Renewable Energy Sources

ESP 313
Masi

Renewable Energy Sources

- Lecture Question
  - What are the renewable energy sources? Make a list, as comprehensive as possible.
  - What are the environmental impacts of these energy sources?

  - Renewable Energy Sources
    - Radiant solar energy
      - Solar heating (passive and active), solar power plants, photovoltaic cells
    - Biomass energy
      - Direct: combustion of biomass
      - Indirect: chemical conversion to biofuel
    - Wind energy
    - Hydro energy
    - Geothermal energy
      - Power plants, direct use, heat pumps
    - Ocean energy
      - Tidal; salinity-driven

Hydro Energy

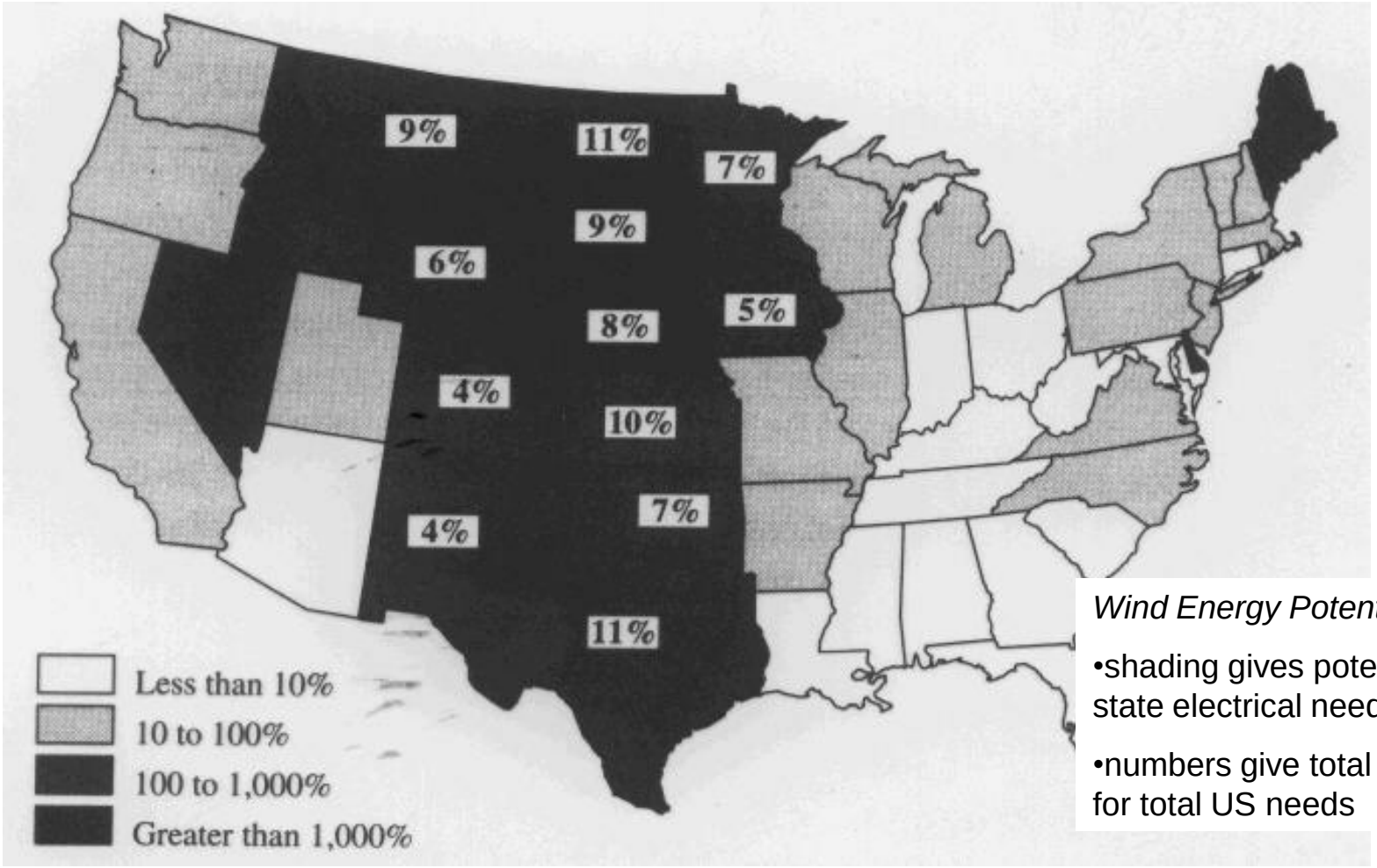
- Advantages
  - Cheap to operate
    - Long life and lower operating costs than all other power plants
  - Renewable
  - High yield
    - Lower energy cost than any other method
  - Pretty plentiful
    - Some countries depend almost entirely on it
  - Not intermittent (if reservoir is large enough)
  - Reservoirs have multiple uses
    - Flood control, drinking water, aquaculture, recreation
  - Less air pollution than fossil fuel combustion

Hydro Energy

- Disadvantages:
  - Human population displacement
  - More significant breeding ground for disease
  - Reduces availability of water downstream
  - Ecosystem impacts
    - Barriers to migrating fish
    - Loss of biodiversity both upstream and downstream
    - Coastal erosion
    - Reduces nutrient flow (dissolved and particulate)
  - Water pollution problems
    - Low dissolved oxygen (DO)
    - Increased H_2S toxicity; other DO-related problems
    - Siltation a big problem (also shortens dam life)
  - Air pollution
    - Actually may be a significant source of GHGs (CH_4, N_2O, CO_2)
  - Decommissioning is a big problem
- The Size Issue
  - Many (most) of the above problems are significantly worse for larger dams
  - However, small dams have shorter lifetimes, less capacity, and are more intermittent

