Chapter 8
Transportation

Lecture #17
HNRS 228
Energy and the Environment
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Overview of Chapter 8

- Transportation
  - Power and Energy
    - Batteries, flywheels, hybrids, hydrogen, alcohol
  - Traffic safety
  - The Automobile
  - Mass Transportation
Remember Transformations of energy

Energy cannot be created or destroyed, only changed from one form to another.

If a person ever says that energy is lost, what really happens is that energy is spent or changed into different forms. It never really is lost.

For example, if you use water energy to create mechanical energy, you might "lose" some energy by creating heat energy in the form of friction.
Some forms of energy are:

- Mechanical
- Heat
- Nuclear
- Electrical
- Light
- Sound
- Chemical
- Electromagnetic

The usefulness of any form of energy depends on our ability to control that energy.

Energy efficiency = useful energy output / total energy output
EXAMPLE

A particular light bulb produces 8 J of thermal energy while producing 2 J of radiant energy, and this is its entire energy output during this time. How energy-efficient is this bulb [as a producer of light]?

(a) 500%.
(b) 400%.
(c) 80%.
(d) 25%.
(e) 20%.

Efficiency = useful output / total input
= 2 / (2+8) = .2 = 20%
Remember Power

Power is the rate at which work is done. Mathematically, it is computed using the following equation:

\[ \text{Power} = \frac{\text{Work}}{\text{time}} \]

Unit: Watt
The power equation suggests that a more powerful engine can do the same amount of work in less time.

Example
Power rating of cars.
40-horsepower engine (1 horsepower = 750 watts) could accelerate the car from 0 mi/hr to 60 mi/hr in 16 seconds.

What about a 160 horsepower-engine????

a 160-horsepower engine could accelerate the same car from 0 mi/hr to 60 mi/hr in 4 seconds.
A 100 W light bulb has an energy efficiency of 5%. It is turned on for one minute. Its total energy output during this minute is

(a) 6000 J.
(b) 5700 J.
(c) 300 J.
(d) impossible to determine because we don't know the voltage.
(e) impossible to determine because we don't know the power.

\[
\text{Power input} = 100 \text{ W}
\]
\[
\text{Power output} = 5\% \times 100 = 5 \text{ W}
\]
\[
\text{Total energy output} = (\text{Power output}) \times (\text{Time})
\]
\[
= (5 \text{ W}) \times (60 \text{ seconds})
\]
\[
= 300 \text{ J}
\]
Remember HEATING:

The Second Law of Thermodynamics states that heat flows from higher temperature body to lower temperature body.
Remember HEAT ENGINES:

Any device that uses thermal energy to do work is called a heat engine

ThermE → Work (any form) + Exhaust

Energy Efficiency = Work output / Energy input
Remember Second Law of Thermodynamics: It is impossible to have a 100% efficient heat engine. The work output will always be less than the energy input.
What is the work output of a heat engine whose thermal energy input is 400 J and whose exhaust is 300 J?

(a) 100 J.
(b) 200 J.
(c) 300 J.
(d) 400 J.
(e) 700 J.

Work output = Energy Input - Exhaust (or waste)
Work output = 400 - 300 = 100 J

Continuing the preceding question, what is the efficiency of this heat engine?

(a) 175%.
(b) 75%.
(c) 50%.
(d) 33%.
(e) 25%.

Efficiency = work output / energy input
= 100 / 400
= 25%
During each cycle of its operation, a certain heat engine does 40 joules of work while exhausting 160 joules of thermal energy to the environment. The energy efficiency of this heat engine is

(a) 20%.
(b) 25%.
(c) 75%.
(d) 80%.
(e) None of the above.

Energy efficiency = Work output / Energy input
= 40 J / (40 J + 160 J)
= 40 J / 200 J
= 20%

Please do not forget that the energy input = work output + exhaust because of the conservation of energy
A 2000 N car travels 50 m along a level road, powered by a drive force of 1000 N. The work done by the drive force is

(a) zero.
(b) 1000 J.
(c) 2000 J.
(d) 50,000 J.
(e) 10,000 J.

\[ W = F \times d = (1000 \text{ N}) \times (50 \text{ m}) = 50,000 \text{ J} \]
Observe in the animation above that each path up to the seat top (representing the summit of the mountain) requires the same amount of work.
Energy Transformation on a Roller Coaster

Height = 72.0 m  Speed = 0.0 m/s
Energy Conservation on an Incline
Remember DEFINITION of POWER
Power is equal work done divided the time it takes to do it.

(Power = Work / time)

What is the UNIT of power?

