Energy Systems Overview
Topics

• Energy sources & consumption
  ▪ U.S. & worldwide

• Basic economics
  ▪ How do the various forms compare in cost?

• General concepts to be used throughout course
  ▪ Definition of efficiencies
Growth of U.S. Energy Consumption

Energy Markets Are Interconnected

Source: LLNL 2014. Data is based on DOE/IA-00135 (2014-08), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (e.g., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 85% for the residential and commercial sectors, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-Mi-416277

World Energy Consumption


![Figure 1. World energy consumption, 1990-2040 (quadrillion Btu)](image)

OECD - Organization for Economic Cooperation and Development
Members as of Sept 2012: United States, Canada, Mexico, Austria, Belgium, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, Japan, South Korea, Australia, and New Zealand.

Source:
http://www.eia.gov/forecasts/ieo/
World Energy Consumption by Source

- Growth will not be uniform among all energy sources
  - Renewable & nuclear power projected to be fastest-growing energy sources, increasing by 2.5% per year
  - Natural gas fastest growing fossil fuel, increasing by 1.7% per year
  - Coal grows faster than petroleum because of China’s increasing consumption

Source:
http://www.eia.gov/forecasts/ieo/
World Coal Consumption

- Coal expected to remain 2nd largest energy source worldwide. World coal consumption to rise at 1.3% per year until 2030 & will start to decline after
  - Near-term expansion of coal consumption from significant increases in China, India, and other non-OECD countries.
  - Decline due to GHG concerns and displacement by natural gas
- Global coal production concentrated among four countries
  - China
  - United States
  - India
  - Australia

Source:
http://www.eia.gov/forecasts/ieo/
Petroleum & Natural Gas

- Consumption influenced by production & cost of fuels

Figure 33. World oil prices in three cases, 1990-2040 (2011 dollars per barrel, Brent crude oil)

Figure 34. World liquids consumption in three oil price cases, 2010 and 2040 (million barrels per day)

Figure 40. World natural gas consumption, 2010-2040 (trillion cubic feet)
Shale Oil & Gas

- Shale oil and gas have the potential to dramatically alter world energy markets

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Source: Supplemental presentation is support of
http://www.eia.gov/forecasts/ieo/
Electricity from Nuclear & Renewables

- World electricity generation expected to grow 93% from 2010 to 2030
  - Renewables fastest growing segment, 80% in wind & hydroelectric

  **Figure 83. World net electricity generation by fuel, 2010-2040 (trillion kilowatthours)**

- Fukushima Daiichi disaster could have long-term implications for nuclear power
  - China halted approval processes for all new reactors until the country’s nuclear regulator completed its safety review
  - Germany & Switzerland announced plans to phase out or shut down their operating reactors by 2022 and 2034, respectively

  **Figure 84. World net electricity generation from nuclear power by region, 2010-2040 (trillion kilowatthours)**
U.S. Residential Energy Consumption

Total energy use in homes

1976
- Appliances and Electronics: 1.77 (17%)
- Space Heating: 0.96 (96%)
- Water Heating: 1.53 (14%)
- Air Conditioning: 0.32 (3%)
- Total: 10.58

2006
- Appliances and Electronics: 3.25 (31%)
- Space Heating: 4.30 (41%)
- Water Heating: 2.12 (20%)
- Air Conditioning: 0.08 (1%)
- Total: 13.55


http://www.eia.gov/consumption/residential/reports/electronics.cfm

Number of electronic devices by household, 2009

Source: U.S. Energy Information Administration, 2006 Residential Energy Consumption Survey
Historical U.S. Vehicles per 1000 People
Symbols 1998 vehicles for other parts of the world

Sources:
U.S. data
Other countries/regions
# Energy & Oil Prices

## Energy & Oil Prices

### CRUDE OIL & NATURAL GAS

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Units</th>
<th>Price</th>
<th>Change</th>
<th>% Change</th>
<th>Contract</th>
<th>Time (ET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil (WTI)</td>
<td>USD/bbl</td>
<td>52.69</td>
<td>0.00</td>
<td>0.00%</td>
<td>Feb 15</td>
<td>17:14:37</td>
</tr>
<tr>
<td>Crude Oil (Brent)</td>
<td>USD/bbl</td>
<td>56.42</td>
<td>-0.91</td>
<td>-1.59%</td>
<td>Feb 15</td>
<td>17:55:21</td>
</tr>
<tr>
<td>TOCOM Crude Oil</td>
<td>JPY/kl</td>
<td>-44,360.00</td>
<td>-%</td>
<td>Jun 15</td>
<td>12/30/2014</td>
<td></td>
</tr>
<tr>
<td>NYMEX Natural Gas</td>
<td>USD/MMBtu</td>
<td>3.00</td>
<td>+0.11</td>
<td>+3.05%</td>
<td>Feb 15</td>
<td>17:14:56</td>
</tr>
</tbody>
</table>

