Next three lectures:

Pros and cons of meeting energy needs by means other than combustion of fossil fuel

We’ll begin today by going over a few Course Logistics and a few loose ends

Lecture 20
23 April 2013

Course Logistics

• Course evaluation now open
  – Everyone encouraged to participate:
    https://www.courseevalum.umd.edu/portal (open now to Friday night, 10 May)

• Problem Set #5 posted:
  – Due Thursday, 2 May
  – 10 points per day late penalty; hard deadline 6 pm, 6 May (Mon)
  – Allison will lead review of P Set #5 at 6 pm, 6 May (Mon)

• Problem Set #6 posted:
  – Due Tuesday, 7 May
  – 20 points per day late penalty; hard deadline Thurs, 9 May (start of last class)
  – A few students will be asked to present P Set #6 in class on 9 May;
    to be considered, must turn problem set in on time

• Projects:
  – Paper due Wed, 8 May
  – Presentation also on Wed, 8 May (evening); all are welcome to attend
  – We’ll be delighted to provide comments on either a draft of the paper and/or
    presentation provided we have by start of class Tues, 7 May
Course Logistics

• Final Exam
  – Wednesday, 15 May, 10:30 am to 12:30 pm
  – This room
  – Format similar to prior exams
  – Closed book, no notes
  – Perhaps slight emphasis on material covered since last exam, but
    entire course will be covered on the final exam
  – Tim and Allison will be present to answer questions
  – Lecture on Thus, 9 May 2013 will be a class review/final exam prep

World Energy & Electricity Supply

![World Energy & Electricity Supply Diagram](image)

Figure 8.1  (a) Share of renewables in world total primary energy supply (TPES) in 2002. (Source: IEA Renewables Information 2004.)
(b) Share of renewables in world electricity production in 2002. (Source: IEA Renewables Information 2004.)

Olah et al., Beyond Oil and Gas: The Methanol Economy, 2006.

World obtains ~80% of its energy & ~68% of its electricity from combustion of fossil fuels
World Electricity Generating Capacity:
Power (energy/time)

<table>
<thead>
<tr>
<th>Total Source</th>
<th>GW (year 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1,627</td>
</tr>
<tr>
<td>Natural Gas</td>
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<td>378</td>
</tr>
<tr>
<td>Wind</td>
<td>226</td>
</tr>
<tr>
<td>Other Renewable (Biomass)</td>
<td>173</td>
</tr>
<tr>
<td>Solar</td>
<td>41</td>
</tr>
<tr>
<td>Geothermal</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>5058</td>
</tr>
</tbody>
</table>

Source: [http://www.eia.doe.gov/forecasts/ieo/ieo_tables.cfm](http://www.eia.doe.gov/forecasts/ieo/ieo_tables.cfm)
World Electricity Generating Capacity:

Power (energy/time)

Source: http://www.eia.doe.gov/forecasts/ieo/ieo_tables.cfm

U.S. Electricity Supply: 2009

Total = 3,950 billion kWh

Coal 44.5%
Natural Gas 23.3%
Nuclear 20.2%
Hydroelectric 6.8%
Other Renewables 3.8%
Other 0.3%

Electric Utility Plants = 60.1%
Independent Power Producers and Combined Heat and Power Plants = 39.9%

http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

U.S. obtains ~70% of its electricity from fossil fuels & ~11% from sources other than fossil fuels + nuclear energy

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Market Force #1: Cost of Fossil Fuel ↑


Residential Electricity Cost, United States

http://www.eia.doe.gov/forecasts/steo/report/electricity.cfm
U.S average residential retail price of electricity:
11.53 cents per kilowatt-hour in 2010


Market Force #2: Cost of Electricity from Renewables ↓

2011 US Average Cost of Electricity: ~11.8 cents per kw-hour


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Hydro

• World’s largest renewable energy source for production of electricity
  – 17% of world’s electricity needs
  – Nearly 100% of electricity in Norway, Uruguay, and Paraguay
  – Canada: 50% US: ~7% in 2005

• Technology very mature

• Only ~20% of world overall potential being tapped

Olah et al., Beyond Oil and Gas: The Methanol Economy, 2006.