Power = Work / time
    = Joules / seconds
    = J / s
    = Watt (W)
Example:

What is the power output of a 100 kg person who runs up a 10 m high flight of stairs in 3 s?

[1] \[ W = Fd \]

\[ = mgh \]

\[ = (100 \text{ kg})(10 \text{ m/s}^2)(10 \text{ m}) \]

\[ = 10,000 \text{ J} \]

[2] \[ P = \text{Work} / \text{time} \]

\[ = (9,800 \text{ J}) / (3 \text{ s}) \]

\[ = 3,333 \text{ W} \]
Remember The kilowatt hour

Of what quantity is the kW·h the unit?

1 kW = 1,000 W

1 h = 3,600 s

(1 kW) x (1 h) = (1,000 W) x (3,600 s)

= (1 x 10^3 J/s)(3.6 x 10^3 s)

= 3.6 x 10^6 J/s · s

1 kW · h = 3.6 x 10^6 J
One horsepower = 750 W. (i.e., a unit of power)

What is the minimum number of horsepower required for a car engine that is supposed to haul a 4,400 lb (2000 kg) car (plus trailer) up a 10,000 foot mountain (3,350 m) mountain in 10 minutes?

\[ P = \frac{W}{t} \] (so find \( W \) first)

\[ W = Fd = (mg)(h) \]
\[ = (2000 \text{ kg})(10 \text{ m/s}^2)(3,350 \text{ m}) \]
\[ W = 6.7 \times 10^7 \text{ J} \]

\[ t = (10 \text{ min})(60 \text{ s/min}) \]
\[ t = 600 \text{ s} \]

\[ P = \frac{W}{t} \]
\[ = \frac{6.7 \times 10^7 \text{ J}}{600 \text{ s}} \]
\[ P = 1.1 \times 10^5 \text{ W} \]

\[ \text{HP} = \frac{P \text{ (Watts)}}{750} \]
\[ = \frac{1.1 \times 10^5 \text{ W}}{750} \]
\[ = 146.7 \text{ Horsepower} \]
Energy Use For Transportation

While transportation does use 27% of our energy resources, there are other areas where we can reduce energy use.

For USA see above, compare to only 1 car for every 2 people in Canada.
Transportation Overview

Feet
Bicycles
Rollerblades
Skateboards
Skis (in snowy places)
Transportation Overview

Transportation Energy Use By Type of Vehicle

- Automobiles: 32%
- Light Trucks: 28%
- Other Trucks: 16%
- Aircraft: 9%
- Water: 5%
- Construction & Agriculture: 4%
- Pipelines: 3%
- Trains & Buses: 3%
Transportation in the United States

- Canals for Ships
- Railroad Tracks for Trains
- Roads and Highways for Animals, Automobiles and Buses
  - Private Transit
  - Public Transit
- Runways for Airplanes
Since the most commonly used fuel for transportation is petroleum, we need to find an alternative before “The Party’s Over”

Richard Heinberg, Author, Post-Carbon Institute Fellow, former faculty member of New College of California
FUEL ECONOMY STANDARDS


[1] The relative stringency of Europe’s CO₂-based standards is enhanced under a fuel economy standard because diesel vehicles achieve a boost in fuel economy ratings due to the higher energy content of diesel fuel.

[2] For Canada, the program includes in-use vehicles. The resulting uncertainty of this impact on new vehicle emissions was not quantified.

[3] Shaded area under the California trend line represents the uncertain amount of non-fuel economy related GHG reductions (N₂O, CH₄, HFCs, and upstream emissions related to fuel production) that manufacturers will generate from measures such as low-leak, high efficiency air conditioners, alternative fuel vehicles, and plug-in hybrid electric vehicles.
FUEL ECONOMY SOLUTIONS

- Raise Fuel Economy Standard to be on par with other countries via CAFE Standards
- Offer incentives for buying cars with good fuel economy
- Increase taxes on auto makers who produce cars with low fuel economy
- Raise gas prices
- Enact a credit system as discussed in “Ending The Energy Stalemate”
- Offer more public transit options
- Create more hybrid cars
- Others?
Transportation Policy

Right now, the government funds 80% to 90% of highway construction costs, and only 50% of mass transit costs after a long process.
Long Distance Travel History - Cars

1900: essentially no automobiles

1920s: due to paved roads and mass production of automobiles there was more travel by automobiles than by railroads
The Beginning of the Automobile

- Karl Benz was the first to use a gasoline Otto engine for automobiles in the late 1800’s.
- Automobiles like this were made one at a time and were expensive.

