Last Time…

Fuel efficiency is influenced by:

- Driving conditions
- Taxes on petroleum and vehicles
- Consumer preferences
- Use of diesel-powered vehicles
- Agreements with automobile manufacturers

Consumer Preferences

- Large vehicles
- Fast acceleration
- Powerful engines

Fuel efficiency is influenced by:

- Driving conditions
- Taxes on petroleum and vehicles
- Consumer preferences
- Use of diesel-powered vehicles
- Agreements with automobile manufacturers

Diesel and GHGs

- More fuel efficient (11%)
- Release 15% more CO_2 per volume of fuel
- Larger, heavier engines (high pressure and temperature)

Diesel-powered light-duty vehicles emit 5% to 30% less GHGs per distance traveled than gasoline equivalents

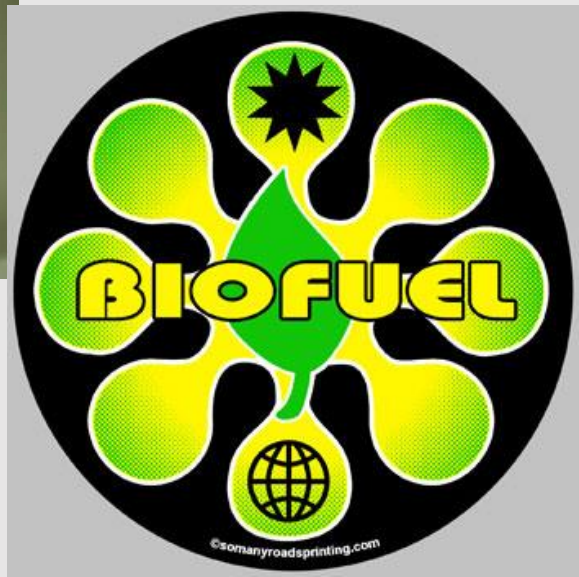
Fuel efficiency is influenced by:

- Driving conditions
- Taxes on petroleum and vehicles
- Consumer preferences
- Use of diesel-powered vehicles
- Agreements with automobile manufacturers