### Refined Products

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Units</th>
<th>Price</th>
<th>Change</th>
<th>% Change</th>
<th>Contract</th>
<th>Time (ET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBOB Gasoline</td>
<td>USD/gal</td>
<td>143.34</td>
<td>0.00</td>
<td>0.00%</td>
<td>Feb 15</td>
<td>17:14:58</td>
</tr>
<tr>
<td>NYMEX Heating Oil</td>
<td>USD/gal</td>
<td>179.57</td>
<td>0.00</td>
<td>0.00%</td>
<td>Feb 15</td>
<td>17:13:20</td>
</tr>
<tr>
<td>ICE Gasoil</td>
<td>USD/MT</td>
<td>527.25</td>
<td>+6.00</td>
<td>+1.15%</td>
<td>Feb 15</td>
<td>17:17:02</td>
</tr>
<tr>
<td>TOCOM Kerosene</td>
<td>JPY/kl</td>
<td>56,470.00</td>
<td>-1,740.00</td>
<td>-2.99%</td>
<td>Jul 15</td>
<td>01:14:57</td>
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</table>

### Emissions

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Units</th>
<th>Price</th>
<th>Change</th>
<th>% Change</th>
<th>Contract</th>
<th>Time (ET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE ECX Emissions</td>
<td>EUR/MT</td>
<td>7.09</td>
<td>-0.25</td>
<td>-3.41%</td>
<td>Dec 15</td>
<td>01/02/2015</td>
</tr>
</tbody>
</table>

Gasoline & Diesel Retail vs. Commodity Prices

**Gasoline Retail Cost Contributions**

<table>
<thead>
<tr>
<th></th>
<th>Per Gallon</th>
<th>Per Barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Retail Price</strong></td>
<td>$2.91</td>
<td>$122.22</td>
</tr>
<tr>
<td><strong>Taxes</strong></td>
<td>15%</td>
<td>$0.44</td>
</tr>
<tr>
<td><strong>Distribution &amp; Marketing</strong></td>
<td>17%</td>
<td>$0.49</td>
</tr>
<tr>
<td><strong>Refining</strong></td>
<td>6%</td>
<td>$0.17</td>
</tr>
<tr>
<td><strong>Crude Oil</strong></td>
<td>62%</td>
<td>$1.80</td>
</tr>
</tbody>
</table>

**Refinery Costs / Commodity Price** $1.98 $83.11

**Diesel Retail Cost Contributions**

<table>
<thead>
<tr>
<th></th>
<th>Per Gallon</th>
<th>Per Barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Retail Price</strong></td>
<td>$3.65</td>
<td>$153.30</td>
</tr>
<tr>
<td><strong>Taxes</strong></td>
<td>14%</td>
<td>$0.51</td>
</tr>
<tr>
<td><strong>Distribution &amp; Marketing</strong></td>
<td>24%</td>
<td>$0.88</td>
</tr>
<tr>
<td><strong>Refining</strong></td>
<td>13%</td>
<td>$0.47</td>
</tr>
<tr>
<td><strong>Crude Oil</strong></td>
<td>50%</td>
<td>$1.83</td>
</tr>
</tbody>
</table>

**Refinery Costs / Commodity Price** $2.30 $96.58

Source: [http://www.eia.gov/petroleum/gasdiesel/](http://www.eia.gov/petroleum/gasdiesel/)
## Coal Prices

### Average weekly coal commodity spot prices
(dollars per short ton)

<table>
<thead>
<tr>
<th>Week Ended</th>
<th>Central Appalachia 12,500 Btu, 1.2 SO₂</th>
<th>Northern Appalachia 13,000 Btu, &lt;3.0 SO₂</th>
<th>Illinois Basin 11,800 Btu, 5.0 SO₂</th>
<th>Powder River Basin 8,800 Btu, 0.8 SO₂</th>
<th>Uinta Basin 11,700 Btu, 0.8 SO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>21-Nov-14</td>
<td>$56.10</td>
<td>$65.30</td>
<td>$44.55</td>
<td>$11.55</td>
<td>$37.75</td>
</tr>
<tr>
<td>28-Nov-14</td>
<td>$56.10</td>
<td>$65.30</td>
<td>$44.55</td>
<td>$11.55</td>
<td>$37.75</td>
</tr>
<tr>
<td>5-Dec-14</td>
<td>$56.30</td>
<td>$63.55</td>
<td>$44.70</td>
<td>$11.55</td>
<td>$37.75</td>
</tr>
<tr>
<td>12-Dec-14</td>
<td>$56.10</td>
<td>$65.30</td>
<td>$44.55</td>
<td>$11.55</td>
<td>$37.75</td>
</tr>
<tr>
<td>19-Dec-14</td>
<td>$56.10</td>
<td>$65.30</td>
<td>$44.55</td>
<td>$11.55</td>
<td>$37.75</td>
</tr>
</tbody>
</table>