Karl Benz's Velo
The Beginning of the Automobile

- In 1902 Ransom Eli Olds began producing automobiles on a production line.
- Later in the 1910’s Henry Ford perfected the assembly line technique.
How an Automobile Works

- Turns Chemical Potential Energy into Mechanical Work
- Modern engines have many components
- Most modern cars and light trucks use a four-stroke spark-ignition engine
How an Automobile Works

-Four Stroke SI Engine-

1. First Stroke: **Intake**: Air and Fuel Mixture enter the cylinder.
How an Automobile Works

-Four Stroke SI Engine-

2. Second Stroke: Compression: Compresses Air and Fuel Mixture in preparation for Combustion (Combustion also takes place during this stroke).
3. Third Stroke: **Power:**
Pressure from Combustion pushes the piston downwards creating an output force on the crankshaft to create mechanical work.
How an Automobile Works

- Four Stroke SI Engine -

3. Fourth Stroke: 

**Exhaust**: After Combustion, exhaust gas is pushed out of the cylinder to prepare for the next cycle.
Automotive Innovations

Supercharger

Nos Kit

Catalytic Converter
Automotive Innovations...

- Do 1 of 2 things...
  1. Make your car go faster...
     OR
  2. Make your car more efficient...
Automotive Innovations

- **Part 1: The faster part**
- Early automobiles (Like Fords Model T) had about 20 hp...capable of reaching speeds as high as... 45 Mph!!!
Automotive Innovations

• Obviously...people needed to go faster...

• There are several ways to make a car go faster, but two best ways are:

  1. Air and fuel Induction

  2. Get a bigger engine
Automotive Innovations

Air and Fuel Induction

• Increases speed and power by forcing more air (oxygen) at higher pressure into the chamber to allow for greater combustion efficiency and greater work output.

Air and fuel enter here

Combustion occurs here
Automotive Innovations

Air and Fuel Induction

Supercharger: Type of compressor which increases pressure of intake air and is driven off of the vehicles crankshaft
Automotive Innovations

Bigger Engines

• Engines can range anywhere from 4-cylinder to 12-cylinder designs, as well as vary in the arrangement of the cylinders.

• Most Common arrangements are: In-line, V, and Flat
Automotive Innovations

Bigger Engines

• The more cylinders an engine block has, the greater amount of hp it can generate, and the faster the car can go!
Part 2: The efficient part
Early automobiles were not very good on gas (think “Hummer”) and emitted hazardous amounts of $\text{CO}_2$ and $\text{NO}_2$, so it has been a constant battle to increase fuel efficiency and reduce emissions.
Automotive Innovations

Efficiency

- Over the years, better engine design such implementation of computers and fuel injection have led to fuel efficiency as high as 35 mpg for regular combustion engines, and as high as 60 mpg for some hybrid vehicles
Automotive Innovations

Efficiency

• The introduction of catalytic converters has helped to reduce the amount of harmful emissions by breaking down compounds such as NO and CO before they are expelled.
The Automobile Today

• The automobile today is one that incorporates all of the innovations and advancements that are available

• Some (hybrids) even use a dual-fuel engine, which is the greatest achievement in automotive research thus far
Long Distance Travel - Trains

-1920s saw a switch from steam powered locomotives to diesel and electric

-The hybrid set-up eliminates the need for a mechanical transmission

-A fully loaded rail car is 15 times more energy efficient than the average automobile

-Based on the amount of energy required to move one passenger one km by train in the U.S.
  -a commercial airplane uses three times the amount of energy
  -an automobile with a single occupant uses six times that amount of energy
Distant Future Prospective - Trains

-Magnetic levitation train (maglev)
-Very expensive to build and operate
-Shanghai maglev at 20,000 passengers a day, $6/passenger will take around 30 years to pay off just the capital costs, not including track maintenance, salaries, and electricity
-Still being studied to be built between large cities in California and Las Vegas
- http://www.magneticglide.com
-THEORY: create in vacuum tunnels
- Tunnels deep enough to pass under oceans train could top at around 5000 mph, making the trip between London and New York only 54 minutes)
Shanghai Maglev
Long Distance Travel - Airplanes

- 1950s: airplane travel for commercial purposes began
- 1970s: fares become cheaper and more affordable for the average traveler
- Consumed more fuel per passenger-mile
- Consumption per passenger-hour was many times higher than the automobile
- Today, the typical airline passenger experiences a mpg roughly equivalent to that of an automobile driver
- Causes noise pollution
- Kerosene
- Only transportation form not significantly regulated to reduce environmental impact
- Currently only small realistic improvements can be made—each saving 1-3% fuel
Mass Transportation

- 98% of urban area travel is by car
- Mass-transit users typically spend $200-$2000 per year for travel, considerably less than car owners
- The problem is construction of mass-transit systems requires a large energy investment

