Anaerobic fermentation & oxidation

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- **Applications**
  - Stabilization of waste sludge
  - Treatment of high-strength organic wastes
  - Pretreatment step for conventional biological treatment

- **Advantage**
  - Low biomass yield
  - Energy production in the form of methane (of recent interest!)
    - WWTP -- ~2% of total energy cost in USA
    - Target on energy positive treatment of wastewater

- **Disadvantage**
  - Effluent quality usually not as good as aerobic treatment

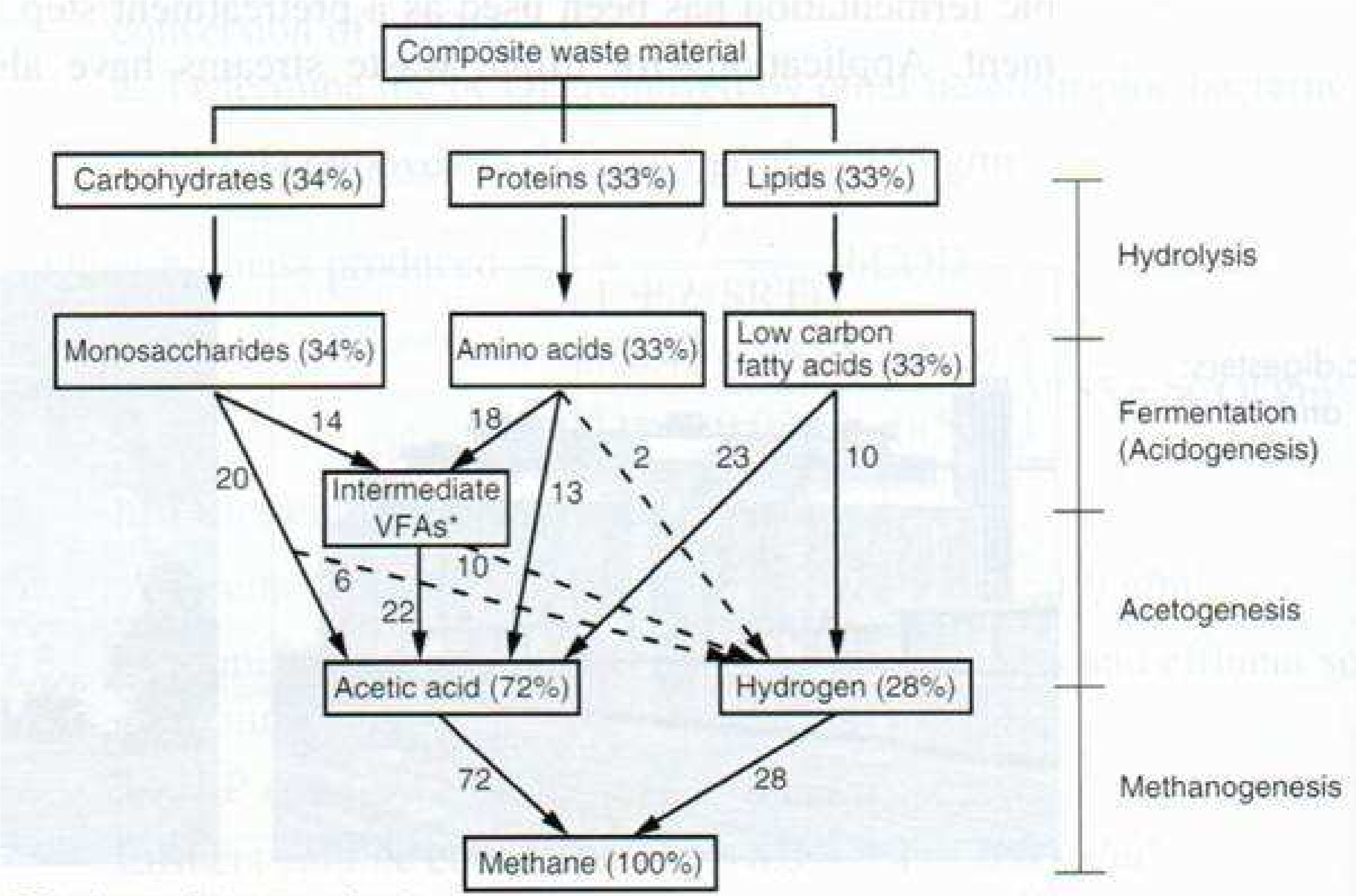
Before construction (Jan 15)