2012: New CAFE Regulations

Light-duty vehicles: 40.3 mpg by 2021, 48.7 mpg by 2025

Alternative Fuels

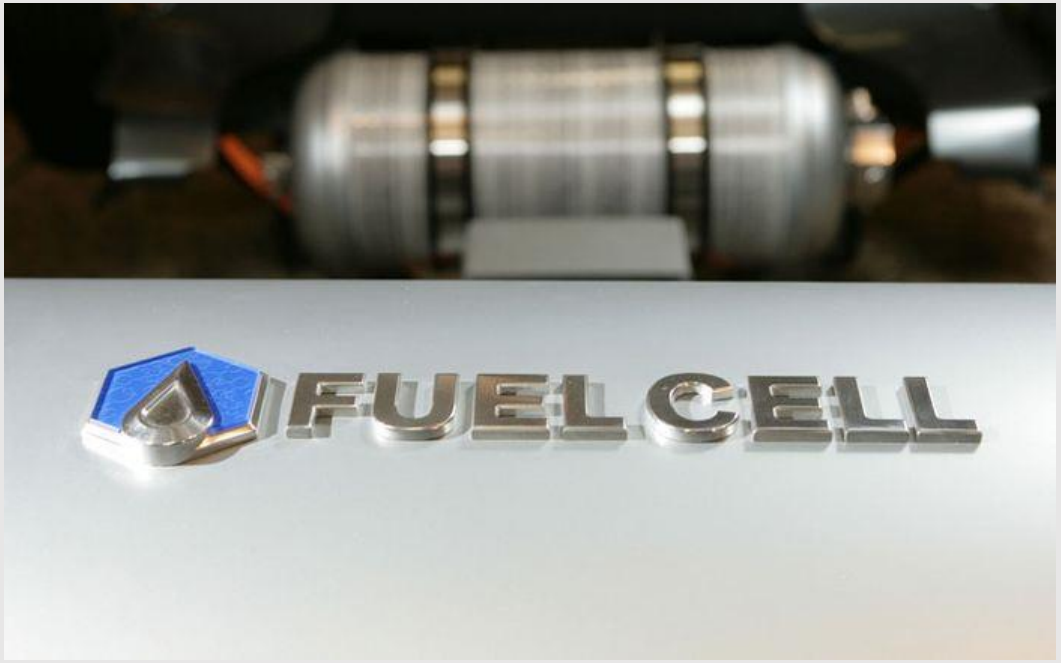


Compressed Natural Gas

- Combustion emits smaller amounts of GHGs than any fuel except hydrogen
- CNG vehicles emit 12% less GHGs than gas powered vehicles.
- Leakage during extraction, refining, distribution and combustion is a problem
  - Mostly methane
  - Leakage amount unclear

Hydrogen Fuel Cell

Hydrogen reacts with oxygen to form water and generates electricity to power the vehicle



Hydrogen Fuel

- Could be a good long term solution
- Not ready for general adoption

Electric Vehicles

Advantages

- Very efficient energy conversion
- Vehicle emits no GHGs
- Recharge at night, not peak hours
- Less maintenance, just tires and brakes
- Breaking can be used to recharge the battery

Disadvantages

- Limited range
- Long recharge time
- High costs
- Power plants to generate electricity produce GHGs

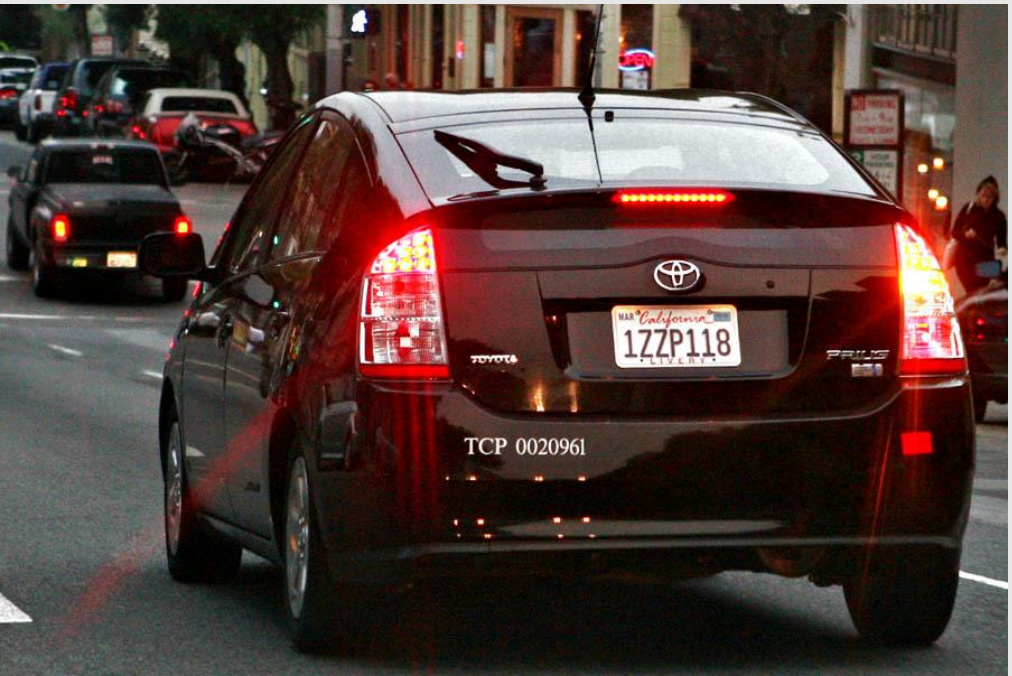
- Gas-electric combination
- Gas-powered engine and electric motors both connected to the wheels
  - Gas engine shuts down when vehicle stops
  - Batteries recharged with gas-powered engine and braking

Hybrids

- Batteries are difficult to recycle
- Guaranteed for 8 years or 100,000 miles
- Replacement battery for a 2011 Prius costs $2,200

Hybrids

- City driving is 30% more efficient than gas power alone
- Highway driving depends heavily on gas engine, little efficiency gain



