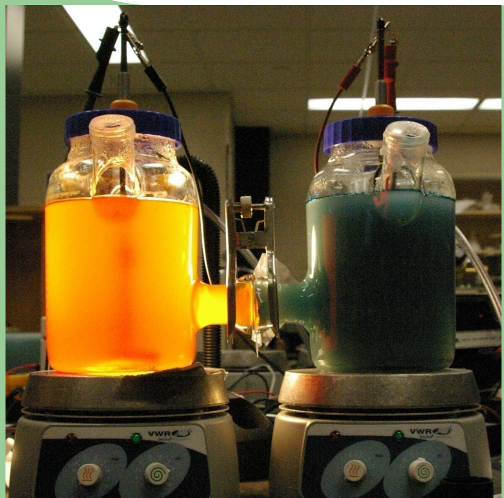
UNIVERSITY OF SASKATCHEWAN

PHOTOSYNTHETIC – FERMENTATIVE FUEL CELL USED IN A BIOFUEL PROCESSING FACILITY



E.E. Powell, G.A. Hill, R.W. Evitts, and J.C. Bolster

Bioenergy II Conference, Rio de Janeiro, Brazil

June 8-13, 2009

Outline

- Describe microbial fuel cell (MFC)
- Novel photosynthetic cathode
- Coupled MFC apparatus
- Experimental results
- Conclusions – coupled MFC study
- Integrated bioethanol-biodiesel facility design
- Future work

Microbial Fuel Cell (MFC)

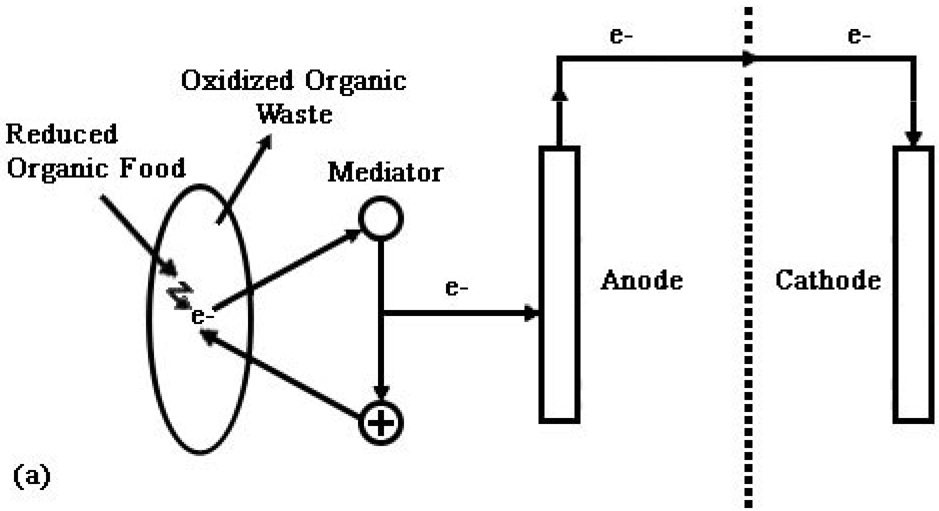
- Electrochemical energy conversion device
  - Battery vs. fuel cell

- Microbial fuel cell
  - Oxidation – reduction reactions within living microorganisms
  - Metabolism of glucose:

$$C_6H_{12}O_6 + 6H_2O + 6O_2 \longrightarrow 6CO_2 + 12H_2O + +24e^-$$

- Anodic MFCs
  - Diverse range of designs, species, organic substrates

Electron Flow in Anodic MFC



Electrochemical
Reduction Reaction

Schematic of Electron Flow in the Completely Biological MFC: (a) anodic release of electrons by consuming organic compounds