After construction (Feb 18)

Hongchun energy town, Korea
(animal manure + food waste)

Dear Island wastewater treatment plant, MA, USA
(sewage sludge)

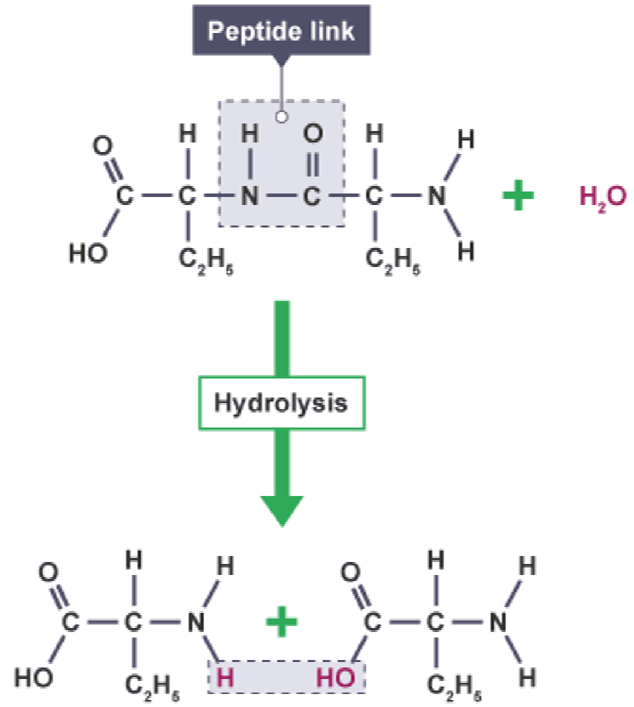
Pathway of anaerobic conversion of wastes



* Propionate, butyrate, valerate

Steps of anaerobic conversion (1)

- **Hydrolysis**
  - Particulates - - - -→ Soluble molecules - - - -→ Monomers
  - By extracellular enzymes



- **Acidogenesis (fermentation)**
  - Use: sugars, amino acids, fatty acids (both e^- donor & acceptor)
  - Produce: VFAs, CO_2, H_2

- **Acetogenesis**
  - Use: VFAs other than acetate
  - Produce: acetate, H_2, CO_2

Steps of anaerobic conversion (2)

- **Methanogenesis**
  - By methanogens (belongs to domain **Archaea**)
  - Two groups of methanogens
    - *aceticlastic* methanogens: acetate → $CH_4 + CO_2$
    - *hydrogenotrophic* methanogens: $H_2 + CO_2$ → CH_4
  - In anaerobic digestion process, ~72% methane from acetic acid & ~28% from H_2 (→ gas production of ~65% CH_4 & ~35% CO_2)

Syntrophic relationship

- Methanogens – acidogens & acetogens
  - Acidogens & acetogens: produce H_2, acetate, etc.
  - Methanogens: cleans up the acido/acetogenesis end products
    - Acetogens require relatively low H_2 partial pressure
- Often called as *“Interspecies hydrogen transfer”*

COD balance for anaerobic process

(COD utilized) = (Biomass COD) + (Methane COD)

- No e^- acceptor consumed!
- COD of methane = 64 g COD/mole CH_4

  = 2.86 g COD/L CH_4 (@ 0°C, 1 atm)

COD balance for anaerobic process

Q: An anaerobic reactor, operated at 35°C, is used to process a wastewater stream with a flow of 3000 m^3/d and a bCOD concentration of 5000 g/m^3. At 95% bCOD removal and a net biomass yield of 0.04 g VSS/g COD, what is the amount of methane produced in m^3/d?