Biofuel: produced from living materials

Bioethanol

Biomenthane

Biodiesel

In all cases, the energy originally comes from photosynthesis

Bioethanol

$6CO_2$ + water + light $\longrightarrow$ carbohydrate + oxygen

Carbohydrates then fermented into ethanol

Combustion of ethanol creates chemical energy, water, and CO_2

ethanol + oxygen $\longrightarrow$ $4CO_2$ + water + ENERGY

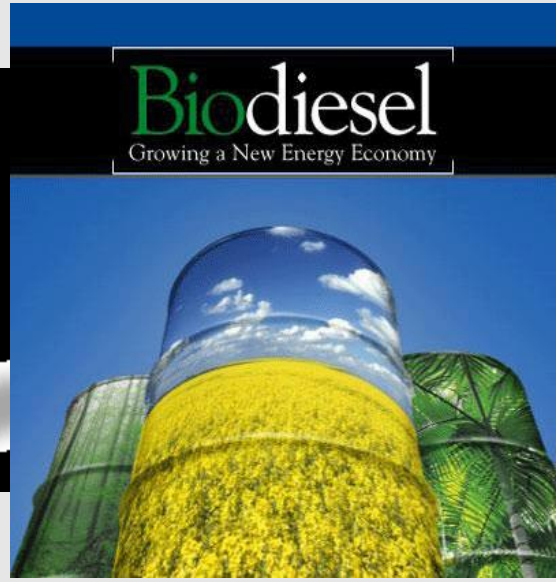
All together: light $\longrightarrow$ ENERGY

No net production of GHGs

Biomethane and Biodiesel

Carbohydrate from photosynthesis converted into methane or biodiesel

- Burning releases same amount of CO_2 that was taken in during photosynthesis



Biofuel

- The burning of biofuels release CO_2 equivalent to that taken in by plants during photosynthesis
- However, the production, transport, conversion and distribution of biofuels generate GHGs

Biomass Production

Agriculture

- Uses sophisticated farm machinery (burns fuel)
- Fertilizers
- Pesticides
- Water use
- New high yield strains of crops

Fertilizer

- Nitrogen fertilizer increases crop yields
- Contributes the majority of GHGs emitted during biomass production
  - Manufacturing requires energy
  - Distribution uses fuel
  - Application stimulates microbes which release N_2O

Biofuel

- We need a plant crop that requires low inputs of nitrogen, water, and less use of mechanical equipment
- Will produce high, sustainable yields that can easily be converted into fuels

Corn

- 40% of U.S. corn used for ethanol
- 36% fed to cattle, pigs, and chickens
- The rest is exported or consumed by Americans (corn syrup)

Diversion of food to fuel

Increase in corn prices in the past 10 years


Coca-Cola
Sprite
ORANGE


French's
FLAVOR
Campbell's
Vegetable
vlasic
BREAD & BUTTER
CHIPS
FAT FREE
PROGRESSO
Miracle Whip
DRESSING
original
KRUSTEAZ
FAT FREE
SUNSWEET
Prunes

Sugarcane

- 10% of Brazil's farmland
- Grows throughout the year
- Produces more energy per hectare than corn
- Has nitrogen-fixing bacteria within its tissues
  - Maintains high productivity with low fertilization

Corn vs Sugarcane

Processing corn is less efficient than sugarcane

- Extra steps to convert starch to sugar

Corn vs Sugarcane

http://www.newsweek.com/biggest-loser-iowa-ethanol-423640

- 1978 – Federal tax breaks on gasoline blended with ethanol and a large tariff imposed on ethanol from sugarcane imported from Brazil
- 2001 – domestic energy initiative, tax credits for E10

  Corn ethanol production increased by 700% between 2001 and 2010
- 2007 – Democrats control Congress, diverting corn from stomachs to cars would cause widespread hunger among world's poor

  Price of corn increased; UN officials labeled biofuels "a crime against humanity"
- 2011 – tax breaks and tariff discarded