Largest Capacities:
• Itaipú, Paraná River, South America: 14,000 MW
  – Built 1975 to 1991
  – Volume of iron and steel: enough to build 380 Eiffel Towers
  – Volume of concrete: 15 × that of Channel Tunnel between France and England

• Three Gorges Dam, Yangtze River, China: 22,500 MW
  – Fully operational in 2012
  – Cost: $22.5 billion or 1 million $ / MW
  – Largest construction project in China since Great Wall
  – 1 million people displaced
  – Provides _____ of China’s electricity needs

Hydro

• Positive:
  – No NOx and SOx during operation
  – CO2 release only during construction (page 90, Olah et al.)

• Negative:
  – Flooding: over 1 million people displaced by Three Gorge Dam
  – Soil fertility: High Aswan Dam in Egypt has resulted in fertile silt collecting at bottom of Lake Nassar, necessitating use of $1 \times 10^6$ tons of fertilizer
  – GHG emissions from lost forest and decaying biomass under dammed water
    http://www.springerlink.com/content/k30639u4n8p5266/
    http://www.newscientist.com/article.ns?id=dn7046

http://ga.water.usgs.gov/edu/hyhowworks.html

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Top Hydropower Producing States, 2011

- Over half of the total U.S. hydroelectric capacity for electricity generation concentrated in three States (Washington, Oregon, and California)
- ~30% in Washington, location of the largest hydroelectric facility: Grand Coulee Dam.

http://www.eia.doe.gov/kids/energy.cfm?page=hydropower_home-basics-k.cfm

Wind

- Fastest growing renewable resource: 30% per year from 1992 to 2004

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- Germany: 29,000 MW capacity, generating 8% of country’s electricity
  - Europe dominates wind energy turbine market
- Turbine capability has increased dramatically past 20 years:
  - Went from 20 m diameter generating 20-60 kW to 100 m diameter generating 2 MW

About ~4.5% of world energy production capacity
Wind Power Potential, World

- Wind power varies as \([\text{Wind Velocity}]^3\):
  - Installation benefits from accurate knowledge of wind fields

![Wind power map](http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html)

Figure 2. Map of wind speed extrapolated to 80 m and averaged over all days of the year 2006 at sounding locations with 20 or more valid readings for the year 2006. Archer and Jacobson, *JGR*, 2006

- Potential electricity generation from "sustainable Class 3 winds" is 72 Terawatts!
- Installation of ~5 Terawatts (current global electricity capacity) requires harnessing only a fraction of this potential with current turbine technology

Wind

- Wind power varies as \([\text{Wind Velocity}]^3\):
  - Installation benefits from accurate knowledge of wind fields

![Wind map](http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html)
Wind Power, Pros & Cons

Environmental Ledger

• Positive:
  – No emissions
  – Land on wind farm can be used for agriculture or livestock

• Negative:
  – Lightning strikes, turbine break / failure, or leaking fluid can lead to fire
  – Long-term performance of turbines not well established
  – Public resistance to visual impact or noise:

  June 29, 2003 - After a wind project was proposed several miles off the coast of Cape Cod, some environmentalists raised objections, as did U.S. Senator Ted Kennedy who owns a summer home in the area

  April 9, 2013 - Maryland Offshore Wind Energy Act of 2013 signed by Gov O’Malley:

See also:
Geothermal

- US largest producer of geothermal electricity (absolute amount):

![Geothermal electricity production chart](chart.png)

**Figure 8.5** Geothermal electricity production, 1999. (Source: IEA, World energy outlook 2001 Insights.)

- Philippines derives largest percentage of electricity from geothermal:

<table>
<thead>
<tr>
<th>Country</th>
<th>Percentage of geothermal in the country's total electricity generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philippines</td>
<td>25.6</td>
</tr>
<tr>
<td>Iceland</td>
<td>15.8</td>
</tr>
<tr>
<td>El Salvador</td>
<td>15.9</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>12</td>
</tr>
<tr>
<td>Kenya</td>
<td>8.6</td>
</tr>
<tr>
<td>New Zealand</td>
<td>6.6</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>4.7</td>
</tr>
<tr>
<td>Indonesia</td>
<td>3.2</td>
</tr>
<tr>
<td>Mexico</td>
<td>2.9</td>
</tr>
<tr>
<td>Italy</td>
<td>1.7</td>
</tr>
<tr>
<td>USA</td>
<td>0.4</td>
</tr>
<tr>
<td>Japan</td>
<td>0.3</td>
</tr>
<tr>
<td>Turkey</td>
<td>0.1</td>
</tr>
<tr>
<td>World</td>
<td>0.3</td>
</tr>
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Olah et al., Beyond Oil and Gas: The Methanol Economy, 2006.

