SMA 521

Governmental Responses to Global Climate Change

LECTURE ON ENERGY

Wednesday
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3:30-5:20 PM

109 Fishery Sciences

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About Our Program on Energy

- Web Site: http://www.energy.washington.edu

- Courses Leading to a Concentration on Energy
  - Energy and Environment (341, 3, AQ)
  - Design for Environment (415, 3, WQ)
  - Combustion (424, 4, SpQ-E)
  - HVAC Engineering (425, 4, SpQ)
  - Sustainable Energy Design (426, 4, SpQ-O)
  - Advanced Energy Conversion (430, 4, AQ)
  - Renewable Energy (442, 3, WQ)
  - Fuel Cell Engineering (CHEM E, 3 courses)
  - Power Engineering (E E, several courses)
  - Graduate Courses in underlying disciples

- Laboratory for Energy and Environmental Combustion
  - Low emission combustion for power generation gas turbines: natural gas and alternative fuels.
  - Low emission combustion of waste fuels used by the forest and paper products industries.
  - Thermo-chemical conversion of thinnings from forest fuels reduction.
  - Renewable energy systems for National Parks in Washington, Oregon, and Hawaii.
  - Sustainable energy technologies and methodologies for Vashon Island, Washington.

CURRENT ENERGY USE

- No Surprise – Fossil Fuels Dominate
- No Surprise – Oil Use is #1
- US Data for 2003 (http://www.eia.doe.gov)

Primary Energy	Quads (10^{15} BTU)	%	Comments
Oil	38.8	39.5	Transportation > Industrial Use
Natural Gas	22.8	23.2	Many users compete for natural gas
Coal	22.5	22.9	Electricity, fastest growing since 1970
Nuclear	8.0	8.1	Electricity, about 100 power plants
Renewables	6.1	6.3	Only hydro and wood are major players
Hydroelectric	2.79		
Wood	2.07		
Wastes	0.56		
Alcohol	0.24	Ethanol as an Oxygenate	
Geothermal	0.31		
Solar	0.06		
Wind	0.11	6 GW installed capacity	
TOTAL	**98.2**	**100**	

WORLD COMPARED TO US

- No Surprise – per capita energy use in US is much greater than for the world.
- US, with somewhat less than 5% of the world's population accounts for about 25% of the world's annual energy consumption.
- Thus, the average resident of the US consumes 5-6 times the energy of the average citizen of the world.
- Compared to western Europe and Japan, a resident of the US uses about twice as much energy.
- Compared to developing nations, the ratio is about 10.
- The world (including the US) uses about 400 quads of energy per year – though this doesn't count the use of non-commercial biomass in developing nations, which could be as great as 50-60 quads per year.
- The percentages of primary energy use are about the same for the world (including the US) as for the US, if non-commercial biomass is not included: OIL > NAT GAS ≅ COAL > NUCLEAR ≅ RENEWABLES. For the world, coal slightly exceeds natural gas, and hydro is the main renewable (since non-commercial biomass neglected).

ENERGY USE FOR TRANSPORTATION (US, 2003)

<table>
<tr><td>Fuel</td><td>Quads</td><td>%</td><td>Comments</td></tr>
<tr><td>Oil</td><td>25.89</td><td>96.6</td><td>Refined to gasoline, diesel fuel, aviation fuel</td></tr>
<tr><td>Natural gas</td><td>0.67</td><td>2.5</td><td>Includes pipelines</td></tr>
<tr><td>Renewables</td><td>0.24</td><td>0.9</td><td>See below</td></tr>
<tr><td>E85</td><td>0.0025</td><td colspan="2">85% ethanol with 15% gasoline</td></tr>
<tr><td>Ethanol as oxygenate</td><td>0.222</td><td colspan="2">Typically, about 10% ethanol and 90% gasoline. Enhances octane number and reduces CO emission in cold weather.</td></tr>
<tr><td>Biodiesel</td><td>0.0033</td><td colspan="2">Crop oils chemically processed with methanol to give a fuel with properties close to those of of petroleum diesel.</td></tr>
<tr><td>TOTAL</td><td>26.80</td><td>100</td><td></td></tr>
<tr><td colspan="4">Note: in spite of over 30 years of significant interest and attention to alternative fuels for transportation, including biofuels, oil remains king! Given this record, to what extent should the US view biofuels as a solution to reducing the nation’s dependency on oil? Engine power plant efficiency improvements, such as offered by hybrid-electric, may provide a better alternative. Widespread integration of HEVs into society over the next 10 years could increase CAFE by 50%, into 30-35 mpg range.</td></tr>
</table>