Wind Energy

- How it works
  - Wind turbines directly generate electricity
  - Quite efficient (not a heat engine)



Wind Energy Potential

•shading gives potential for in-state electrical needs

•numbers give total potential for total US needs

Wind Energy

- Advantages
  - High net energy yield
  - Renewable and free
  - Very clean source of energy
    - No pollution (air or water) during operation
  - Long operating life
  - Low operating/maintenance costs
  - Can be quickly built; not too expensive
  - Now almost competitive with hydro and fossil fuels
  - Land can be used for other purposes
    - Can combine wind and agricultural farms

Wind Energy

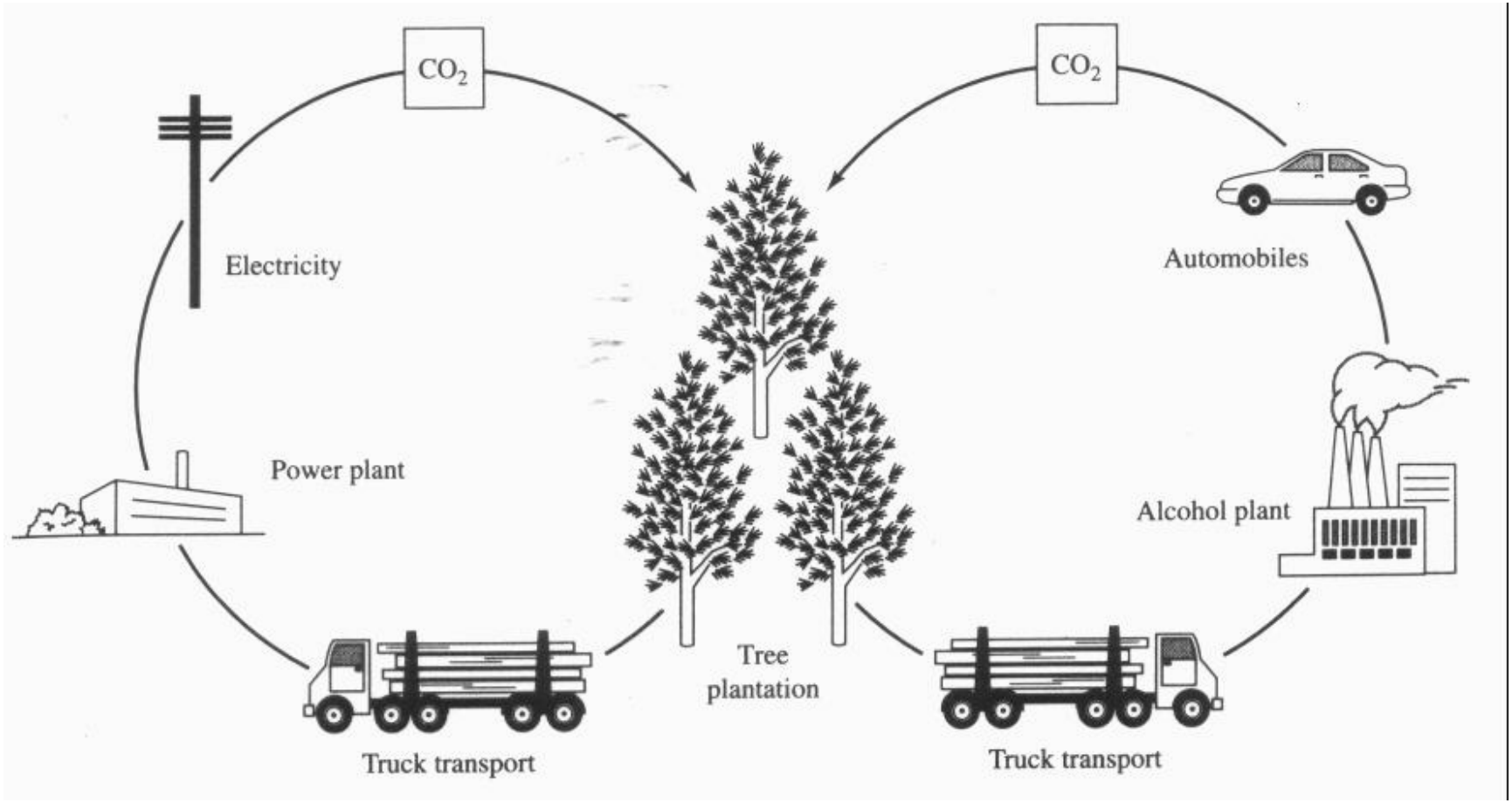
- Disadvantages
  - Energy storage issues
    - An intermittent source of energy; need backup (eg stored energy) for low-wind days
    - Or must be connected to the electrical grid
  - Only practical in areas that are windy enough
  - Visual pollution
  - Danger to birds
    - New (slow turning) designs largely eliminate this problem
  - Low energy density of wind
    - Must use large areas of land

Biomass Energy

- What is it?
  - Biomass energy is the use of living and *recently* dead biological material as an energy source
  - Ultimately dependent on the capture of solar energy and conversion to a chemical (carbohydrate) fuel
  - Theoretically it is a *carbon neutral* and renewable source of energy
- How it works?
  - Traditional: forest management, using wood as fuel
  - Use of biodegradable waste
    - Examples: manure, crop residue, sewage, municipal solid waste
  - Recent interest in agricultural production of ***energy crops***
    - Should be high yield and low maintenance
    - Examples: corn, sugarcane, switchgrass, hemp, willow, palm oil, rapeseed, and many others
    - Does not have to be a food crop
    - Recent interest in bioengineered (GM) plants as fuel sources
  - Production of a liquid or gaseous ***biofuel***
    - *Biogas* due to the breakdown of biomass in the absence of O_2
      - Includes capture of landfill methane
    - *Bioethanol* from fermentation, often from corn. Cellulosic bioethanol is usually from a grass (switchgrass)
    - *Biodiesel* from rapeseed and other sources