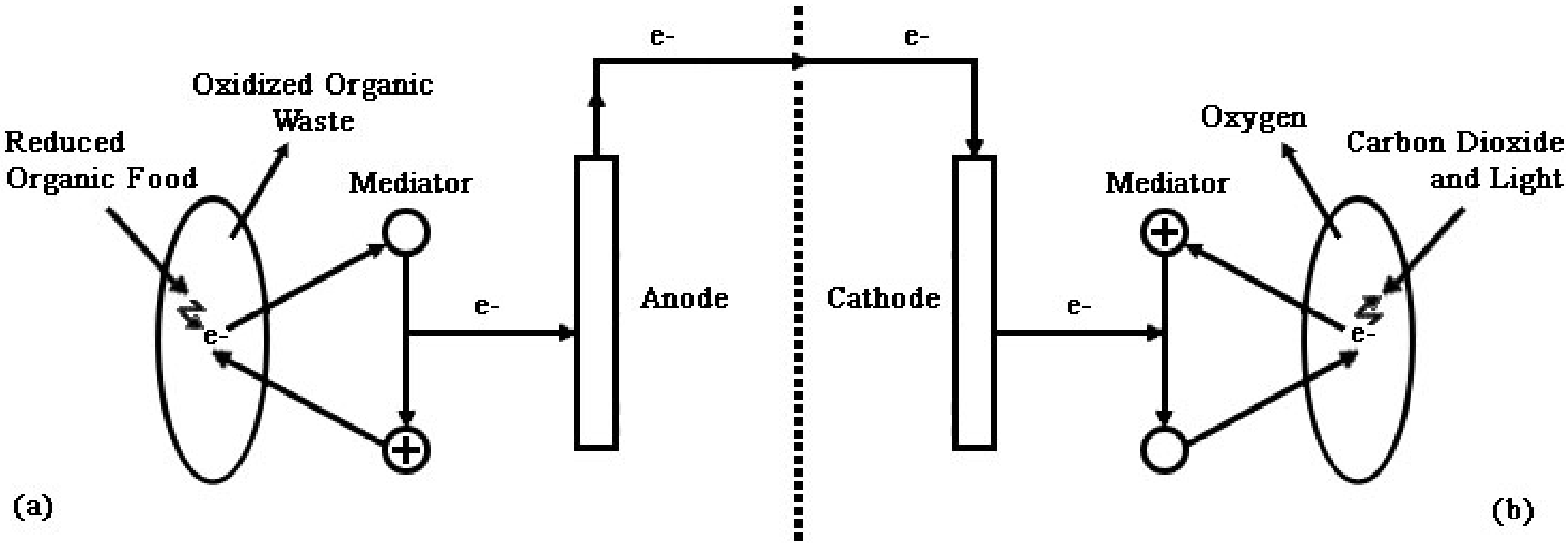
Recent Work – Cathodic MFC

- Photosynthetic microbial culture as biological electron acceptor
  - Microalgae *Chlorella vulgaris*

$$6CO_2 + 12H^+ + 12e^- \xrightarrow{\text{light}} \text{-}C_6H_{12}O_6\text{-(biomass)} + 3O_2$$