Geothermal electricity growing rapidly:

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but total production capacity, about **12,000 MW in 2012**, represents only 0.2% of total world electricity generation capacity.

Olah et al., Beyond Oil and Gas: The Methanol Economy, 2006.
Geothermal

• Temperature of source critical:
  – dry steam (T > 220°C) most profitable
  – hot water (150 to 300°C) can generate electricity using “flash steam”
    (depressurization and boiling)
  – low temperature (T < 150°C) used for heat (Iceland) or to extract H₂ from H₂O or fossil fuels

Where will favorable conditions for geothermal most likely be found?


Geothermal

• Margins of tectonic plates most favorable

1. Geothermal fields producing electricity
2. Mid-oceanic ridges crossed by transform faults (long transversal fractures)
3. Subduction zones, where the subducting plate bends downwards and melts in the asthenosphere (~100 to 200 km below surface)

http://iga.igg.cnr.it/geo/geoenergy.php
Geothermal

- Temperature of source critical:
  - dry steam (T > 220°C) most profitable
  - hot water (150 to 300°C) can generate electricity using “flash steam” (depressurization and boiling)
  - low temperature (T < 150°C) used for heat (Iceland) or to extract H$_2$ from H$_2$O or fossil fuels

Map of U.S. Water Temperature

![Map of U.S. Water Temperature](http://www1.eere.energy.gov/geothermal/geomap.html)

Geothermal Heating

About 95% of the buildings in Reykjavik are heated with geothermal water. Reykjavik is one of the cleanest cities in the world.

![Reykjavik Using Geothermal](http://geothermal.marin.org/geopresentation/sld095.htm)
Low Earth Geothermal Heating

Winter: pump drives fluid to transfer energy from ground to building

http://geothermal.marin.org/geopresentation/sld102.htm

Geo-thermal heating/cooling at local church:
Paint Branch Unitarian / Universalist, Adelphi, Md
Geothermal


- Claim: geothermal is a largely untapped resource for electricity in the US
  - improvements in deep drilling and management of water flow within wells needed

- Strong association of electricity production and price:

  GETEM: Geothermal Electric Technology Evaluation Model
  EGS: Enhanced Geothermal Systems: i.e., engineered reservoirs that have been created to extract economical amounts of heat from geothermal resources

![Graph showing cost of power versus availability of power](image)

Figure 9.8 Predicted supply curves using the GETEM model for identified EGS sites associated with hydrothermal resources at depths shallower than 3 km. The base case corresponds to today’s technology and the 5-, 15-, 25-, and 35-year values correspond to the state of technology at that number of years into the future.

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Solar PV

- Sun delivers about 10,000 times more energy than world consumption

- Photovoltaic: converts solar energy into electricity
  - photovoltaic effect: Nobel Prize in 1921 to __________
  - solar cells developed in 1960s for military and satellites
  - crystals from silicon, cadmium, copper, arsenic, etc
  - efficiency increased from 15% in mid-1970s to ~25% today

- PV capacity increased 30% per year from 1990 to 2004:

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar MW</th>
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<tbody>
<tr>
<td>2005</td>
<td>4,267</td>
</tr>
<tr>
<td>2006</td>
<td>6,274</td>
</tr>
<tr>
<td>2007</td>
<td>8,535</td>
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<tr>
<td>2008</td>
<td>13,992</td>
</tr>
<tr>
<td>2009</td>
<td>18,275</td>
</tr>
<tr>
<td>2010</td>
<td>25,249</td>
</tr>
<tr>
<td>2011</td>
<td>32,710</td>
</tr>
<tr>
<td>2012</td>
<td>41,180</td>
</tr>
</tbody>
</table>

World Capacity - All Sources, 2012: 5,058,000

![Graph showing cumulative installed photovoltaic (PV) power in reporting IEA countries](image)

0.1% of world electricity capacity

0.8% of world electricity capacity

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Solar PV Efficiency

<table>
<thead>
<tr>
<th>Material</th>
<th>Laboratory Efficiency</th>
<th>Production Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monocrystalline Silicon</td>
<td>24 %</td>
<td>14 to 17 %</td>
</tr>
<tr>
<td>Polycrystalline Silicon</td>
<td>18 %</td>
<td>13 to 15%</td>
</tr>
<tr>
<td>Amorphous Silicon</td>
<td>13 %</td>
<td>5 to 7 %</td>
</tr>
</tbody>
</table>

In Oct 2010, efficiency of 42.3% reached using a triple junction cell array. [http://optics.org/news/1/5/5](http://optics.org/news/1/5/5)