Process kinetics

- Low yield coefficients
  - Low energy gain by chemical transformation
  - Fermentation: Y ~ 0.06 g VSS/g COD; b ~ 0.02 d^{-1}
  - Methanogenesis: Y ~ 0.03 g VSS/g COD; b ~ 0.008 d^{-1}

- Consider two steps:
  - Hydrolysis
  - Soluble substrate utilization for fermentation and methanogenesis
    - Methanogenesis the rate-limiting step

- High SRT is needed (around 40 d) due to slow degradation rate

Process stability

- Kinetics of VFA production is faster than utilization (methanogenesis)
- At steady state, sufficient methanogen population is established to maintain low VFA concentration (<200 g/m^3) & pH≥7.0
- Unstable digester operation may develop under transient loading conditions (VFA production > utilization): VFA accumulation & pH drop
- Low pH leads to decline in methanogenic activity: process failure
- Methanogenic inhibition can also occur by acetate accumulation (acetate conc. > 3000 g/m^3)

Microbial fuel cells

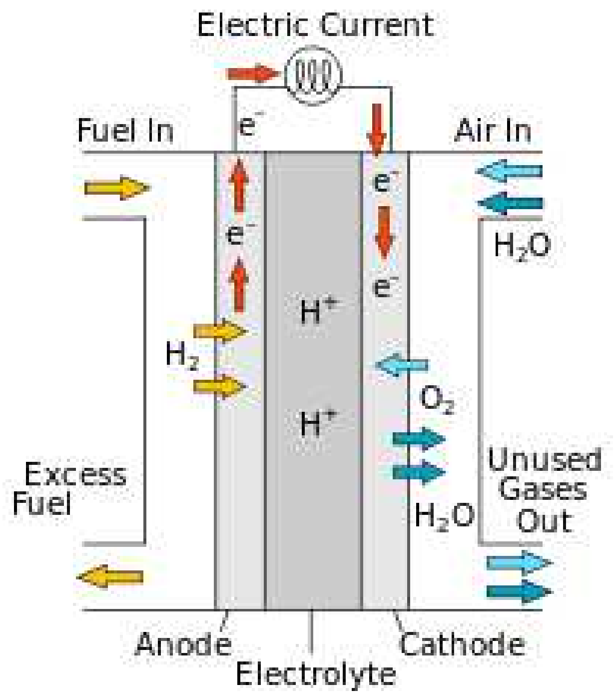
Fuel cell

- A device that converts the chemical energy from a fuel into electricity through an electrochemical reaction of hydrogen with oxygen or another oxidizing agent

- Each half reaction of the overall redox reaction occurs separately at each electrode
  - Oxidation half reaction (Anode)

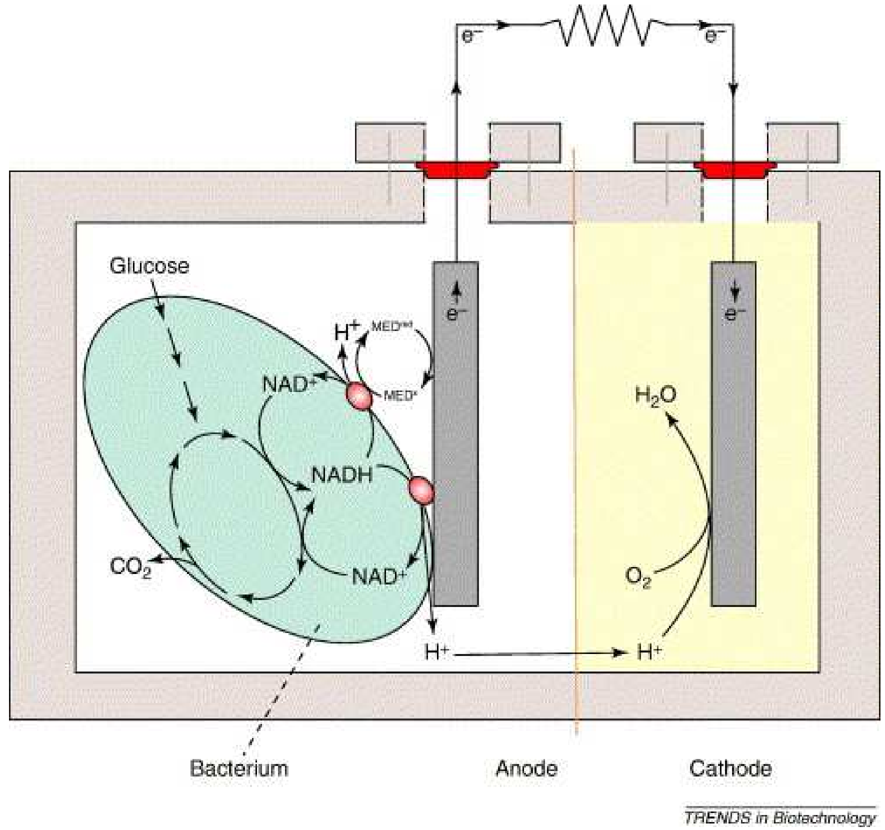
    ex) $\frac{1}{2}H_2 \rightarrow H^+ + e^-$
  - Reduction half reaction (Cathode)