<table>
<thead>
<tr>
<th>Mode of Travel</th>
<th>BTUs per passenger mile</th>
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<tbody>
<tr>
<td>automobiles</td>
<td>5,000</td>
</tr>
<tr>
<td>19 people on a train car</td>
<td>2,300</td>
</tr>
<tr>
<td>19 people on a bus</td>
<td>1,000</td>
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Light Rail Transit (LRT)

- Less massive than other rail systems (street cars and trolleys)

- Trolley is an electric streetcar that draws power from a live suspended wire

- 1998: state legislature in Minnesota approved $40 million towards a light rail project in Minneapolis
Trolleybus

- Powered by two overhead electric wires, from which it draws electricity using 2 trolley poles
- Rubber tires have better roadway adhesion than streetcar steel wheels on steel rails
- Regenerative breaking
- Dilemma: difficult to compete with efficiencies of light rail but are very flexible in uses and have lower start up costs than conventional buses
- Buses are beginning to run more and more on biodiesel and natural gas

- Ballard Power Systems of Vancouver has developed and demonstrated the world’s first hydrogen fuel cell-powered city transit bus

- Compressed natural gas vs. hybrid buses vs. diesel buses
Hydrogen Fuel Cells

- Hydrogen is most abundant element in universe, easy to produce
- Converts hydrogen and oxygen to water, heat, and electricity
- Used in “stacks” of 100+
Hydrogen Fuel Cells

- Less pollutants and emissions because not a combustion reaction

- Safety is uncertain - H₂ is highly flammable, hazardous to ingest

- Challenges include: cost; durability; size; air, thermal, and water management; heat recovery systems
How It Works

• \( H_2 \) fed thru anode and loses electrons
• \( O_2 \) fed thru cathode, gains electrons
• Hydrogen atoms split into protons and electrons, protons pass thru membrane to cathode
• Electrons circulate from anode to cathode via current in flow plates
• \( p^+ \) and \( e^- \) reunited w/ \( O_2 \) to create water in cathode, heat, and electrical current
Electric Vehicles

- Energy from direct connection to land-based generation plant

- Chemical energy stored on board

- Propelled by electric motor

- Generator converts fuel and repowers battery

Toyota Rav-4 EV: over 300 operating in US today, collectively traveled over 1 million miles, reach 80 mph
Pros

- Saves money (gas)
- Uses recyclable materials
- 90% conversion efficiency
- Better control
- Regenerative breaking
- 90% cleaner than gas-powered cars
- Eliminate smog checks, tune ups, oil changes, gears, torque converters, differentials
Cons

-Fragile

-Sensitive to contamination

-Require external reactants such as hydrogen

-Batteries require unstable chemicals and must be recycled

The Nissan Altra
Hybrid Cars

-Mix between gasoline-powered car and an electric car

-Rising fuel costs and better designs are making hybrids more and more competitive

-Incremental cost more than standard equivalent is about $2,000-$3,000

-U.S. Energy Policy Act of 2005 provided a tax credit of up to $3,400 for owners of hybrid cars to help make hybrids more competitive
Hybrids

- Hybrids have smaller, more efficient gas engines.
- Gas engines on conventional cars are sized for peak power requirement which is used by drivers less than 1% of the time.
- Regenerative breaking—hybrid cars capture some of the energy usually lost through heat when a car breaks and stores it in the battery.
Hybrids

- The gasoline engine can be turned off at stop signs, doesn’t need to be on at all times.

- Key components of the car like the air-conditioning can run off the battery

- The best hybrids have made fuel economy gains of 30-80% while maintaining, and sometimes, increasing horsepower with no decline in weight or size.
Models of Hybrids

- 2 most widely owned hybrids in the U.S. are the Honda Insight and Toyota Prius.

- Toyota Motor Corp. wants hybrids to make up 25 percent of its U.S. sales by early in the next decade.

<table>
<thead>
<tr>
<th>Model</th>
<th>MPG</th>
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<tbody>
<tr>
<td>Honda Insight</td>
<td>56</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>55</td>
</tr>
<tr>
<td>Honda Civic Hybrid</td>
<td>48</td>
</tr>
<tr>
<td>Ford Escape Hybrid</td>
<td>34</td>
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</tbody>
</table>
Numerous Transportation Suggestions

- Promote use of hybrids
- Research safer and more efficient ways to implement new technology in passenger vehicles
- Encourage use of mass transit in urban areas through government funding and community planning
- Discourage flights for travel <200 miles
- Close the 30-40% gap between government subsidies of highways and mass transit
- Stronger standards