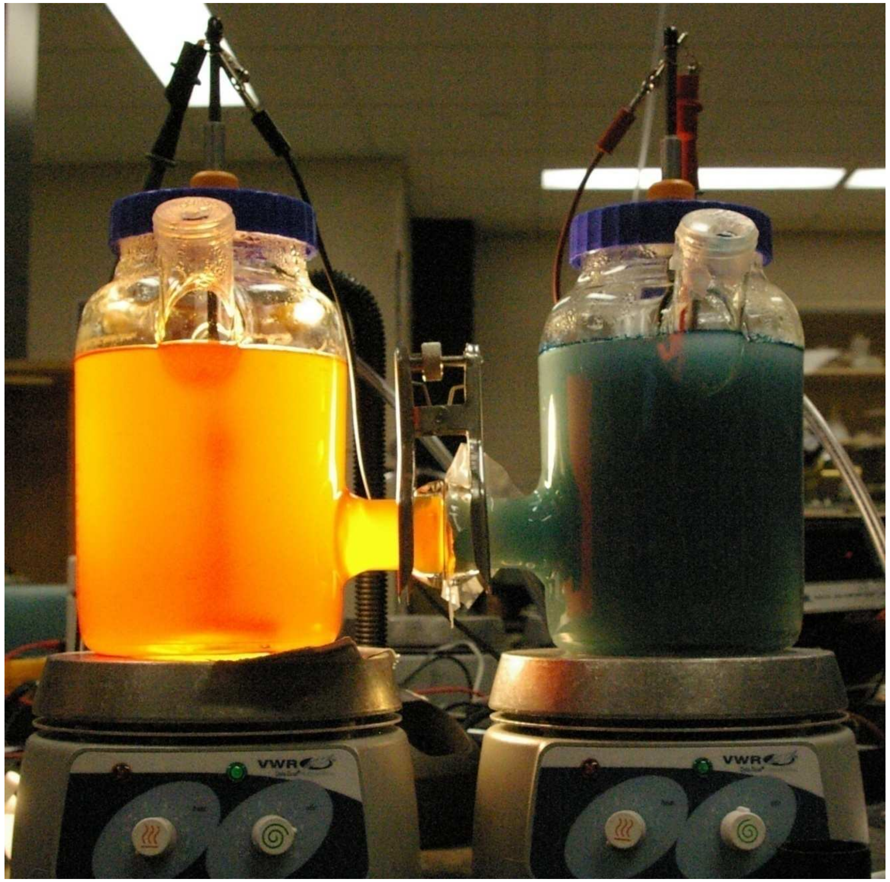
- Working cathodic microbial half cell

Electron Flow in Coupled MFC



Schematic of Electron Flow in the Completely Biological MFC: (a) anodic release of electrons by consuming organic compounds, (b) cathodic capture of electrons by photosynthetic growth on CO_2

Coupled MFC in Operation



MFC Confirmation and Loading Effects

- Blank run
- Calomel reference electrode

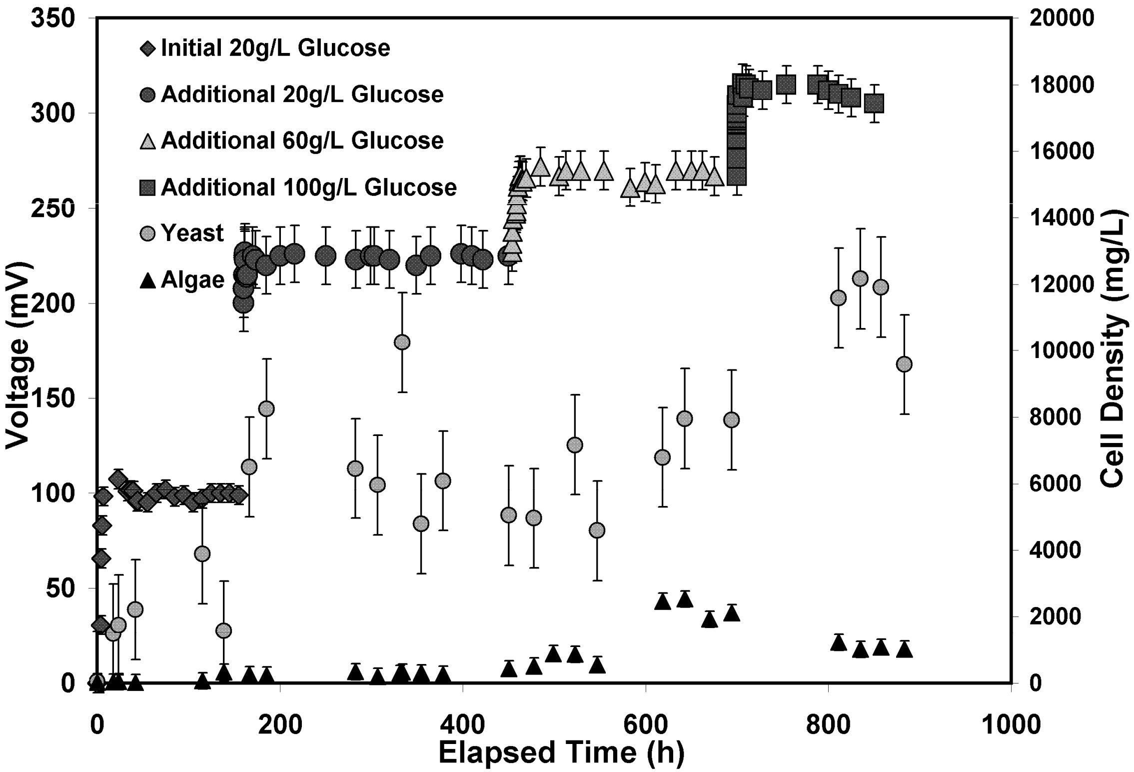
- Maximum power density 0.95 mW/m^2 at 90 mV and 5000 Ω
- Current flows up to 40 μA

