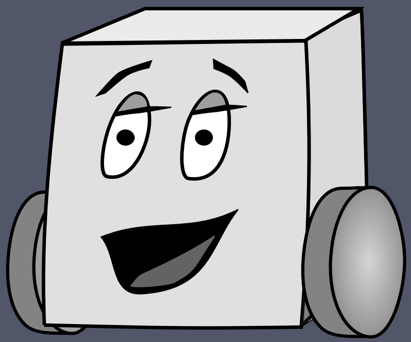
E11 Lecture 8: Fuel Cell Power and Energy Conservation



Professor Lape

Fall 2010

Overview

- How much power can your FC produce?
  - Maximum power
  - Polarization curve

- How can we convert this power to other forms of useful energy?
  - 1^{st} law of thermodynamics

Hydrogen Fuel Cell

Overall Reaction: $H_2 + \frac{1}{2}\, O_2 \rightarrow H_2O$

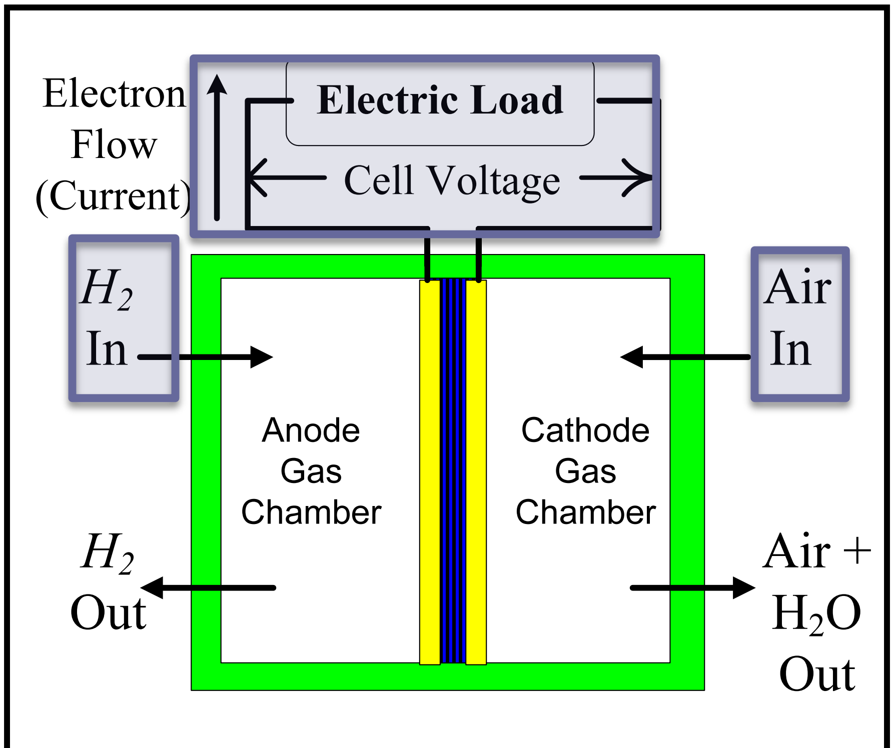


Figure from "Fuel Cell Efficiency", a CACHE Module on Energy in the Curriculum.

Chemical → **Electricity**

Electric Power

- **Voltage, *V***: Energy required to move a coulomb of electrical charge.
  - Units = Joules/Coulomb (J/C)

- **Current, *I***: Rate of electrical charges flowing, *dq/dt*.
  - Units = Amperes (A), = Coulombs/sec

- **Electric Power, P_e or** $\dot{W}_e$ = Rate of electric work output.
  - Units = Watts (W) = J/s

$$P_e \text{ or } \dot{W}_e = VI$$

Maximum Theoretical Voltage

- The maximum theoretical voltage that can be obtained from a fuel cell by converting all chemical energy into electricity at standard pressure is

$$V^0 = -\frac{\Delta G}{nF}$$

where:

  - ΔG is the Gibbs free energy of the overall FC reaction
  - n is the number of moles of electrons per mole of fuel
  - F is Faraday's constant, 96,485 C/mol e^-