Biomass Energy

- Carbon neutral
  - CO_2 ultimately released in energy generation is *recently* captured and so ideally does not change total atmospheric levels
  - *Carbon leaks* can result in a net increase in CO_2 levels
  - Sequestration in soil can result in a net *decrease* in CO_2 levels



Biomass Energy

- Advantages
  - Versatile
  - Renewable
  - No net CO_2 emissions (ideally)
  - Emits less SO_2 and NO_x than fossil fuels
- Disadvantages
  - Low energy density/yield
    - In some cases (eg, corn-derived bioethanol) may yield no net energy
  - Land conversion
    - Biodiversity loss
    - Possible decrease in agricultural food productivity
  - Usual problems associated with intensive agriculture
    - Nutrient pollution
    - Soil depletion
    - Soil erosion
    - Other water pollution problems

Geothermal Energy

- How it works
  - Geothermal power plants
    - Use earth's heat to power steam turbines
  - Geothermal direct use
    - Use hot springs (etc) as heat source
  - Geothermal heat pumps
- Advantages
  - Renewable
  - Easy to exploit in some cases
  - CO_2 production less than with fossil fuels
  - High net energy yield
- Disadvantages
  - Not available everywhere
  - H_2S pollution
  - Produces some water pollution (somewhat similar to mining)

Radiant Solar Energy

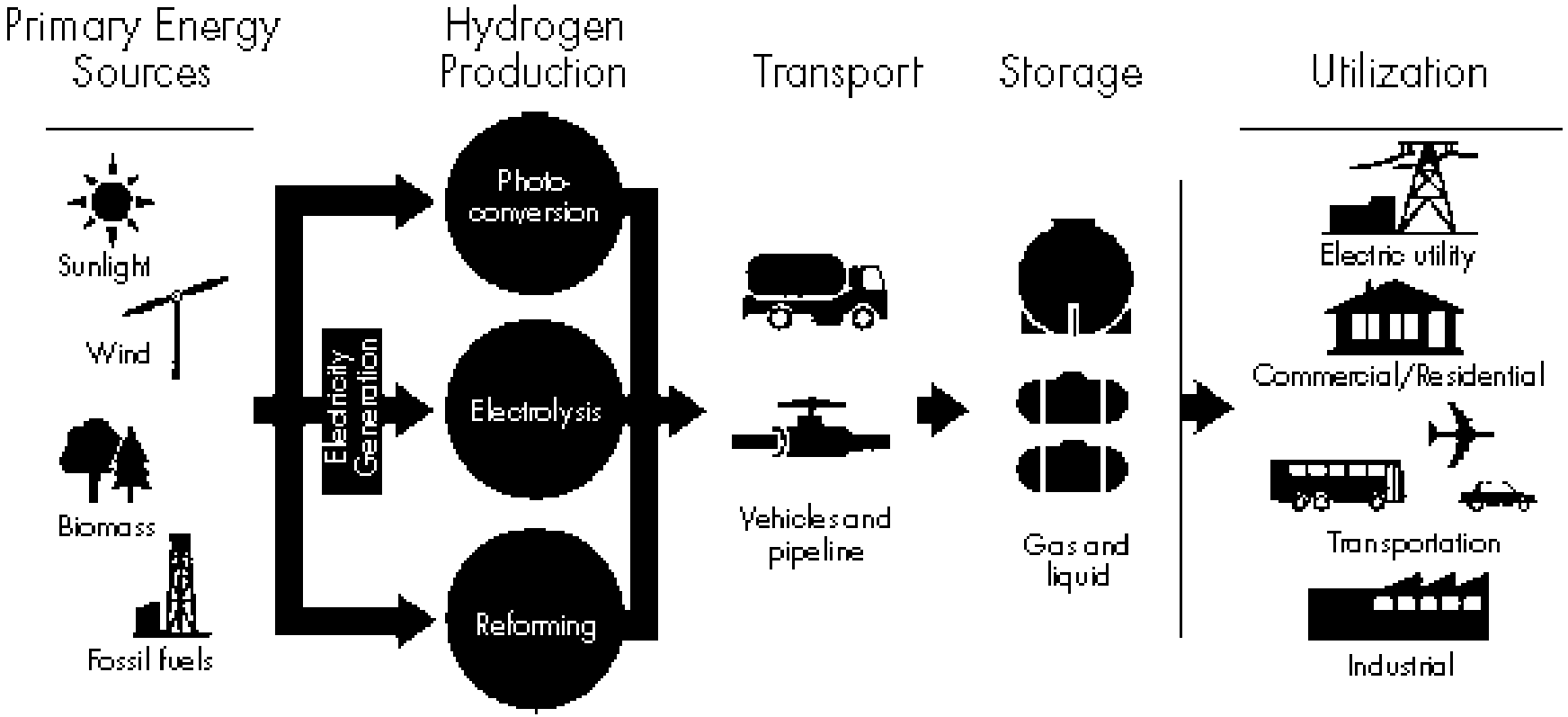
- How it works
  - Solar power plants
    - Steam produced to turn turbine
  - Solar heating
    - Active and passive systems
  - Photovoltaic cells
    - “Solar batteries” use special semiconductors
- Advantages
  - Renewable and free
  - High energy yield
  - A very clean source of energy
    - No air/water pollution during operation
  - Low operating costs
    - Will pay for themselves over time
- Disadvantages
  - Intermittent source
    - Energy storage issues
  - Low energy density
    - Requires pretty much land