ELECTRICITY GENERATION
(US, 2003)

PRIMARY ENERGY	BILLION KWH	%	COMMENTS
Coal	1970	51.2	About evenly split between deep and surface mining
Natural Gas	629	16.4	4-5% annual growth rate, combined cycle
Oil	118	3.1	Not a major player
Nuclear	764	19.9	Capacity factor improvements
Renewables			
Hydro	275	7.2	Environmental concerns limit growth potential
Wood	37	1.0	Combustion-steam-electric
Wastes	23	0.6	Combustion-steam-electric
Geothermal	13	0.3	Steam-electric
Wind	11	0.3	30-35% capacity factor
Solar	0.5	0.01	20% capacity factor
TOTAL	**3848**	**100**	
Notes:			
Conversion to quads: 1 kwh = 3412 BTU. Therefore: 3848 billion kwh = 13 quads.			
Assuming 33% efficiency (eia.doe), means 39 quads of primary energy is used to generate the electricity.			
However, large hydro plants are more efficient by at least a factor two, and gas fired combined cycles are 50-60% efficient. Therefore, per unit of energy produced, gas fired CCs produce about ½ the CO_2 of coal fired power plants.			

ELECTRICITY GENERATION FOR THE FUTURE (1)

- Electricity is the most desired form of energy – faster growth rate than oil.
- In light of global climate change, is coal a viable fuel? Will societies turn away from coal?
- It has been nearly impossible to build coal fired steam-electric power plants in the US. And because of the success of the combined cycle gas turbine, there has been little incentive to proceed with new coal fired plants.
- But the situation may be changing. It depends on how power producers view the long term for natural gas: cost and availability. At $6 per million BTUs, the cost of generating electricity in a combined cycle power plant is 4-5 cents/kwh, which is about the same as estimated for coal gasification combined cycles. The cost of coal is $1.3 per million BTUs. Furthermore, the US has a lot more coal resource than natural gas resource. The same holds for China and India – huge growth markets for electricity.
- Coal IGCC (integrated gasification combined cycle) power plants have been commercially demonstrated in the US and Europe. In this technology, the coal is oxygen-gasified to a syngas of CO, H_2, CO_2, and steam; the syngas is cleaned (this is the hard part), and burned in a combined cycle. Overall efficiency should reach 45% before too long. Coal IGCC is posed to become a significant electricity producer.

ELECTRICITY GENERATION FOR THE FUTURE (2)

- Coal IGCC emissions are significantly lower than for conventional coal fired steam power plants:
    - SO_2
    - NOx
    - Particulate
    - Hg
- But there is still a big CO_2 problem.
- But gasification opens up the following possibilities:
    - Co-production of H_2 and electricity.
    - CO_2 separation, leading to sequestration.
- Already in Europe IGCC plants based on refinery wastes and oil heavy ends are used for tri-generation: H_2, electricity, and process heat.
- If any massive subsidy should be provided to the coal industry, it should be to try to demonstrate coal IGCC with CO_2 capture and sequestration and H_2 production. Does the engineering make sense? Are the economics reasonable? Will the environment gain or lose? Massive mining operations would continue, with their impacts on land, water, and human health.
- Or should the use of coal be strongly discouraged, and we turn elsewhere for our electricity? What are possibilities?
    - More natural gas CC power plants?
    - A new round of nuclear fission reactors?
    - Wind turbines?
    - Solar generated electricity?