**Source:** With permission, SNL Energy

**Note:** Coal prices shown are for a relatively high-Btu coal selected in each region, for delivery in the "prompt quarter." The prompt quarter is the quarter following the current quarter. For example, from January through March, the 2nd quarter is the prompt quarter. Starting on April 1, July through September define the prompt quarter. In the column headings, the Btu value is per pound and the SO₂ value is percent per pound. The historical data file of spot prices is proprietary and cannot be released by EIA; see SNL Energy.

[http://www.eia.gov/coal/news_markets/]
No Such Thing as a “Global” Gas Price

There has always been a major disparity between regional prices.

In 2012, Henry Hub in the United States averaged $2.76/MMBtu; the price in Japan was $16.75/MMBtu. European pricing was somewhere in the middle: $9.46/MMBtu in the UK to $11.03/MMBtu in Germany.

http://www.slideshare.net/enalytica/gas-market-outlook-lng-business-fundamentals
Price Changes With Time

Natural Gas & WTI Spot Prices

Updated January 2, 2015
Sources: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm & http://www.eia.gov/dnav/ng/ng_pri_fut_s1_d.htm
How do energy prices compare?

<table>
<thead>
<tr>
<th></th>
<th>Given Price</th>
<th>Heating Value</th>
<th>Price [$/MWh]</th>
<th>Price [$/MMBtu]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBOB Gasoline - wholesale</td>
<td>2.7906</td>
<td>$ per gallon</td>
<td>115,000 Btu/gal</td>
<td>LHV 82.80</td>
</tr>
<tr>
<td>Heating Oil - wholesale</td>
<td>2.8373</td>
<td>$ per gallon</td>
<td>130,500 Btu/gal</td>
<td>LHV 74.19</td>
</tr>
<tr>
<td>WTI Crude Oil</td>
<td>93.27</td>
<td>$ per bbl</td>
<td>5.8 MMBtu/bbl</td>
<td>HHV 54.87</td>
</tr>
<tr>
<td>Brent Crude Oil</td>
<td>102.06</td>
<td>$ per bbl</td>
<td>5.8 MMBtu/bbl</td>
<td>HHV 60.04</td>
</tr>
<tr>
<td>Ethanol - rack</td>
<td>2.71</td>
<td>$ per gallon</td>
<td>75,700 Btu/gal</td>
<td>LHV 122.15</td>
</tr>
<tr>
<td>Natural Gas - Henry Hub</td>
<td>3.97</td>
<td>$ per MMBtu</td>
<td></td>
<td>HHV 13.55</td>
</tr>
<tr>
<td>Powder River Basin Coal (low sulfur)</td>
<td>10.55</td>
<td>$ per ton</td>
<td>8,800 Btu/lb</td>
<td>HHV 2.05</td>
</tr>
<tr>
<td>Illinois No. 6 Coal (high sulfur)</td>
<td>45.15</td>
<td>$ per ton</td>
<td>11,800 Btu/lb</td>
<td>HHV 6.53</td>
</tr>
<tr>
<td>Electricity (Residential, winter season)</td>
<td>4.604</td>
<td>¢ per kWh</td>
<td></td>
<td>46.04</td>
</tr>
<tr>
<td>Electricity Commercial, winter season)</td>
<td>3.920</td>
<td>¢ per kWh</td>
<td></td>
<td>39.20</td>
</tr>
<tr>
<td>Electricity (Ave consumer, early summe)</td>
<td>11.4</td>
<td>¢ per kWh</td>
<td></td>
<td>114.00</td>
</tr>
<tr>
<td>Hydrogen dispensed cost</td>
<td>4.03</td>
<td>$ per kg</td>
<td>324.2 Btu/scf</td>
<td>HHV 102.20</td>
</tr>
</tbody>
</table>

References:
Gasoline, Heating Oil, & Crude Oil from Blomberg (6/3/2013)
http://www.bloomberg.com/energy/

Ethanol price from NYMEX (6/3/2013)
http://quotes.ino.com/exchanges/category.html?c=energy

Coal from US EIA Coal News & Markets (week ending 5/31/13).
http://www.eia.gov/coal/news_markets/

Xcel Energy electric tariff book (as of 12/28/2011)

Hydrogen cost from DOE report, DOE Hydrogen & Fuel Cells Program Record, Sept. 24, 2012
General Concepts for Class

• ROM (Rough order of magnitude) vs. precise calculations
  ▪ Is it on the order of 1, 10, 100, 1000, or something else?