The Hydrogen Economy

- *Lecture Questions*
  - What is the hydrogen economy?
  - Explain how the hydrogen economy could potentially serve as the basis for a renewable energy system that emits little or no air pollution

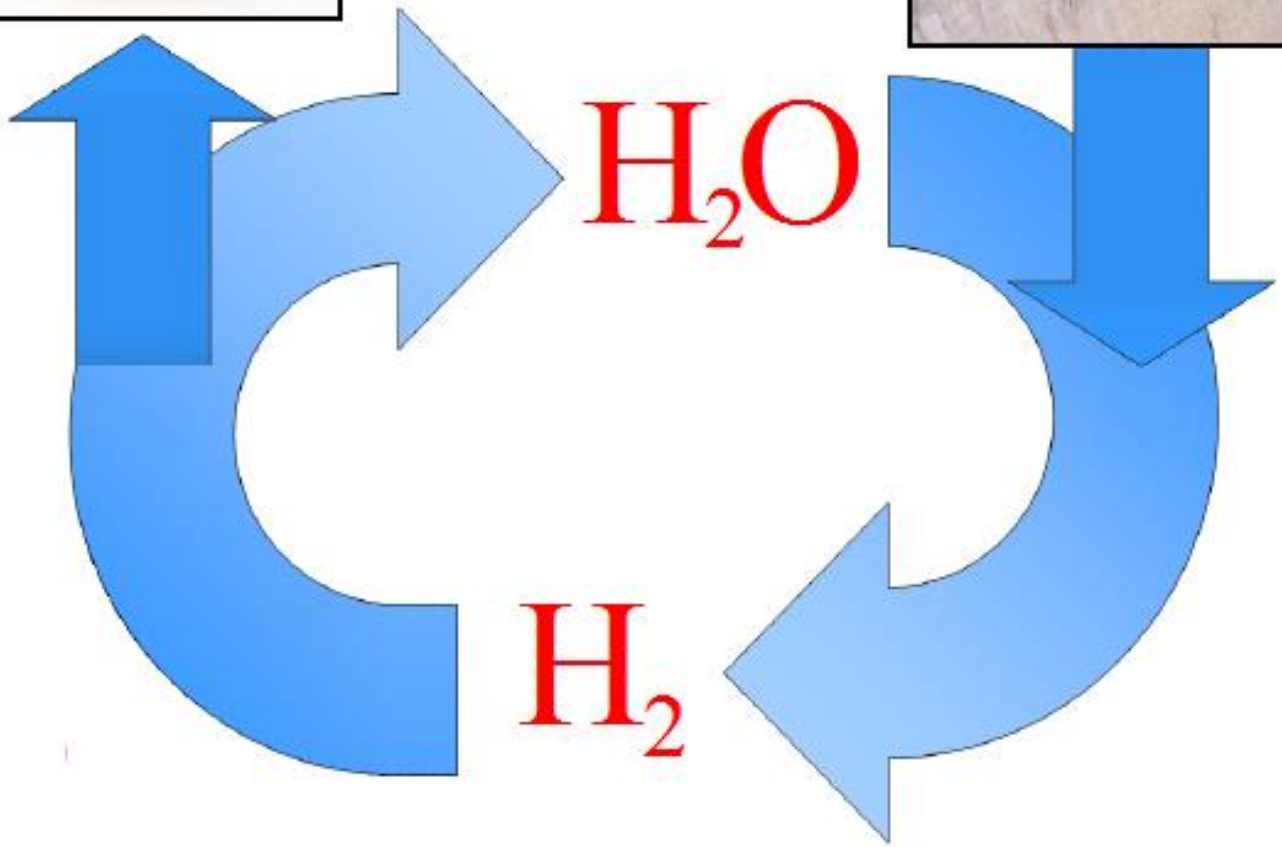
- Definition
  - *The Hydrogen Economy* is a hypothetical large-scale system in which elemental hydrogen (H_2) is the primary form of energy storage
    - Fuel cells would be the primary method of conversion of hydrogen to electrical energy.
      - Efficient and clean; scalable
    - In particular, hydrogen (usually) plays a central role in transportation.
- Potential Advantages
  - Clean, renewable
  - Potentially more reliable (using distributed generation)
- BUT many roadblocks *including potential showstoppers*
  - Poses great technological challenges for efficient hydrogen production, storage, and transport