    ex) $\frac{1}{4}O_2 + H^+ + e^- \rightarrow 2H_2O$
  - Electrons move through the electric circuit (electricity generated)
  - H^+ move through the electrolyte



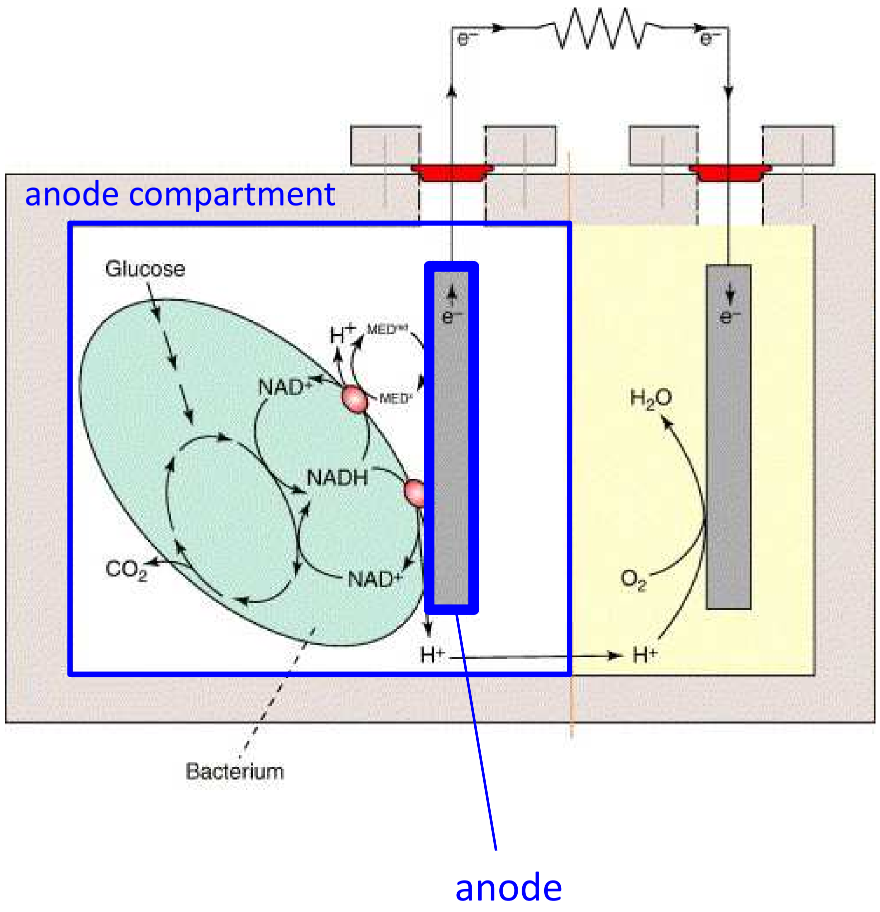
Microbial Fuel Cell (MFC)

- A device that converts the chemical energy to electrical energy by the action of microorganisms
- The redox reaction is catalyzed by microorganisms