• Unit conversions!
  ▪ Example: relationship of kJ/sec to kW; kJ/hr to MW

• Physical properties to further relate quantities
  ▪ Example: what property is needed to convert kg CO₂/kg fuel to kg/L?

• Production of products & by-products from stoichiometry
  ▪ Example: kg CO₂ produced per kg of fuel
  ▪ Example: kg CO₂ produced per mile driven

• Efficiency as relationship between available energy (potential) vs. energy transferred
  ▪ Example: kW electricity produced per kJ/sec heat transferred through boiler
  ▪ Example: kWh electricity produced per kg coal (with specified assay)
**Efficiencies**

- **Thermal efficiency** – ratio of net work out of system to heat input to system

  \[
  \eta_{th} = \frac{W_{net}}{Q_{in}} = \frac{\sum W_{out,j} - \sum W_{in,j}}{\sum Q_{in,j}}
  \]

- **Ratio of useful energy out of system to all energy input to the system**

  \[
  \eta = \frac{\sum E_{out,j}}{\sum E_{in,j}} \Rightarrow \frac{\sum W_{out,j}}{\sum Q_{in,j} + \sum W_{in,j}}
  \]

- **May need to account for chemical potential energy effects (i.e., heating values)**

  \[
  \eta = \frac{\sum E_{out,j}}{\sum E_{in,j}} \Rightarrow \frac{\sum W_{out,j} + \sum m_{j,products} (\hat{H}_c^i)}{\sum Q_{in,j} + \sum W_{in,j} + \sum m_{j,reactants} (\hat{H}_i^c)}
  \]

- **“Heat rate”** is the reciprocal of thermal efficiency based on heating value

  \[
  \eta = \frac{W_{out,j} - W_{in,j}}{\sum m_{j,reactants} (\hat{H}_i^c)} \Rightarrow \text{Heat Rate} = \frac{1}{\eta} = \frac{\sum m_{j,reactants} (\hat{H}_i^c)}{\sum W_{out,j} - \sum W_{in,j}}
  \]
Thermodynamic Efficiencies

- Thermodynamic – ratio of actual energy change to that for reversible situation
  - No energy lost to universe – transfer of possible energy different from ideal but stays within the fluid
  - Isentropic efficiency

\[
\left( \Delta H_{\text{fluid}} \right)_{\text{turbine}} = \eta_{\text{thermo}} \left( \Delta H_{\text{fluid}} \right)_{\Delta S=0} \quad \text{and} \quad \left( \Delta H_{\text{fluid}} \right)_{\text{pump}} = \frac{\left( \Delta H_{\text{fluid}} \right)_{\Delta S=0}}{\eta_{\text{thermo}}}
\]

- Mechanical efficiencies – relates energy to/from fluid that is lost to the universe due to friction, ...

\[
W_{\text{turbine}} = \eta_{\text{mech}} \left( \Delta H_{\text{fluid}} \right) \quad \text{and} \quad W_{\text{pump}} = \frac{\left( \Delta H_{\text{fluid}} \right)}{\eta_{\text{mech}}}
\]
Heating Values

- Depends on state of produced water
  - Lower / Net Heating Value (LHV) — water in gas state
    \[
    \text{Fuel} + \text{O}_2 \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g) + \text{N}_2(g) + \text{SO}_2(g)
    \]
  - Higher / Gross Heating Value (HHV) — water in liquid state
    \[
    \text{Fuel} + \text{O}_2 \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) + \text{N}_2(g) + \text{SO}_2(g)
    \]
    \[
    \tilde{H}_{\text{HHV}} = \tilde{H}_{\text{LHV}} + n_{\text{H}_2\text{O}} \cdot \Delta \tilde{H}_{\text{H}_2\text{O}}(T_{\text{ref}})
    \]

<table>
<thead>
<tr>
<th>Compound</th>
<th>Ideal Gas Heating Value (60°F)</th>
<th>Liquid (in Vacuum) Heating Value (60°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net Btu/scf</td>
<td>Gross Btu/scf</td>
</tr>
<tr>
<td>Methane</td>
<td>909.4</td>
<td>1010.0</td>
</tr>
<tr>
<td>Propane</td>
<td>2314.9</td>
<td>2516.2</td>
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<tr>
<td>n-Hexane</td>
<td>4403.8</td>
<td>4756.0</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>4179.7</td>
<td>4481.6</td>
</tr>
<tr>
<td>Benzene</td>
<td>3590.9</td>
<td>3741.8</td>
</tr>
<tr>
<td>Methanol</td>
<td>766.2</td>
<td>866.9</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1447.5</td>
<td>1598.5</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>273.8</td>
<td>324.2</td>
</tr>
</tbody>
</table>