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
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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

6CO₂ + water + light → carbohydrate + oxygen

Carbohydrates then fermented into ethanol

Combustion of ethanol creates chemical energy, water, and CO₂

   ethanol + oxygen → 4CO₂ + water + ENERGY

All together: light → 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 $\text{CO}_2$ 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$_2$O
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
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 its 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
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 less sulfur dioxide and nitrogen oxides
• Combined with Carbon Capture and Storage

Not really “clean,” just cleaner.
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 $\text{CO}_2$
- Carbon capture and storage (CCS):
  - Collect $\text{CO}_2$ released
  - Concentrate it
  - Transport it
  - Store it to prevent it from mixing with the atmosphere
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).