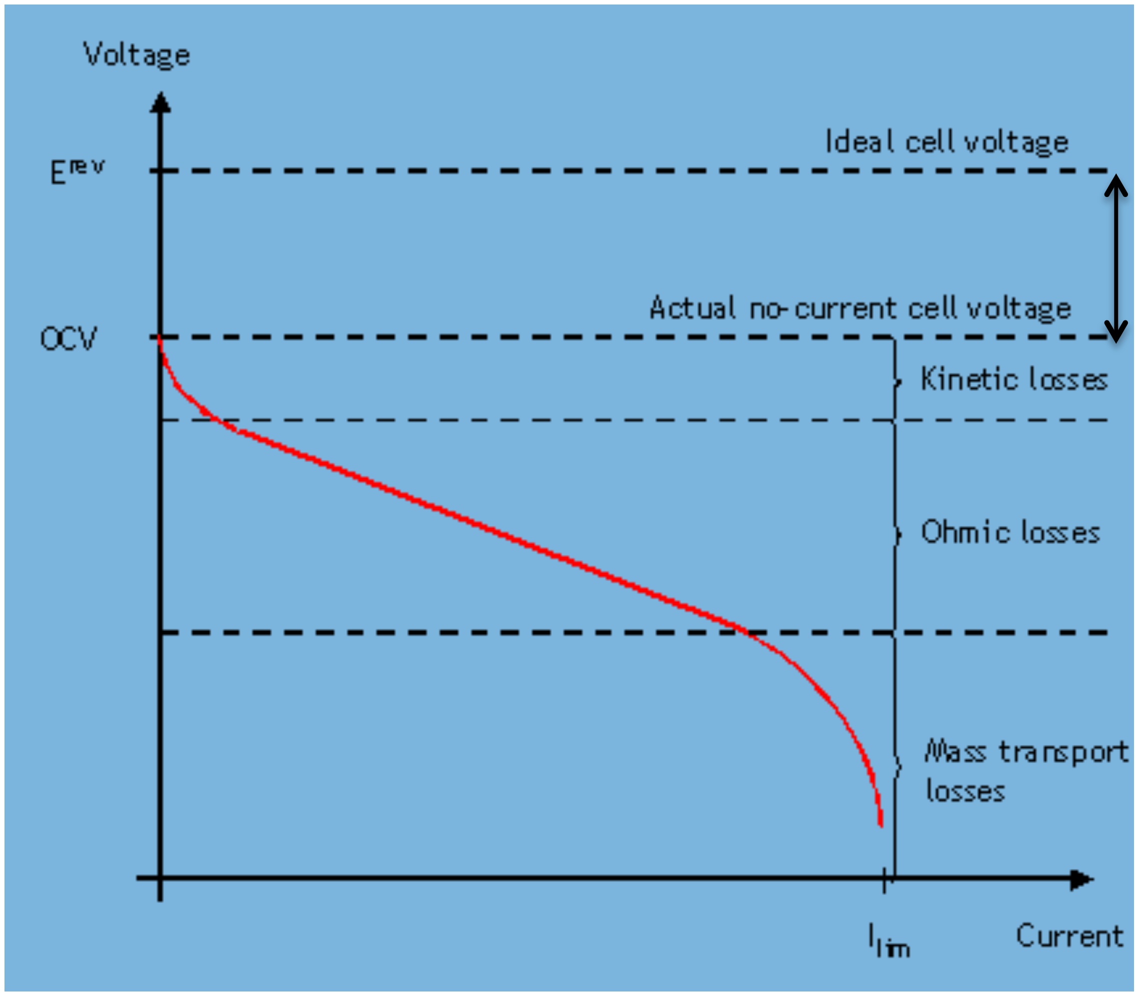
PEMFC Problem #1

- What is the maximum theoretical voltage for a hydrogen PEMFC operating at standard pressure and temperature? The standard Gibbs free energy for the reaction of hydrogen and oxygen to produce liquid water $\Delta G_{r.}^{\circ}$ -237.13 kJ/mol.

PEMFC Problem #2

- If a PEMFC were to consume all of the hydrogen fed at 5 μg/s, what current would it produce?