Switchgrass

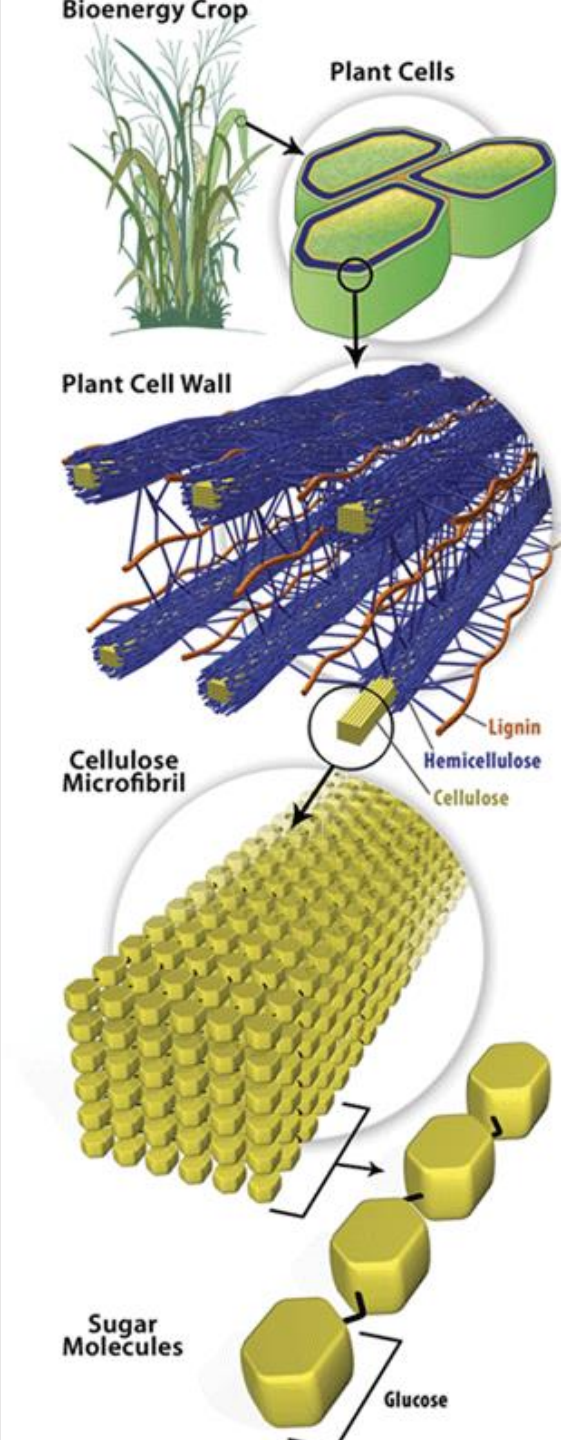
- Grows on lands unsuitable for cultivation of human food
- Require 1/3 less nitrogen, other chemicals and water than corn

Sources of GHG Emissions

- Transportation of biomass to processing facilities
- Biomass processing
  - –Burning
  - –Fermentation
  - –Distillation

Conversion of Cellulose to Ethanol

- Cellulose has a very strong structure. Forms plant cell walls.
- Very difficult to break down into ethanol



Cellulose to Ethanol

- Many steps involved in the process
- Most steps are expensive. Can't compete with other energy sources

- Research being done on genetic engineering of bacteria/fungi for efficient ethanol production