Components of the Hydrogen Economy



- Infrastructure needs
  - Production
  - Storage
  - Delivery
  - End use

Hydrogen as a Transportation Fuel



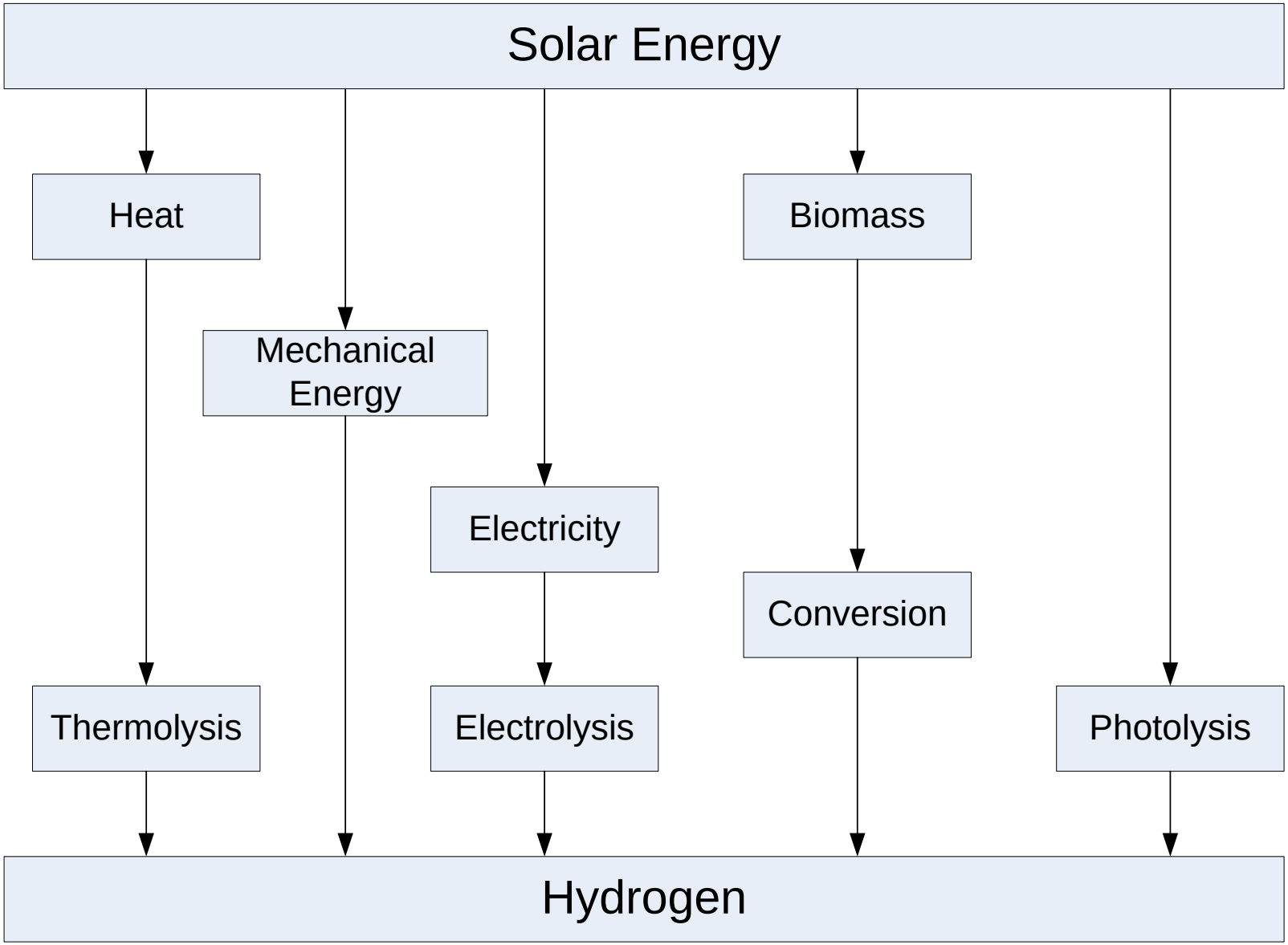
Hydrogen Production

- Fossil Fuels
  - Steam Reforming of Natural Gas
    - Combination of methane and steam produces hydrogen gas
      - Carbon monoxide is also produced
      - The “water gas shift” reaction can produce further hydrogen from the carbon monoxide. *Carbon dioxide is produced too*.
    - Most economical; main current method
      - Carbon sequestration one method to reduce CO_2 emission
  - Partial Oxidation (POX) of Hydrocarbons
    - HC partially oxidized to produce hydrogen and carbon monoxide
  - Coal Gasification
    - Gasified at high temps, then processed
    - Can also be used to get hydrogen from biomass

Hydrogen Production

- Electrolysis
  - Efficiencies 70-85%
  - Produces highest purity of hydrogen
  - Currently, the electricity consumed is usually worth more than the hydrogen produced
- Experimental methods
  - Biological hydrogen production
  - Direct photolysis
  - Thermolysis