MFC – Anode compartment

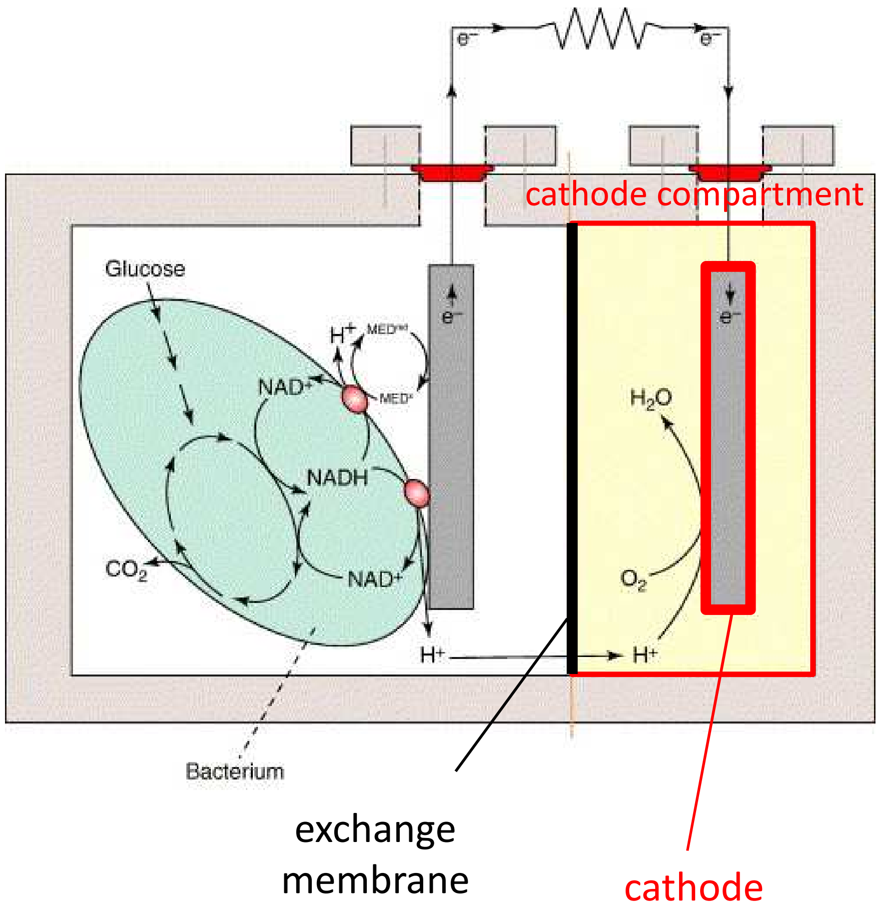
- Anode
  - Should be conductive, bio-compatible, chemically stable with substrate
  - Stainless steel mesh, graphite plates or rods
- Bacteria live in the anode compartment and oxidize the substrate provided
- Anode compartment should be kept low in DO
- Substrates: usually organics – carbohydrates, protein, VFAs, cellulose, and wastewater



MFC – Cathode compartment / EM

- Cathode compartment
  - Usually oxygen is used as an oxidizing agent
  - Catalysts used for the oxygen reduction reaction: Pt most common

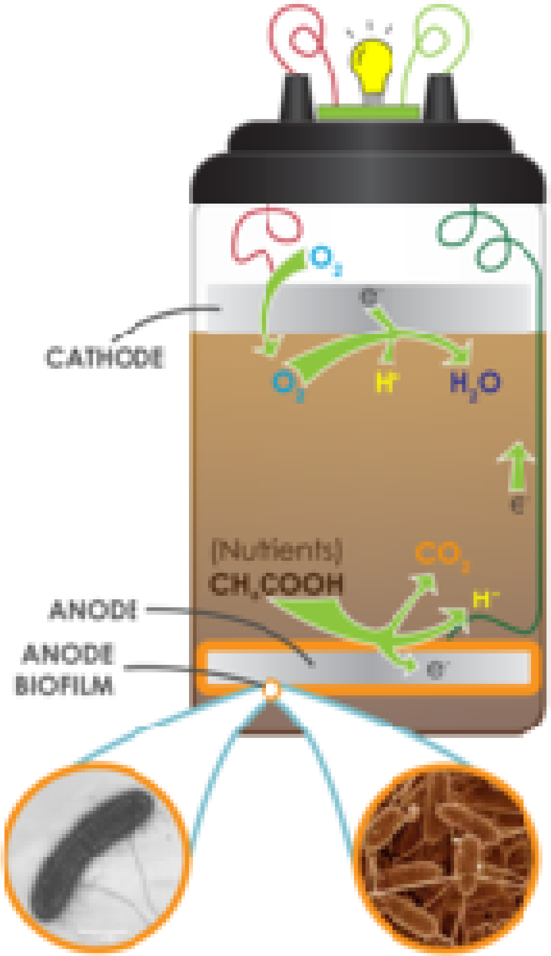
- Exchange membrane
  - Allows proton (H^+) to flow from the anode compartment to cathode compartment