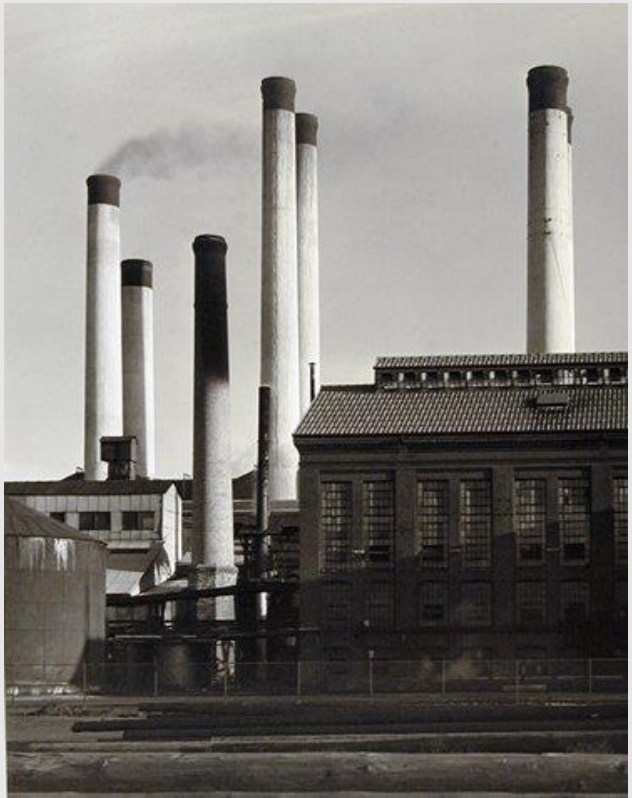
Overall Efficiency

Many different findings, based on several different assumptions

- Will production require substantial fertilization and irrigation?
- How much energy for processing will come from the biomass itself?

Electric Power Generation

- The human activity that emits the largest share of GHGs
- More than double the amount of any other source



Electricity Generation

- Coal-Fired Power Plants
- Natural Gas Power Plants
- Nuclear Power Plants
- Renewable Energy Sources
  - Hydroelectric, wind, solar, geothermal, tidal and wave

Industrial Power

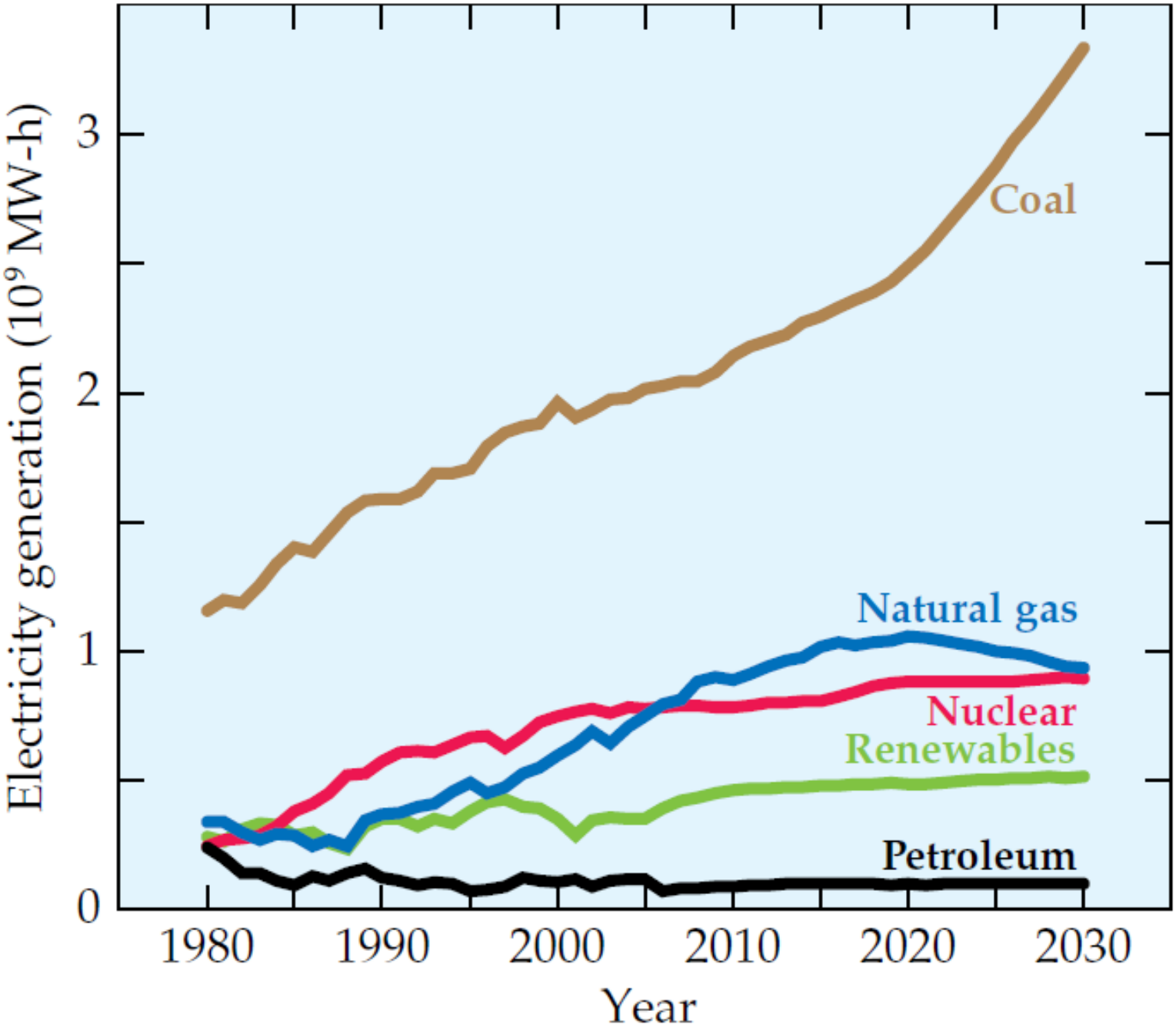
- Industry = processing of raw materials and manufacture of goods in factories
- Industry shifting from developed to developing countries
- As nations develop, their energy demands increase
  - In 2006, China increased is power-generating capacity by the total amount used by France
  - 1990-2000 India doubled its power-generating capacity

