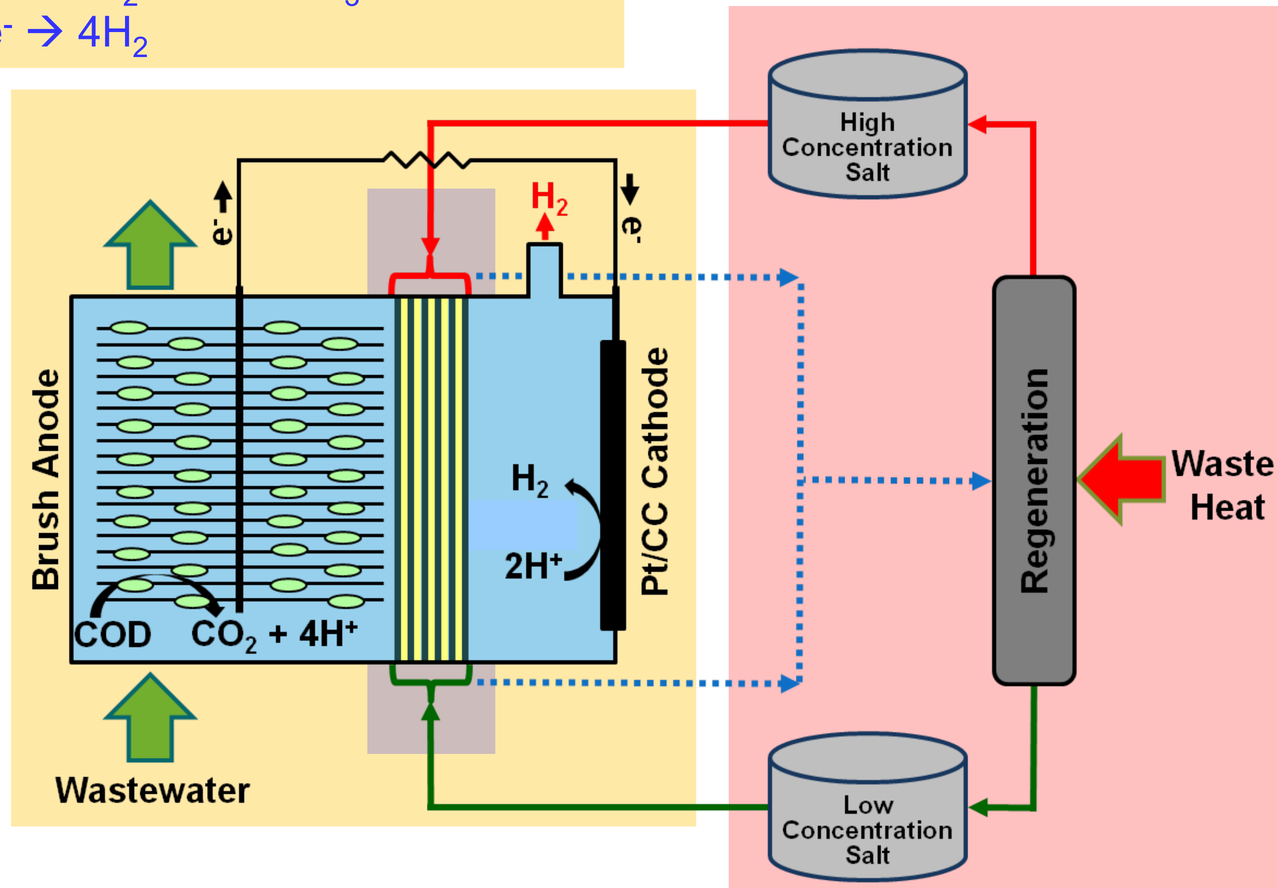
Technical Approach

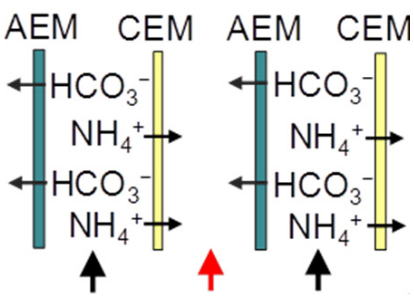
1) microbial electrolysis cell

Anode: $CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^-$

Cathode: $8H^+ + 8e^- \rightarrow 4H_2$







2) reverse electrodialysis stack

$NH_4HCO_3 \leftrightarrow NH_4^+ + HCO_3^-$

energy from salinity gradient

3) thermal regeneration of feed salinity

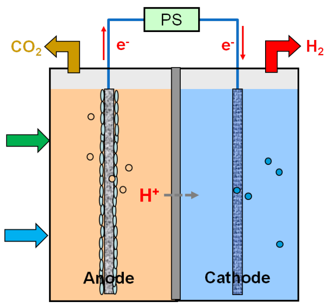
$NH_4HCO_3 \leftrightarrow NH_3 + CO_2 + H_2O$

energy from salinity gradient

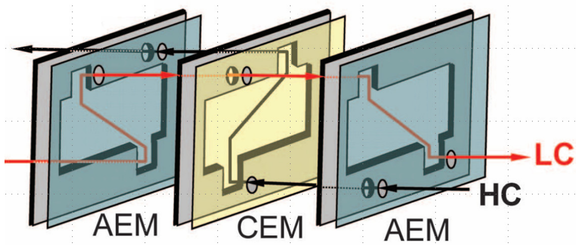
Nam, Cusick, Kim & Logan (2012) *Environ. Sci. Technol.*

Technical Approach

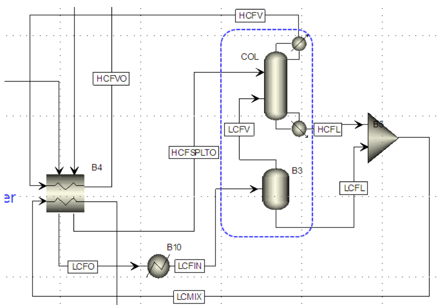
- Technical innovation – unique combination



Microbial Electrolysis



Reverse Electrodialysis



Thermolytic Salt Regeneration

- Overcomes previous limitations
  - *Low* temperature waste heat for NH_4HCO_3 dissociation
  - Cost economies – *combined* cells, *combined* benefits
- Effective use of essential skills and resources

PENNSTATE

microbial electrolysis
materials

AIR PRODUCTS

cycle development
scale-up
operation

DOE EERE
Advanced Manufacturing Office

project management
technical oversight
funding

Transition and Deployment

TRL 6 → TRL 7 → TRL 8 → TRL 9 → External Deployment → Sustainment

Project Complete

Pilot operation at AP facility

Scale-up to production unit

<u>1st phase deployment</u>
Intra-company installations (productivity improvement)

<u>2nd phase deployment</u>
Complete product plan
Develop modular design
Market as H_2 generator

CI in-house
Product improvements
Explore license out

Measure of Success

Go / No Go Criteria

Budget Period 1 (complete)

- ✓ COD removal response
- ✓ H_2 yield
- ✓ Viable substrate sources

Budget Period 2 (current)

- Net power output
- Financial viability

Budget Period 3

- Project conclusion
- Decision to proceed to pilot phase

Energy, Environmental and Economic Benefit for US manufacturing

Total amenable facilities	#	400
Wastewater treated	Mm^3/year	1800
H_2 production	Ktons/year	180
CO_2 reduction	Mtons/year	2.2
Power production (alt.)	Tbtu/y	22.4
CO_2 reduction	Mtons/year	16.8