Renewable Solar Paths to Hydrogen



Hydrogen Storage

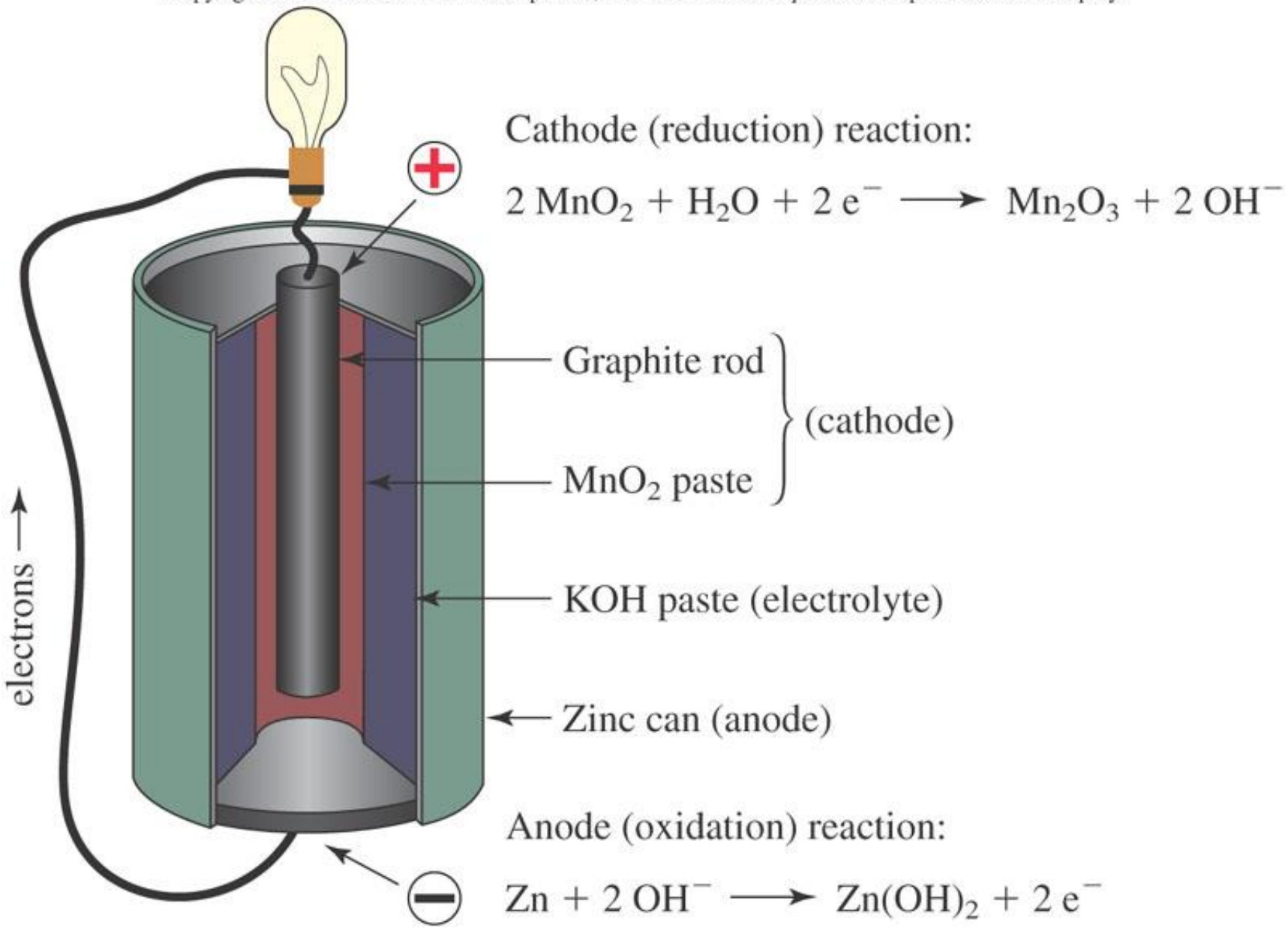
- Large-Scale Stationary Storage
  - Underground in depleted oil/gas fields, aquifers, caverns
- Intermediate- and Small-Scale Stationary/Mobile Storage
  - The focus of most current research
  - As a liquid
    - Advantage: higher energy density, cheaper transport
    - Disadvantage: economic/energy cost of liquefaction is significant
  - As a compressed gas
    - Probably best short-term method, particularly with advanced materials to decrease weight
    - Advantages
      - Rapid charging/discharging
      - Lower costs than liquid storage
    - Disadvantages:
      - Low energy density, Probably still acceptable for motor vehicles
      - Safety (esp public perception)
  - Metal hydrides
    - Hydrogen is absorbed under pressure, released when heated
    - Less filling pressure needed
    - Low energy density, long recharge time, expensive
- Experimental Methods
  - Improved hydrides; carbon nanotubes; many other materials (eg conversion to ammonia)

Chemical Batteries

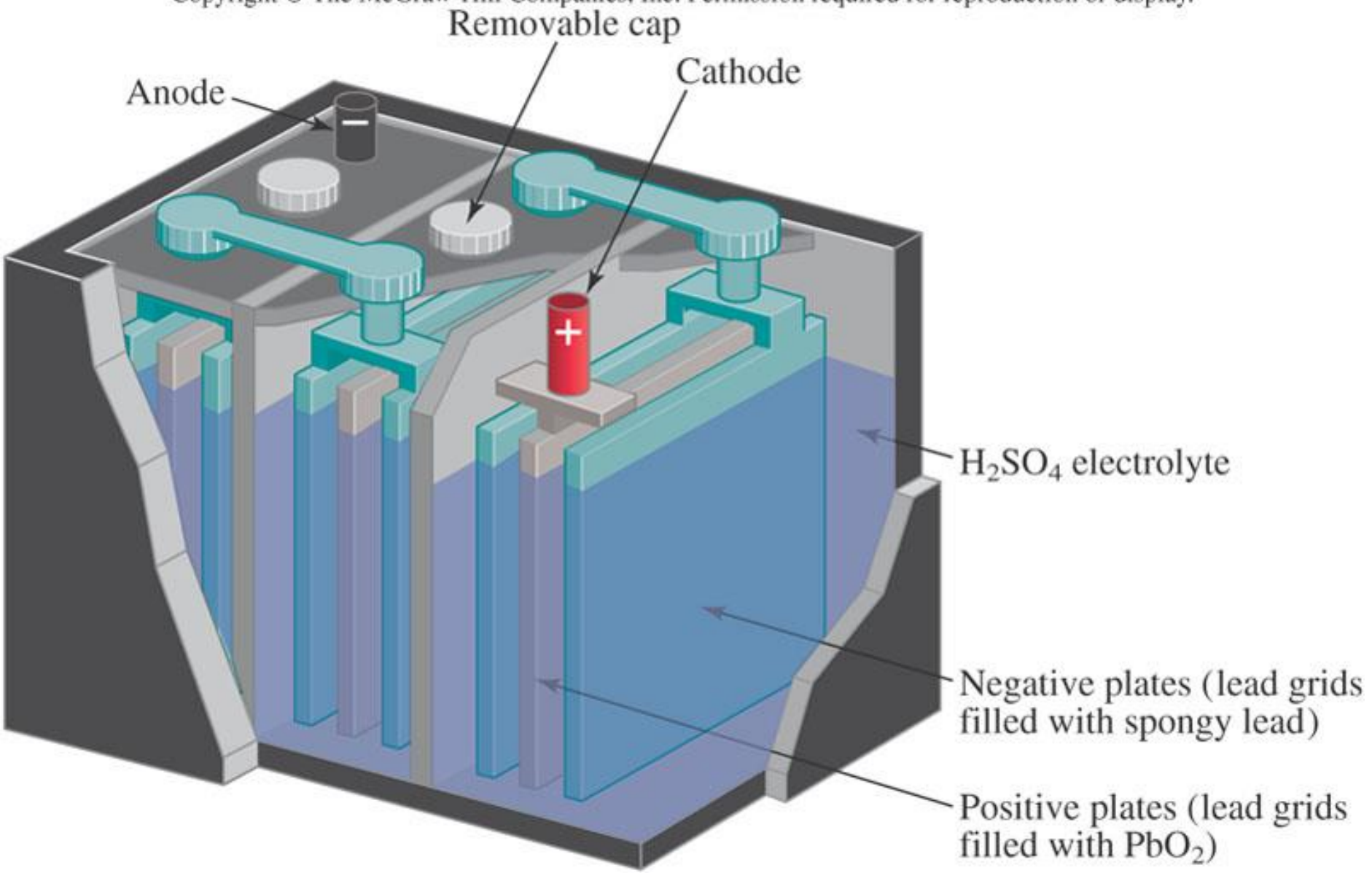
- *Lecture Questions*
  - What are batteries and how do they work?
  - What's the difference between a "regular" and a "rechargeable" battery? Why are rechargeable batteries sometimes referred to as "storage" batteries?