Power Plants

- All types have a lifespan of 30-50 years
- Building new plants with new GHG abating equipment is cheaper than retrofitting older plants
- Developing nations have a choice: what kind of power plants will they build?
  - Coal is cheapest
  - International agreements provide economic incentives for cleaner technologies

Coal Fired Power Plants

- Generate 50% of the electricity in the United States
- Provide over 60% of capacity in China and India
- In the next decade
  - China plans to build 500
  - India plans to double capacity


Electricity generation (10^9 MW-h)
3
2
1
0
Coal
Natural gas
Nuclear
Renewables
Petroleum
1980
1990
2000
2010
2020
2030
Year

Coal Fired Power Plants

- Higher GHG emissions per unit of power generated than other types
- Cheaper to construct and operate
- US, China, and India have large reserves of coal
  - Much more than gas, oil or uranium needed for other types of power plants

“Clean” Coal

- Release <u>less</u> sulfur dioxide and nitrogen oxides
- Combined with Carbon Capture and Storage

Not really “clean,” just clean**<u>er</u>**.

Natural Gas Power Plants

- Second-largest energy source in US and world
- Converting natural gas to electricity is simpler than converting coal
  - Fewer steps
  - Less processing

Converting natural gas to electricity is simpler than converting coal

This means:

–Inexpensive and rapid to construct