FC Polarization Curve



Losses from fuel and e⁻ crossover through electrolyte

Figure from http://www.fuelcell.no/principle_fctheory_eng.htm

PEMFC Problem #4

- A PEMFC with a hydrogen utilization of 75% is fed 5 μg/s of hydrogen. What is the current produced by the fuel cell?

PEMFC Problem #5

- A PEMFC with a hydrogen utilization of 75% is fed 5 μg/s of hydrogen. What is the maximum power the fuel cell can produce?

PEMFC Problem #6

- A PEMFC with a hydrogen utilization of 75% is fed 5 μg/s of hydrogen. If it produces 60% of the maximum power, what is the rate of heat production by the fuel cell?

PEMFC Problem #7

- A PEMFC with a hydrogen utilization of 75% is fed 5 μg/s of hydrogen. If it produces 60% of the maximum power, how many identical PEMFCs would be necessary to provide sufficient power for a Mudduino operating at 5 V with a maximum current of 500 mA?

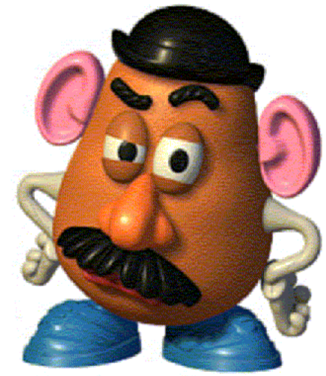
How is energy stored in a system?

How is energy transferred to and from a system?

Law of Conservation of Energy: The 1st Law of Thermodynamics

Change in amount of energy contained within the system during some time interval	=	Net amount of energy transferred ***in*** across the system boundary by heat transfer during the time interval	+	Net amount of energy transferred ***in*** across the system boundary by work during the time interval
$\Delta KE + \Delta PE + \Delta U$	=	Q	+	W

i-Clicker #1



- Hot potato! You packed your hot potato in a well-insulated lunch bag with a cold soda and let it sit for 15 minutes. *If you define the entire lunch bag as the system, what is the sign of the heat transfer with the environment?*

A. $Q < 0$ (heat transfer out of the lunch bag)
B. $Q \approx 0$ (approx. no heat transfer w/ surroundings)
C. $Q > 0$ (heat transfer into the lunch bag)
D. I heart Mr. Potato Head

i-Clicker #2

- You packed your hot potato in a well-insulated lunch bag with a cold soda and let it sit for 15 minutes. *If you define the potato as the system, what is the sign of the heat transfer with the environment?*

A. $Q < 0$ (heat transfer out of the potato)
B. $Q \approx 0$ (approx. no heat transfer w/ surroundings)
C. $Q > 0$ (heat transfer into the potato)

i-Clicker #3

- You packed your hot potato in a well-insulated lunch bag with a cold soda and let it sit for 15 minutes. What is the simplest correct first-law balance on the potato for this process?