Soil-based MFCs

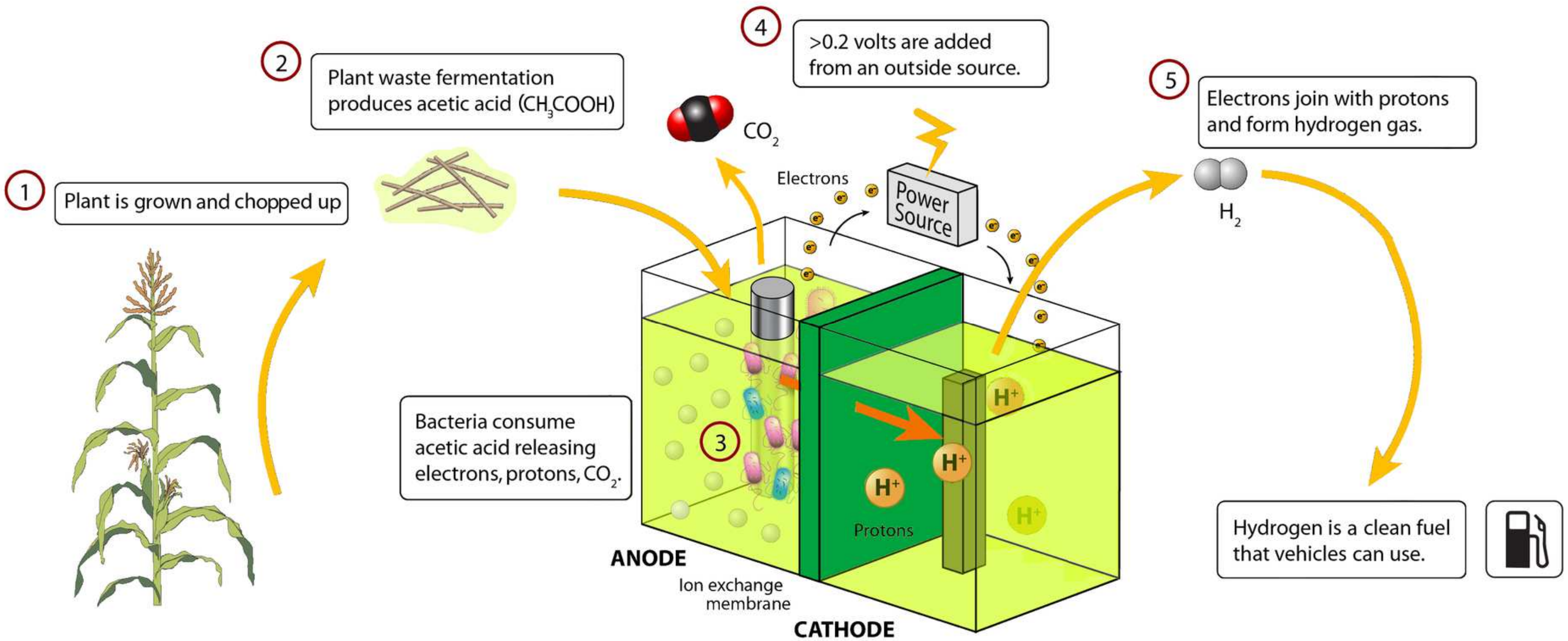
- Soil serves as
  - Anode compartment
  - Proton exchange membrane

- And soil provides
  - Microorganisms
  - Nutrients



Microbial electrolysis cell (MEC)

- Not an electricity-generating, but electricity-consuming process to produce hydrogen or methane as a fuel
- Hydrogen is produced by reducing protons at the cathode
  - The voltage required to reduce protons is provided by: substrate utilization by microorganisms at the anode + additional voltage supply from an outside source



MFC – pros & cons

- Advantages
  - Generation of energy out of bio-waste / organic matter
  - Direct conversion of substrate energy to electricity
  - No gas treatment required
  - Aeration may not be needed (the cathode may be passively aerated)

- Disadvantages
  - Low power density: losses of electric potential significant
  - High initial cost