–Efficient to operate

–Easy to maintain

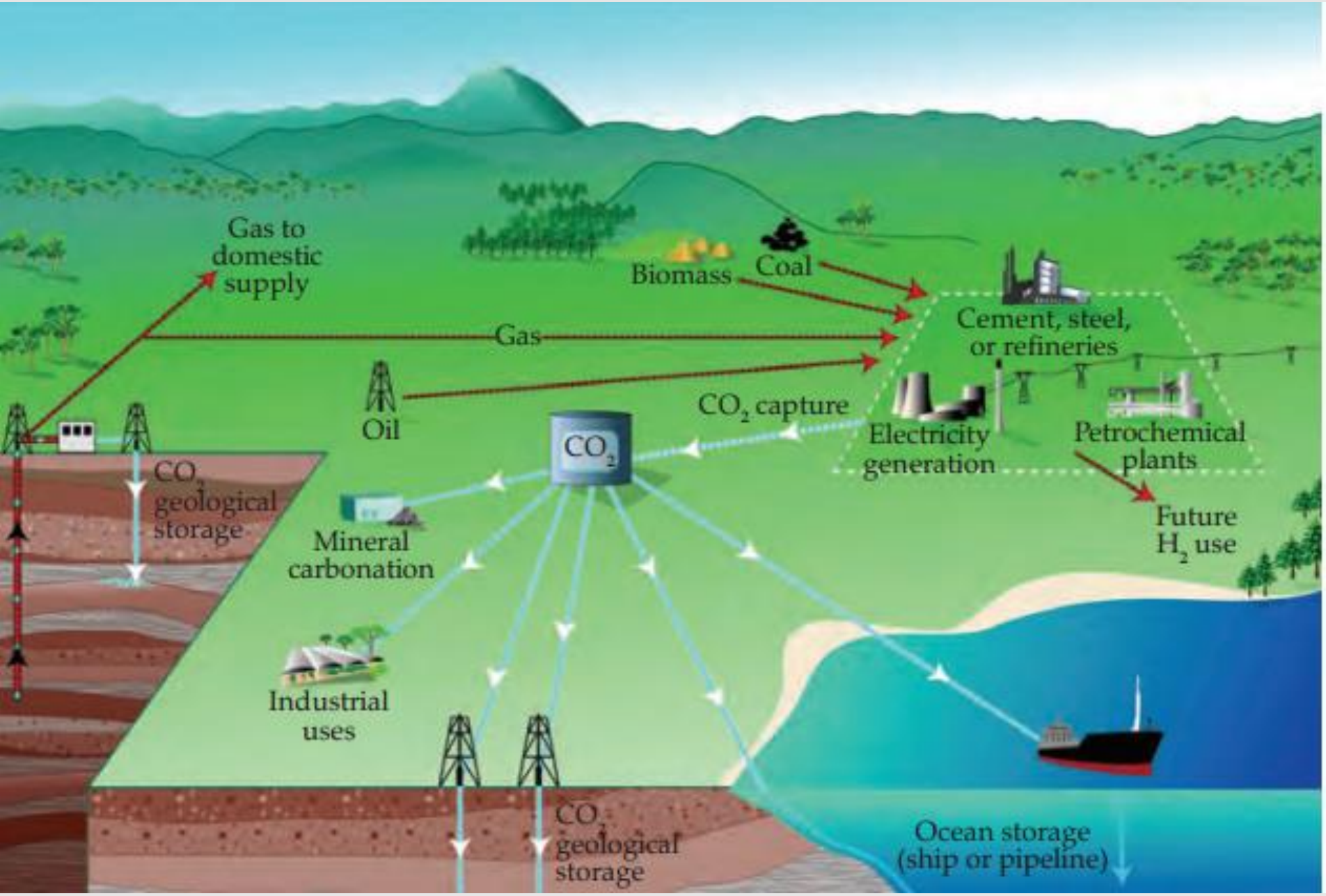
Natural Gas Power Plants

- Low GHG and pollutant emissions
- High fuel efficiency

Problem: natural gas is more expensive than coal, and also not a renewable resource

Carbon Capture and Storage

- Burning hydrocarbon fuel, both coal and natural gas, releases CO_2
- Carbon capture and storage (CCS):
  - Collect CO_2 released
  - Concentrate it
  - Transport it
  - Store it to prevent it from mixing with the atmosphere


Gas to domestic supply
Biomass
Coal
Cement, steel, or refineries
Gas
Oil
CO_2 capture
CO_2
Electricity generation
Petrochemical plants
CO_2 geological storage
Mineral carbonation
Future H_2 use
Industrial uses
CO_2 geological storage
Ocean storage (ship or pipeline)

CO_2 Capture

- Carbon capture almost doubles the construction cost of a power plant
- Adds 50% to the cost of electricity generation

CO_2 Transport

- Power plants not often near areas where CO_2 will be stored
- Transportation using pipelines and tanker ships

CO_2 Transport Problems

- Pipes and storage vessels must be made of carbonic acid resistant alloys. More expensive than steel
- Leaks from transportation will accumulate in depressions (denser than air). CO_2 is colorless and odorless. A leak sink could endanger people
- Transportation as a liquid is more efficient, but more dangerous (higher pressure and low temperature)