Last Time...
Mitigation Strategies: Transportation

Mitigation = Diminishing the severity of the problem
Transportation

14.4% of global emissions currently come from transportation

- 28.2% in high income countries (USA)
- 7% in low-middle income countries (China)

Expected to increase by 25% from 2010-2030, mostly from passenger cars/trucks
Fuel Efficiency of light-duty vehicles

Hard to get people to drive less
Easier to get people to drive more efficiently
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
Since the mid 1980s, vehicles in the US and Europe have gained weight, more powerful engines, and faster acceleration.
The graph shows the production share (%) of different types of vehicles across model years from 1975 to 2005. The categories include cars, crossovers, SUVs, minivans, and pickup trucks. The production share for SUVs and crossovers has shown a significant increase over the years, while cars and minivans have seen a decline.
2014 in the US:

• Sales of pickup trucks, vans, SUVs, and crossovers grew five times faster than cars during 2014, increasing to a production share equal to cars

• Sales of gas-electric hybrid vehicles declined 9%
Fuel efficiency is influenced by:

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– **Use of diesel-powered vehicles**
– Agreements with automobile manufacturers
Diesel-Powered Vehicles

- Diesel fuel is denser than gasoline
- Contains 11% more energy per volume
- Diesel engines more efficient than gasoline engines
  - Operate at higher pressures and temperatures
- Diesel engines are 40% more fuel efficient per volume of fuel than gasoline engines of the same power.
Diesel personal vehicles

Past Problems:

– Noisier

– Generate more vibrations

– More difficult to start

– Emit thick black smoke in their exhaust

– Slower acceleration than gasoline
Diesel personal vehicles

• Technological advances:
  – Computer-controlled electronic ignition
  – Turbocharged direct fuel injection

• In Europe, diesel powered light duty vehicles now account for half of all new vehicles.
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
Nitrous Oxide (N$_2$O)

- Diesel engines emit 20% more than gasoline engines
  - GHG, smog
- Manufacturers use technology to remove N$_2$O
- Volkswagen: trap absorbs N$_2$O. Chemical reaction transforms it to gas and water
• 11 million cars (2009-2015) were intentionally programed to cheat on N₂O emission tests
• Computer detects fuel test is happening, purges N₂O more frequently
• During tests, fuel efficiency = 43 mpg
• Normal driving, fuel efficiency = 55 mpg; N₂O emissions increase by 5 to 40%
Fuel efficiency is influenced by:

– Driving conditions
– Taxes on petroleum and vehicles
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Agreements with Manufacturers

1975, US Congress enacted the Corporate Average Fuel Economy (CAFE) regulations.

- Passenger cars: 18 mpg in 1978 and 27.5 mpg in 1985
- Small trucks: 17.2 mpg in 1979 and 21.6 mpg in 1985
2012: New CAFE Regulations

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

• Central factor for fuel efficiency: passenger occupancy
• Doubling passenger occupancy nearly halves the effect of GHG emissions per distance traveled
Alternative Fuels
Natural Gas

Extracted from oil wells, coal beds, natural gas fields, landfills

$$\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{energy}$$
Compressed Natural Gas

- Low energy content at normal atmospheric pressure
- Compressed. Pressurized to several hundred times normal atmospheric pressure
- ¼ or less of the energy content in gasoline
  - Requires larger storage tanks
  - Slower refueling
Large Storage Tanks
Compressed Natural Gas

“Clean” fuel:

—Produces fewer particulates, non-methyl hydrocarbons, and NO$_x$ than gas or diesel
—Great for cities with smog problems
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 Cell

Expensive

– Catalyst contains platinum, costs over $30 per gram

– Currently a typical fuel cell vehicle contains over $30,000 of platinum.
Dependability

Cars go through a lot!

- Constant vibration
- Rapid temperature changes
- Frequent bombardment with dirt and water
- Neglect/incompetence
• Fuel cell membranes are thin (permeable to gas). Venerable to contamination by dirt or CO.
• Principal reaction generates water. If fuel cell floods, reaction will stop.
• Too little water, reaction will stop
• Water freezes, reaction will stop
• Water boils, reaction will stop
Hydrogen Production

• Over 95% of hydrogen generated today comes from fossil fuels.

• $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$
Electrolysis

- Electrolysis: electric current passes through water and releases hydrogen and water
- Requires energy (electricity)
- Not very efficient
Under Investigation:

– Splitting water at very high temperatures
  • could be done using heat produced from nuclear reactors or solar collectors with modifications

– Biological production
  • Nitrogen fixation releases hydrogen gas
  • Cyanobacteria and green algae in anaerobic conditions release hydrogen
Hydrogen Distribution

Need refueling stations

– Could produce hydrogen in large factories and ship it long distances
– Or could produce locally at small facilities
– Hydrogen gas pipelines
Hydrogen Fuel

• Could be a good long term solution
• Not ready for general adoption
Electric Vehicles

Require batteries to carry electricity
Lead-acid batteries are inexpensive and reliable

Top speed of 40 mph, range of 25 miles, recharge in 8 hours
Tesla Model X, Lithium Ion Battery

$132,000
155 mph
0-60 in under 4 seconds
Range of 260 miles
Recharge in 20 min
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