A. $\Delta U + \Delta KE = Q - W$

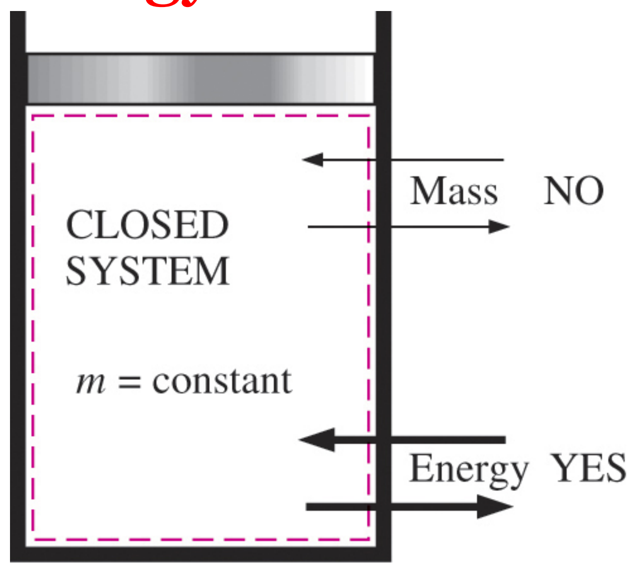
B. $\Delta U = Q - W$

C. $\Delta U = Q$

D. $0 = Q$

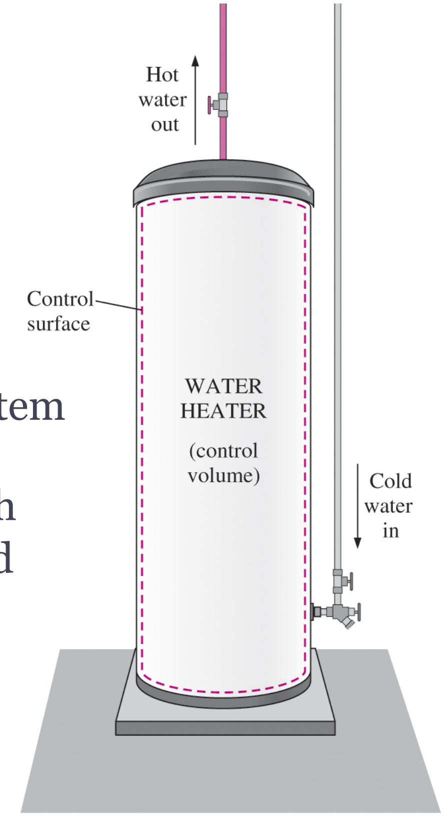
Closed System = Control Mass

- **Closed system (Control mass)**: A fixed amount of mass, and no mass can cross its boundary, but energy can cross its boundary.



Open System = Control Volume

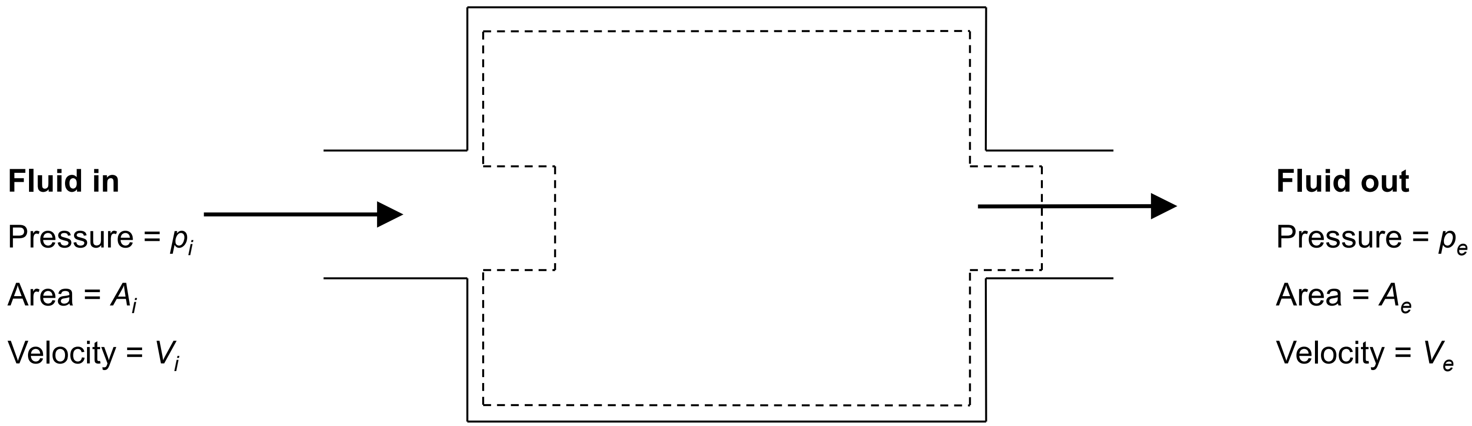
- Open system (control volume): A properly-selected region in space.
  - Usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle.
- Both mass and energy can cross the boundary of a control volume.



An open system (a control volume) with one inlet and one exit.

Flow Work in Open Systems

- Flow Work: Net rate of work done by the entering and exiting fluid to push fluid in or out.