Limited Efficiency

Limited spectral range of effective photons (depends on material used)

Surplus energy transformed into heat

Optical losses from shadowing and/or reflection

Concentrated Solar Power (CSP)

- Parabolic mirrors heat fluid that drives Stirling engine
  - Fluid is permanently contained within the engine’s hardware
  - Converts heat to energy


Kramer Junction, Calif

- Fully operational in 1991: 350 MW capacity
- Low output in 1992 due to Pinatubo aerosol!
- Present operating cost: ~11 ¢ / kWh

Nevada Solar One

- Output: 64 MW capacity / 134,000 MW-hr / year
- Could supply all US electricity needs if built over a ~ 130 mile × 130 mile area
- Construction cost: ~$2 / kW-hr for one yr’s prod
Renewable Energy Portfolio Standard (RPS)

29 States have a RPS mandating that a certain % of electricity must be generated using renewable sources by a particular year

[Map of Renewable Energy Portfolio Standards with states and their targets marked]

Renewable Energy Credits (RECs)

• **Property right** to 1 megawatt-hour (MWh) of electricity generated by a renewable source
• Sold on the open market
• Designed to facilitate achievement of state RPS
  - States can mandate that utilities either generate electricity using renewable sources (in which cases RECs are not sold but rather “retired”) or purchase RECs

• Maryland RECs:
  - **Tier I**: Solar: ~$200/SREC  
    Non-Solar (wind, biomass, etc.): ~$1/REC  
  - **Tier II**: Hydro only (expiring)

[Map of 29 states + Washington DC and 2 territories with Renewable Portfolio Standards]

http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf
Renewable Energy Credits (RECs)

Maryland RECs:
Tier I: Solar: ~$200/SREC
Non-Solar (wind, biomass, etc.): ~$1/REC
Tier II: Hydro only (expiring)

Maryland Compliance Requirements:

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar</th>
<th>Other Tier I</th>
<th>Tier II</th>
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</thead>
<tbody>
<tr>
<td>2006</td>
<td>0.00%</td>
<td>1.00%</td>
<td>2.50%</td>
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<tr>
<td>2007</td>
<td>0.00%</td>
<td>1.00%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2008</td>
<td>0.005%</td>
<td>2.00%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2009</td>
<td>0.01%</td>
<td>2.00%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2010</td>
<td>0.025%</td>
<td>3.00%</td>
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<tr>
<td>2011</td>
<td>0.05%</td>
<td>4.95%</td>
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<tr>
<td>2012</td>
<td>0.10%</td>
<td>6.40%</td>
<td>2.50%</td>
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<tr>
<td>2013</td>
<td>0.20%</td>
<td>8.00%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2014</td>
<td>0.30%</td>
<td>10.00%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2015</td>
<td>0.40%</td>
<td>12.10%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2016</td>
<td>0.50%</td>
<td>12.20%</td>
<td>2.50%</td>
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<tr>
<td>2017</td>
<td>0.55%</td>
<td>12.55%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2018</td>
<td>0.90%</td>
<td>14.90%</td>
<td>2.50%</td>
</tr>
<tr>
<td>2019</td>
<td>1.20%</td>
<td>16.20%</td>
<td>0.00%</td>
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<tr>
<td>2020</td>
<td>1.50%</td>
<td>16.50%</td>
<td>0.00%</td>
</tr>
<tr>
<td>2021</td>
<td>1.85%</td>
<td>16.85%</td>
<td>0.00%</td>
</tr>
<tr>
<td>2022+</td>
<td>2.00%</td>
<td>18.00%</td>
<td>0.00%</td>
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http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MD05R&re=1&ee=1

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Solar Renewable Energy Credit (SREC) Prices

<table>
<thead>
<tr>
<th>State</th>
<th>2010-03</th>
<th>2011-03</th>
<th>2012-03</th>
<th>2013-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delaware</td>
<td>$225</td>
<td>$163</td>
<td>$40</td>
<td>n.a.</td>
</tr>
<tr>
<td>Maryland</td>
<td>$390</td>
<td>$275</td>
<td>$218</td>
<td></td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>$250</td>
<td>$181</td>
<td>$15</td>
<td>$10</td>
</tr>
<tr>
<td>Washington, DC</td>
<td>$290</td>
<td>$200</td>
<td>$275</td>
<td>$381</td>
</tr>
</tbody>
</table>

http://srectrade.com/srec_prices.php

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