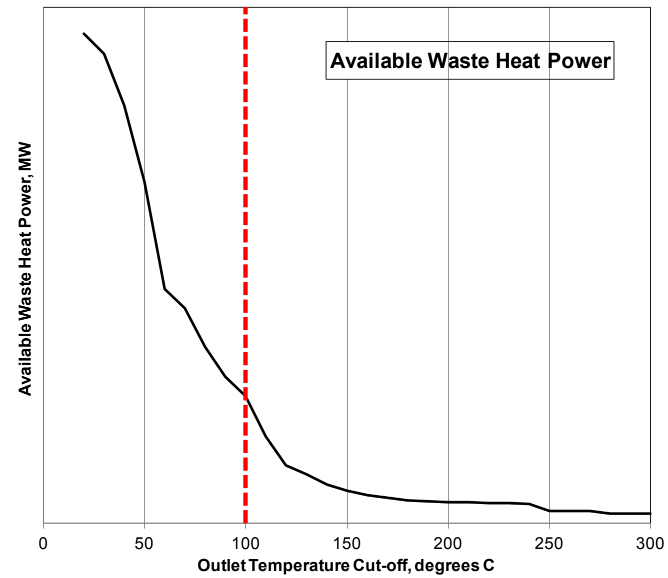
Project Management & Budget

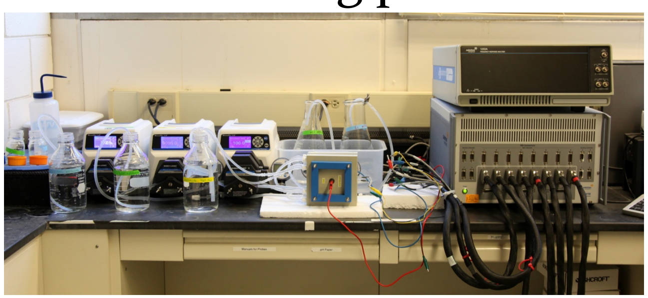
	TASK	Budget Period 1 Sep 2012 - Dec 2013	Budget Period 2 Jan 2014 - Mar 2015	Budget Period 3 Apr 2015 - (Aug 2015)
1	Data collection and characterization			
2	Screening analysis of waste heat and effluent			
3	Initial treatability tests			
4	Detailed treatability tests			
5	Process models and economics			
6	Project Management and Reporting			
7	MRC integrated laboratory analyses			
8	MHRC process modeling and economics			
9	Prototype plan development			
10	Prototype system preliminary design/costing			
11	Project Management and Reporting			
12	Lab testing to support prototype operation			
13	Prototype system construction and installation			
14	Prototype startup and testing			
15	Prototype testing data analysis/recommendations			
16	Project Management and Reporting			

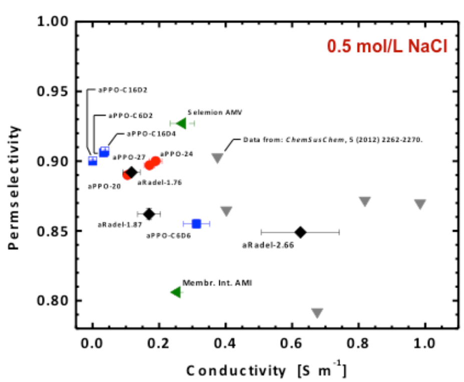
	TOTAL	Budget Period 1	Budget Period 2	Budget Period 3
DOE Investment	$ 1,200,000	$ 204,948	$ 284,584	$ 710,468
Cost Share	$ 300,000	$ 51,237	$ 71,146	$ 177,617
Project Total	**$ 1,500,000**	**$ 256,185**	**$ 355,730**	**$ 888,085**

Results and Accomplishments

- BP1 results
  - 22 - 82% ΔCOD in 6 substrate effluents
  - 13.5 – 45.3% H2 yield on COD reduction
  - Full characterization of US facilities
  - BP2 facility identified
  - Learning plan – focus on RED in BP2







Geise, Hickner & Logan (2013) *ACS Appl. Mater. Inter.*

- BP2 work in-progress
  - RED performance optimization
  - Ion exchange membrane improvements
  - Integrated system experimental testing
  - Process model and process economics
  - Prototype test plan