Law of Conservation of Energy: The 1st Law of Thermodynamics

Best Balance for Closed system (no mass crosses boundaries; Δ usually = change in time)*:*

$$\underbrace{\Delta KE + \Delta PE + \Delta U}_{\text{Depend only on initial and final state of system}} = \underbrace{Q + W}_{\text{Depend on process}}$$

Depend only on initial and final *state* of system

Depend on *process*

Best Balance for Open system, SS (mass can cross boundaries; Δ usually = change in position) :

$$\underbrace{\Delta \dot{K}E + \Delta \dot{P}E + \Delta \dot{H}}_{\text{Depend only on state of system at inlet and exit}} = \underbrace{\dot{Q} + \dot{W}_{cv}}_{\text{Depend on process}}$$

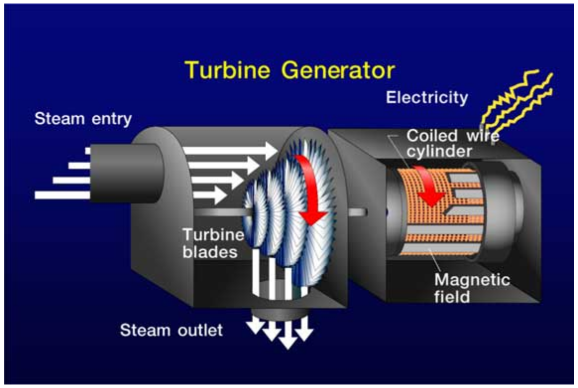
Depend only on *state* of system at inlet and exit

Depend on *process*

i-Clicker #4:

- Steam enters a rotary turbine and turns a shaft connected to a generator. The inlet and outlet steam ports are approximately at the same height (ignore difference in picture below) but the inlet and exit velocities are not equal. The system is *not* perfectly insulated.

  Is the system open or closed? What is the simplest correct energy balance?



A. Closed; $\Delta KE + \Delta U = Q + W$
B. Closed; $\Delta U = Q + W$
C. Open; $\Delta KE + \Delta H = \dot{Q} + \dot{W}_{cv}$
D. Open; $\Delta H = \dot{Q} + \dot{W}_{cv}$
E. Open; $\Delta H = \dot{W}$

i-Clicker #5:

- A tray filled with water at 20 °C is put into a freezer. The water turns into ice at - 5 °C .

  Is the system (tray + water) open or closed? What is the simplest correct energy balance?

A. Closed; $\Delta U = Q + W$
B. Closed; $\Delta U = Q$
C. Open; $\Delta H = \dot{Q} + \dot{W}_{cv}$
D. Open; $\Delta H = \dot{Q}$

i-Clicker #6:

- Hydrogen and air enter a fuel cell and unused fuel and water exit; the fuel cell produces electric work and waste heat.

  Is the fuel cell an open or closed system? What is the simplest correct energy balance?

A. Closed $\Delta U = Q + W$

B. Closed; $\Delta U = W$

C. Open; $\Delta H = \dot{Q} + \dot{W}_{cv}$

D. Open; $\Delta H = \dot{W}_{cv}$

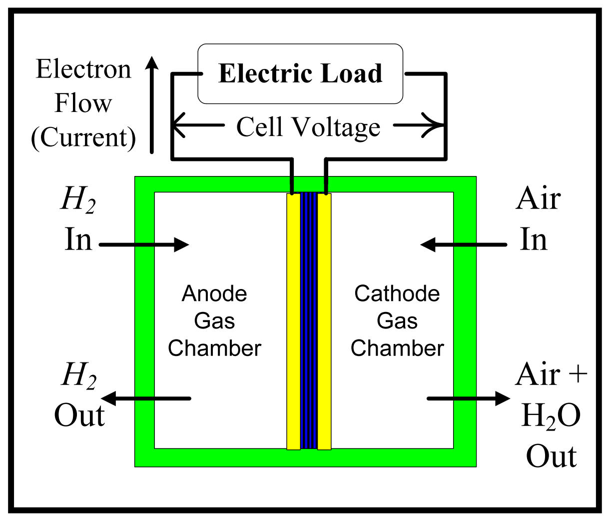


Figure from "Fuel Cell Efficiency", a CACHE Module on Energy in the Curriculum.

Example Problem

A fan is to accelerate quiescent air to a velocity of 10 m/s at a rate of 4 m^3/s. Determine the minimum power that must be supplied to the fan. The density of air at the entrance conditions is 1.18 kg/m^3.

System:

Assumptions:

1st Law:

Example Problem

Solution: