Physics 105  
Fall 2010  
Physics for Decision Makers:  
The Global Energy Crisis

Lecture 15 Pollution and Transportation

Reading  
Chapter 6 - Wolfson
Real World: Cost benefit analysis

- How much is a human life worth?
  - Willingness-to-pay model
    - How much will you pay to do ...
    - Depends on the question...

<table>
<thead>
<tr>
<th>Risk</th>
<th>Days of life expectancy lost by taking the risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riding in cars (10,000 miles/yr)</td>
<td>200</td>
</tr>
<tr>
<td>Not using seat belts</td>
<td>50</td>
</tr>
<tr>
<td>Driving small cars</td>
<td>50</td>
</tr>
<tr>
<td>Smoking one pack/day</td>
<td>2,200</td>
</tr>
<tr>
<td>Overeating by 200 calories/day</td>
<td>400</td>
</tr>
<tr>
<td>Being one pound overweight</td>
<td>30</td>
</tr>
<tr>
<td>One diet drink/day</td>
<td>2.5</td>
</tr>
<tr>
<td>Fire</td>
<td>30</td>
</tr>
<tr>
<td>Drowning</td>
<td>40</td>
</tr>
<tr>
<td>Being poisoned</td>
<td>20</td>
</tr>
<tr>
<td>Choking on food</td>
<td>12</td>
</tr>
<tr>
<td>Being asphyxiated</td>
<td>7</td>
</tr>
<tr>
<td>Struck by falling object</td>
<td>6</td>
</tr>
<tr>
<td>Electrocution</td>
<td>6</td>
</tr>
<tr>
<td>Lightning</td>
<td>6</td>
</tr>
<tr>
<td>Being bitten by an animal or insect</td>
<td>0.3</td>
</tr>
<tr>
<td>Being murdered</td>
<td>90</td>
</tr>
<tr>
<td>Consuming nuclear electricity (if it were all nuclear)</td>
<td>0.05</td>
</tr>
<tr>
<td>Consuming electricity from coal</td>
<td>15</td>
</tr>
<tr>
<td>Air pollution (all sources)</td>
<td>25</td>
</tr>
<tr>
<td>Being male rather than female</td>
<td>2,700</td>
</tr>
<tr>
<td>Remaining unmarried</td>
<td>1,800</td>
</tr>
<tr>
<td>Working as a coal miner</td>
<td>1,500</td>
</tr>
</tbody>
</table>
How much will you pay for 10 extra years of life?

1. $100  
2. $1,000  
3. $10,000  
4. $100,000  
5. $1,000,000  
6. $10,000,000

How much will you pay to reduce risk of death by 10%?

1. $100  
2. $1,000  
3. $10,000  
4. $100,000  
5. $1,000,000  
6. $10,000,000
Insurance model – earning potential

- Government regulations
  - Human life is worth 1-5 M$
  - Depends how old you are…
  - Depends on your level of education…

How much is an animal’s life worth?

How much is a natural feature worth?

What is the top cause of death listed below…

1. Cancer
2. Drowning
3. Falling
4. Firearm assault
5. Heart disease
6. Motor vehicle accident
7. Pedestrian accident
8. Stroke
9. Suicide
What is the second leading cause of death listed below...

1. Cancer
2. Drowning
3. Falling
4. Firearm assault
5. Heart disease
6. Motor vehicle accident
7. Pedestrian accident
8. Stroke
9. Suicide

What is the third top cause of death listed below...

1. Cancer
2. Drowning
3. Falling
4. Firearm assault
5. Heart disease
6. Motor vehicle accident
7. Pedestrian accident
8. Stroke
9. Suicide
Death continued….
Fossil Fuel Pollutants

- Carbon Dioxide $\text{CO}_2$
- Carbon Monoxide CO
- Hydrocarbons
- Nitrous Oxides $\text{NO}_x$
- Particulates
- Sulfur Dioxide $\text{SO}_2$
- Volatile Organic Compounds (VOC)
- Ozone $\text{O}_3$

American Lung Association estimates 27,000 to 58,000 deaths per year from air pollution
Fossil Fuel Pollutants

- Carbon Dioxide \( \text{CO}_2 \)
- Carbon Monoxide \( \text{CO} \): bad for people with heart disease
  - contributes to smog
  - current standard: 9 ppm
  - lethal: 800 ppm

- Hydrocarbons
- Nitrous Oxides \( \text{NO}_x \)
- Particulates
- Sulfur Dioxide \( \text{SO}_2 \)
- Volatile Organic Compounds (VOC)
- Ozone \( \text{O}_3 \)

American Lung Association estimates 27,000 to 58,000 deaths per year from air pollution

One old gas powered lawn mower running for an hour emits as much pollution as driving 650 miles in a 1992 model automobile

American Lung Association estimates 27,000 to 58,000 deaths per year from air pollution
Fossil Fuel Pollutants

- Carbon Dioxide $\text{CO}_2$
- Carbon Monoxide CO:
- Hydrocarbons
- Nitrogen Oxides $\text{NO}_x$
  - main contributor to smog from vehicles, electricity generation
- Particulates
- Sulfur Dioxide $\text{SO}_2$
- Volatile Organic Compounds (VOC)
- Ozone $\text{O}_3$

- American Lung Association estimates 27,000 to 58,000 deaths per year from air pollution

The Car Pollution Problem

- Low Combustion temperatures leave fuel unburned - Hydrocarbon emissions
- High Combustion temps - produce Nitrous Oxides
- Solution = Catalytic converter = precious metals = large area
  - Reduction of nitrogen oxides to nitrogen and oxygen:
    \[ x\text{O}_2 + N_2 \]
  - Oxidation of carbon monoxide to carbon dioxide:
    \[ 2\text{CO} + O_2 \rightarrow 2\text{CO}_2 \]
  - Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water:
    \[ C_{xH_{2x+2}} + [(3x+1)/2]O_2 \rightarrow x\text{CO}_2 + (x+1)\text{H}_2\text{O} \]
- Need computer control
- Need unleaded gasoline
Fossil Fuel Pollutants

- Carbon Dioxide $CO_2$
- Carbon Monoxide $CO$:
- Hydrocarbons
- Nitrogen Oxides $NO_x$
- Particulates ($< 10^{-5}$ m) bad for lungs

- Sulfur Dioxide $SO_2$
- Volatile Organic Compounds (VOC)
- Ozone $O_3$

- American Lung Association estimates 27,000 to 58,000 deaths per year from air pollution
Acid Rain

\[
\text{SO}_2 + \text{O}_3 \rightarrow \text{SO}_3 + \text{O}_2
\]
\[
\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 \quad \text{(sulfuric acid)}
\]

- Typical rain: pH of about 5.6 (dissolved CO₂)
  - In east rain pH 4.5 (vinegar = 2.9)
    - Recorded as low as 2.4!

- Kills forests/aquatic life
- Depends on local geology
  - Upstate NY Adirondacks especially vulnerable
**Acid Rain**

**Czech Republic**

**Maine**

**Krakow, Poland**

---

**Smokestacks**

- Kennecott smokestack (Utah)
- Tallest structure west of the Mississippi
- 4th tallest smokestack in world
- Built in '74 for copper smelting
- Emitted 48,000 lbs./hr SO$_2$
- Refitted in '95 to recover gases
- Now emits a few lbs./hr
- Sells ~ million tons of Sulfuric acid each year!
Smokestacks

- Kennecott smokestack (Utah)
- **370.4 meter (1,215 ft) high**
- Tallest structure west of the Mississippi
- 4th tallest smokestack in world
- Built in '74 for copper smelting
- Emitted 48,000 lbs./hr SO₂
- Refitted in '95 to recover gases
- Now emits a few lbs./hr
- Sells ~ million tons of Sulfuric acid each year!

Acid Rain

[Map showing hydrogen ion concentration as pH from measurements made at the field laboratories, 1999]
Cap and Trade

- Government sets total Cap on emissions
- Distributes permits (e.g. one ton) to companies (“right to pollute”) usually based on existing pollution rates
- Companies buy and sell permits
- If Company A can reduce pollution for low cost, it is advantageous to do that and sell permits to company B
- Advantages: sets total rates, but allows flexibility in achieving the goal

- 1990 Clean Air Act: cap-and-trade for SO$_2$

Cap and Trade SO$_2$

- 100% compliance
- Emissions 20% below limit
- Value of permits about 20% of expected
- Total costs 3-10X smaller than predicted
Does the fact we managed $\text{SO}_2$ mean we can do the same for $\text{CO}_2$?

1. Yes
2. No
3. Don’t know

SMOG

- Photochemical smog
  - Sunlight + $\text{NO}_x$ + VOCs = smog
  - Particulates + ground level ozone
  - Irritation of lungs
  - Aggravation of asthma
  - Reduced lung function
Olympics – Beijing

- 16 of the world’s 20 most polluted cities are in China

2006 test - ban 800,000 cars for 3 days (30% of traffic)
amount of NO\textsubscript{x} dropped by 40%

Transportation
Transportation - 28% of US energy

Energy usage in the U.S.
Distribution of U.S. energy usage in 2006, grouped by end-use sector (transportation, buildings and industry). Annual consumption for 2007 was 101.6 Quads (101.5 BTU).

Gas Prices Near Record Higns in Northern California, says AAA; San Francisco, Eureka and San Jose Break or Equal Prior Price Records

Gasoline prices rose in recent weeks, with some Northern California cities breaking or equaling all-time highs set last spring, AAA reported today in a special survey of select cities.

“For the second time this year, many consumers are paying record high prices at the gas pump,” said Paul Kreman, spokesman for AAA of Northern California. “Refinery trouble has left West Coast gasoline supplies tight, while the summer driving season and strong economy have kept demand strong.”

Analysts say gasoline prices this year have been among the highest ever.

“The higher retail prices are the result of tight supplies and high demand,” said Kreman. “And this time, the tightness is widespread.”

In Northern California, local

- Chico, $1.64 (up 7 cents and a penny high set in April)
- Eureka, $1.81 (up 6 cents and an all-time high)
- Fresno, $1.60 (up 14 cents and 2 cents below the city’s all-time high set in April)
- Monterey, $1.66 (up a nickel and 5 cents high set in April)
- Oakland, $1.64 (up 6 cents and 8 cents high set in April)
- Sacramento, $1.61 (up a dime and 6 cents high set in April)
Gas prices hit record high for tenth straight day
But analysts say relief may come when summer driving season winds down

Gas prices continue to rise with oil prices. The average price for a gallon of regular unleaded in the San Francisco Bay Area is about $2.60 with many stations selling at over $3.

By John W. Schoen
Senior producer
MSNBC
Updated 11:06 p.m. ET, Thursday, Aug. 10, 2006

Gas prices hit all-time high
Motorist group survey says nationwide pump prices reach a fresh record as crude keeps cruising; California and Hawaii pay the most.

Last Updated: March 12, 2008 8:30 AM EDT

NEW YORK (CNNMoney.com) — The price of gasoline rose to an all-time high Wednesday, according to the widely followed survey conducted for the motorist group AAA.

The average price of regular rose overnight to $3.246 a gallon, according to AAA's Web site. That's nearly 2 cents higher than the previous record of $3.227, which was first set last May and matched Tuesday.

Regular was $2.953 on average at this time last month and $2.543 a year ago.

Hawaii and California fetched the highest prices at the pump, as consumers had to shell out an average of $3.61 and $3.59 respectively for a gallon of gas. But New Jersey and Missouri drivers found gas prices to be nearly 60 cents a gallon cheaper, paying $3.02 and $3.04 respectively.

When adjusted for inflation, gas prices are still below their peak. The record on that basis was $3.405 and set in March 1981, according to the Energy Information Administration.
Record gas prices: 21 straight days

Average at the pump tops $3.94 a gallon, with 11 states and D.C. above $4. But crude futures are on the downturn.

By Catherine Clifford, CNNMoney.com staff writer
Last Updated: May 28, 2009: 7:05 AM EDT

NEW YORK (CNNMoney.com) — Retail gas prices hit record highs for the 21st day in a row, motorist group AAA’s Web site showed Wednesday.

The nationwide average for a gallon of regular unleaded rose to $3.944, up 0.7 cent from $3.937 Tuesday.

Meanwhile, crude oil prices retreated into the $126-a-barrel range Wednesday after dropping almost $5 a barrel from intraday highs to settle at $128.85 on Tuesday.

2009 prices of Gasoline

Page 38
US gas prices

Weekly U.S. Retail Gasoline Prices, Regular Grade

Source: Energy Information Administration

Oil Prices, 1994-March 2008
(NYMEX Light Sweet/WTI)
Is gasoline significantly more expensive than in the 1950’s in real dollars?

1. Yes
2. No
### Price per Gallon

<table>
<thead>
<tr>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>$2.51</td>
</tr>
<tr>
<td>Milk</td>
<td>$2.99</td>
</tr>
<tr>
<td>Coca-Cola</td>
<td>$2.84</td>
</tr>
<tr>
<td>Gatorade</td>
<td>$5.20</td>
</tr>
<tr>
<td>Evian Water</td>
<td>$5.60</td>
</tr>
<tr>
<td>Orange Juice</td>
<td>$6.64</td>
</tr>
<tr>
<td>Crisco Oil</td>
<td>$7.44</td>
</tr>
<tr>
<td>Snapple</td>
<td>$10.32</td>
</tr>
<tr>
<td>Olive Oil</td>
<td>$51.04</td>
</tr>
<tr>
<td>Jack Daniels</td>
<td>$101.12</td>
</tr>
</tbody>
</table>

### Energy Usage in Transportation

- Newton’s Laws:
  1) body in motion stays in motion
  2) \( F = ma \)
- You are driving at constant 60 mph
- Q: what is \( a \)?
  - A: 0
- Q: then why does the engine need to run?
  - A: FRICTION
    - Microscopically: weak bonds are made and broken converts KE into thermal energy
Energy Usage in Transportation

Friction
Rolling, Sliding, Static

- In a car: engine; tires
  - Sliding or rolling friction:
  - \( F = \mu m g \) : coeff. of friction \( \times \) weight
  - If \( ma = f = \mu mg \) then the max \( a = \mu g \)
- \( \mu_{\text{slide}} \ll \mu_{\text{rolling}} \)

Aerodynamic Drag

Air is a fluid
- must expend energy to move
air around vehicle

\[
F = \frac{1}{2} \rho C_d A v^2
\]

\( \rho \) is fluid density; \( C_d \) is coeff. of drag; \( A \) is area;

\( C_d = 1.17 \) for flat plate, \( 0.3 \) for good aero car, \( 0.9 \) for bicyclist