Production of Biomass and Ethanol

- Average Biomass
  - 300 mg/ L *C. vulgaris*
  - 3025 mg/L *S. cerevisiae*

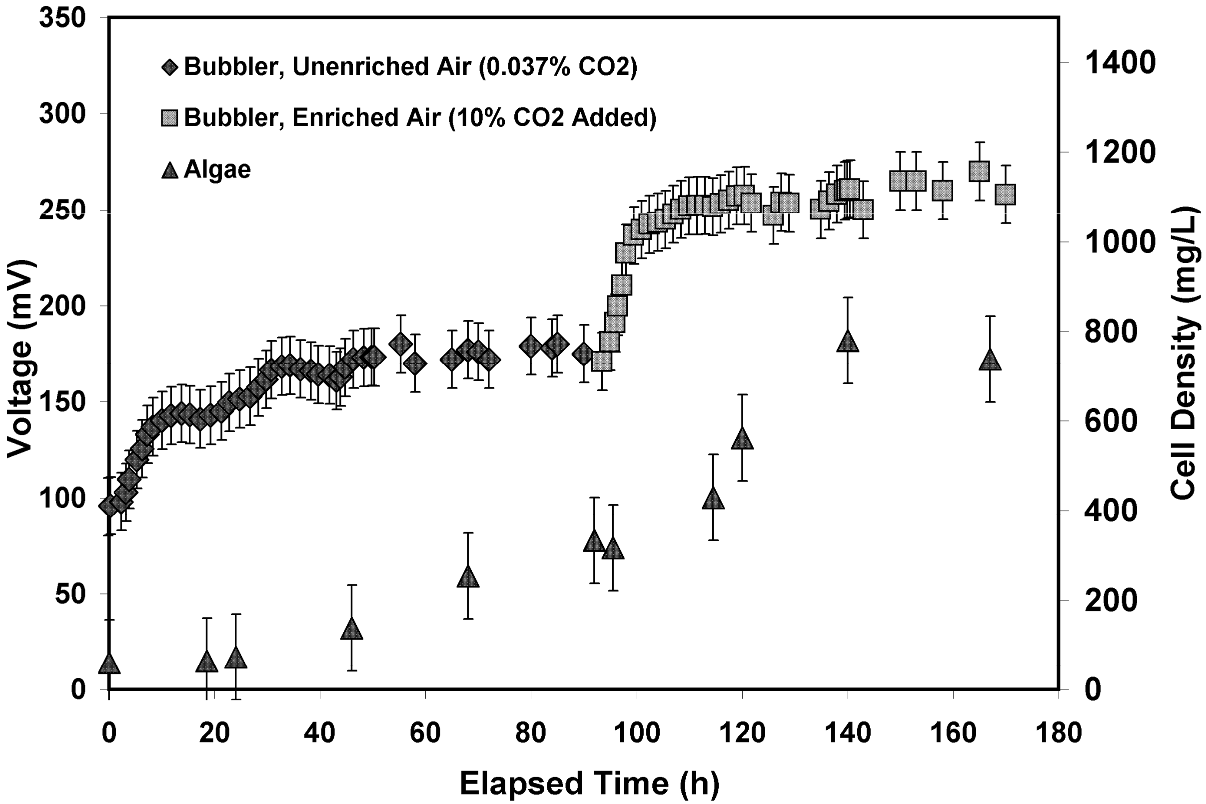
- Valuable Fuel Cell By-products
  - *C. vulgaris*
    - Biomass, Oil for Biodiesel
  - *S. cerevisiae*
    - Ethanol
      - 5% (vol)

Supplemental Glucose Addition



Effect of Supplemental Glucose Addition on Open Circuit Voltage Levels for the Complete MFC

Carbon Dioxide Enrichment of Feed Air



Effect of CO_2 Addition on the Microalgae Cathodic Half Cell

Conclusions – Coupled MFC Study

- Completely biological MFC using novel photosynthetic cathode is feasible
- Maximum power density was 0.95 mW/m^2 at 90 mV and 5000 Ω
- Feeding increases output
- Glucose renews a drained MFC
- CO_2 neutral technology
- Valuable by-products

Novel Photobioreactor (PBR)

- For *C. vulgaris* cultivation
  - Airlift loop design
  - Increased biomass productivity
  - Improved light penetration