  - Chemical batteries are based on reduction-oxidation (redox) reactions, which are reactions where electron transfer occurs.
    - The oxidation half-reaction occurs at the *anode*
    - Electrons flow from the anode, through an external circuit, and to the *cathode*, where the reduction half-reaction occurs
  - Chemical batteries are a very efficient method of generating electricity
    - Efficiencies of 80% are regularly achieved
    - Significantly (2-3 times) more efficient than heat engines
  - Rechargeable batteries can be hooked up to an external source of electricity to regenerate the redox reactants through electrolysis.
    - Rechargeable batteries thus provide a means of storing electricity in chemical form. They are thus sometimes called *storage batteries*.

The Alkaline Battery



The Lead Storage Battery

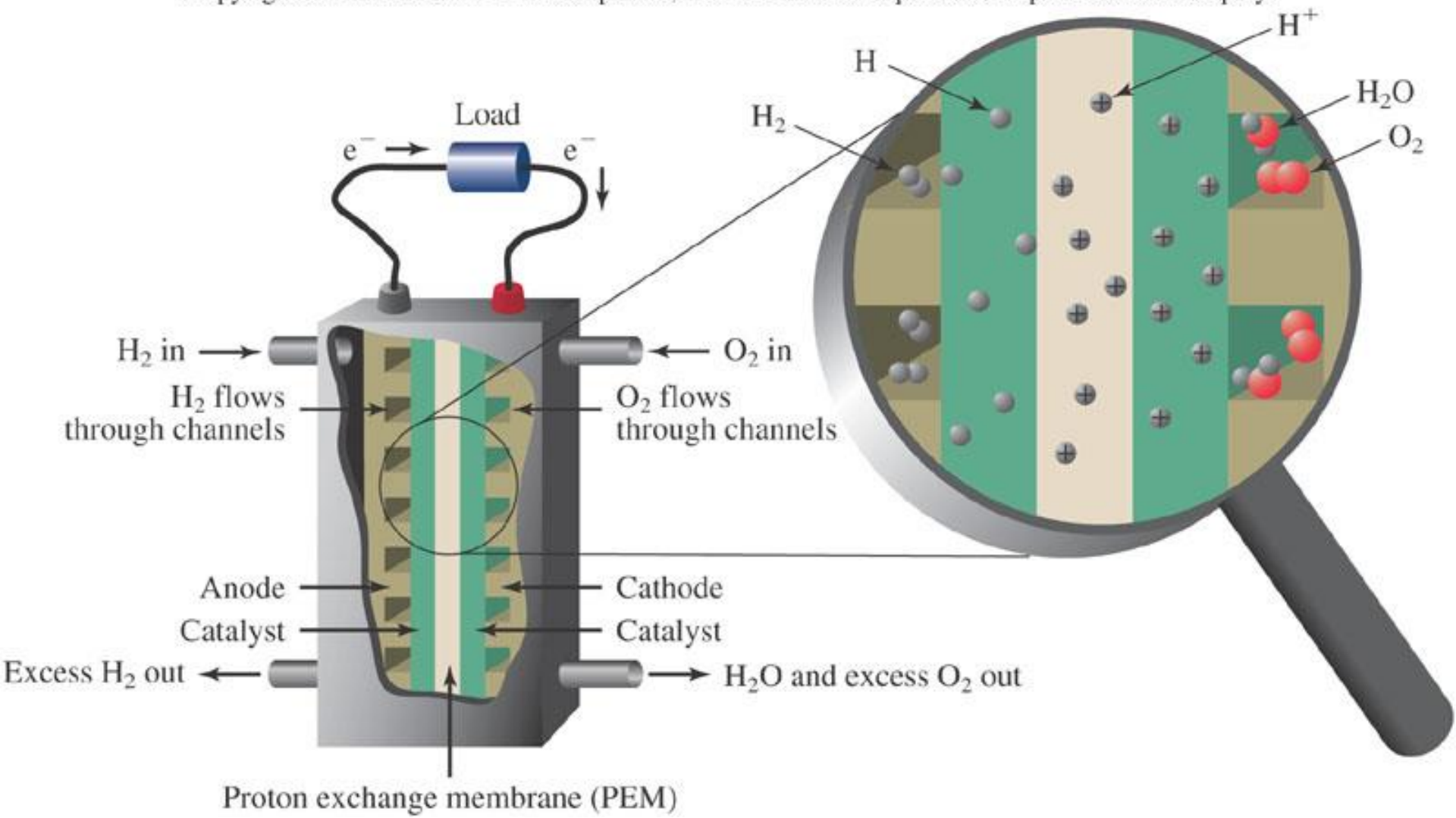


Fuel Cells

- *Lecture Questions*
  - What is a fuel cell and how does it work?
  - What is *distributed generation*?

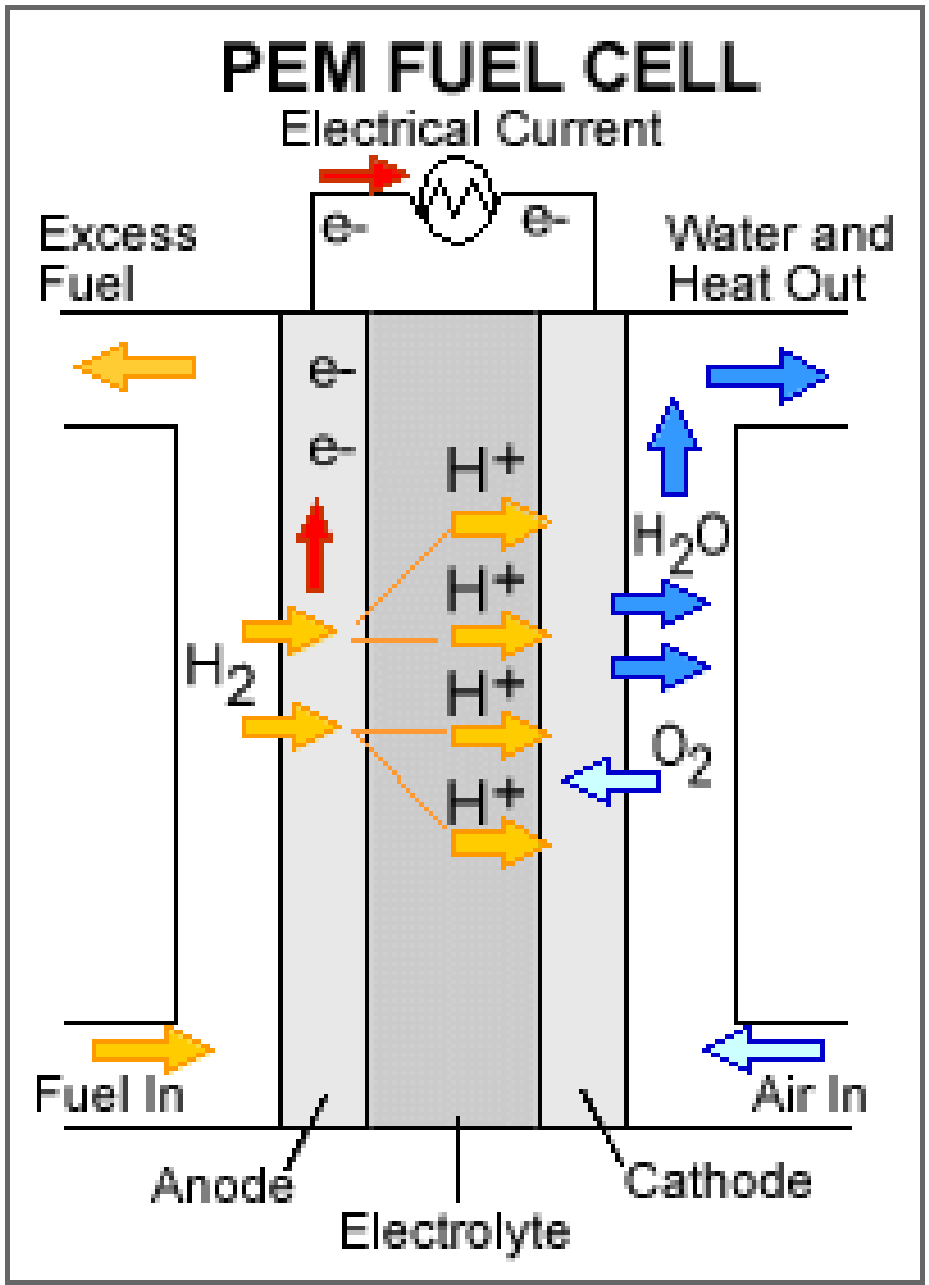
  - A fuel cell is basically a battery in which the reactants are continually supplied to the electrodes, and the products are continually removed.
    - Much more efficient (2-3 times) than heat engines at generating electricity
    - Most common type of fuel cells based on hydrogen (there are others)
  - Fuel cells are *scaleable*
    - Large ones can power homes or neighborhoods
    - Small ones can be used in appliances
    - Distributed generation is a decentralized power system consisting of hydrogen generators and fuel cells

A Hydrogen Fuel Cell



Hydrogen Fuel Cells: Scalable

Polymer Electrolyte Fuel Cell



Alkaline Fuel Cell (AFC)