- Presently testing experimentally

MFCs in Integrated Bioethanol-Biodiesel Plant

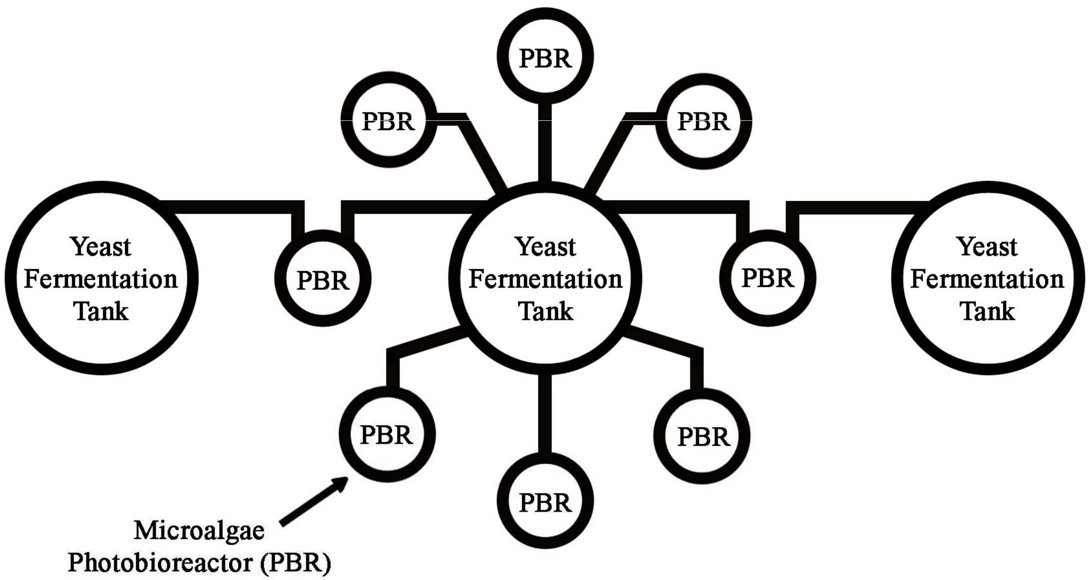
- Existing 130 x 10^6 L/year bioethanol plant
  - Existing yeast fermentors used as anodic half cells
  - 15 of 23 fermentors (1.5 x 10^4 m^3 volume) are working at any one time
- Novel airlift photobioreactor (PBR)
  - Improved *C. vulgaris* cultivation
  - Used as cathodic half cells
    - CO_2 from yeast fermentors
    - Light from sunlight

Integrated Bioethanol-Biodiesel Plant Design

- Design method for economic feasibility:
  - Capital and operating costs, revenue from algae oil (biodiesel) and power generation, value of CO_2 emission recovery (carbon credits), taxation, depreciation, loan repayment

- Maximize Net Present Worth (NPW)
- Total number and column dimensions of PBRs (cathodes)
  - Each PBR creates a coupled MFC

Schematic of Bioreactors and Connections in Integrated Plant



Multiple PBRs surrounding a single existing fermentation tank.
Connections are required to multiple fermentors.

Optimum Design

- PBR cathode dimensions:
  - 50 m height,1 m diameter
  - 39.3 m^3 volume
- Total number of PBRs in plant: 50
  - 3 or 4 cathodes connected to each fermentor anode
  - 50 MFCs
- NPW: \$28.2 x 10^6
- 100% CO_2 consumption

Effect of Design Parameters on NPW

- Minimum number of PBRs (MFCs) → 21
  - (optimum 50 m height, 1 m diameter)
- Maximum number of PBRs (MFCs) → 50
  - insufficient CO_2 available
- Combination: short column, small diameter
  - negative NPW
- Revenue streams offset costs
  - Electrical power, algae oil (biodiesel), CO_2 removal (carbon credits)

Future Work

- Finish testing of novel airlift PBR
- Experimental testing of PBR as cathodic half cell
  - Coupled to electrochemical anodic half cell
  - Coupled to a yeast anodic half cell

Acknowledgements

- Natural Sciences and Engineering Research Council of Canada (NSERC)
- Department of Chemical Engineering, University of Saskatchewan
- Majak Mapiour
- Divya Sasi

QUESTIONS?