<u>ELECTRICITY GENERATION FOR THE FUTURE (3)</u>

- What about a lot more natural gas fired combined cycle gas turbine power plants?
  - This power plant has been very popular – over 50% of new electrical generating capacity installed worldwide since about 1990 is based on the gas turbine.
  - Combined cycle gas turbine power plants are very efficient – typically 55% -- as high as 60% electrical generation efficiency (GE H-class).
  - Exhaust emissions are very low – because of the development of the lean-premixed combustor.
  - However, there is uncertainty about the future:
    - The high cost of natural gas – as noted above.
    - There are many demands on natural gas. Of the 22.5 quads used in the US in 2003, the demands were.
      - 8.47 for residential and commercial
      - 8.32 direct use in industry
      - 5.05 for electricity generation
      - 0.67 for transportation.
    - The US is a net importer of natural gas, mainly as pipeline gas from western Canada (about 15%), and some LNG from Caribbean area.

ELECTRICITY GENERATION FOR THE FUTURE (4)

  - Significant gas resource exists in Canada and Alaska, but for the long run, the US will have to face the fact that Eurasia and the Middle East have most of the world's natural gas.
  - Current proved reserves (www.bp.com): North America (7.3 trillion cubic meters) and South America (7.2) versus 175 for the world.
  - Coal bed methane (an example of unconventional natural gas) is being developed in the Rocky Mt west, but not without controversy and degradation of water and land.
- In order to meet a large demand for increased use of natural gas for electricity generation, an LNG economy based on overseas LNG may need to be developed, but this is not without resistance; or the other demands on natural gas may need to be curtailed, though this could be very difficult.
- Exploitation of other sources of unconventional natural gas, such as methane hydrates, is only in the research stage, and may be premature for serious long term planning.
- Uncertainties in natural gas could impact the move to a hydrogen economy, since steam reforming of natural gas is one of the leading candidates for H_2 generation.

ELECTRICITY GENERATION FOR THE FUTURE (5)

- What about a massive building of new nuclear fission power plants?
    - Over the past 40 years, society has learned a lot about designing and operating nuclear power plants. Currently, there are over 400 nuclear power plants operating in the world, generating slightly under 20% of the world's electrical energy.
    - Current nuclear power plants have an age of about 10 to 40 years. Some have been retired already; normal lifetime is 40 years; some may be extended to 60 years.
    - We are nearing a decision: let nuclear power die, build some new plants, or built many new plants, perhaps bringing nuclear power to the point that it generates 30-40% of worldwide electricity.
    - New reactors would have many new passive safety features – it would be extremely unlikely for loss-of-coolant meltdown to occur (as happened at TMI). From the technical standpoint, very safe reactors could be built.
    - New high temperature gas cooled reactors, operating on the gas turbine cycle rather the steam cycle (as used today), could improve electrical generating efficiency by about 50%.
    - The critical concerns should spent fuel storage and reprocessing, and maintaining the security of the nuclear material.

ELECTRICITY GENERATION FOR THE FUTURE (6)

- What about renewable energy? Can it be a big player? The energy is free, but the energy conversion system is expensive.
- Currently, hydroelectric is the only big player. About 10% of electricity is produced by hydroelectric. There is a lot of untapped capacity in South America, Africa, and Asia.
- However, there are impacts on societies and habitats. Even micro-hydro and run-of-the-river hydro are being opposed. The World Bank has changed its policies on the funding of large scale hydroelectric in developing nations. Changes in rain and snowfall patterns could cause apprehension on the part of potential investors. Thus, there is uncertainty about the long term prospects for significantly more hydroelectric.

- Wind turbine installed capacity is currently 30-40 GW worldwide. This is about 1% of total electrical generating capacity. However, wind turbines only run at capacity 30-35% of the time, whereas a coal or nuclear fired steam-electric power plant can run 80-90% of the time at capacity.
- Wind turbine farms can compete with combined cycle power plants. They can produce electricity at 4-5 cents/kwh – lower if they qualify for the 1.8 cent/kwh production tax credit.

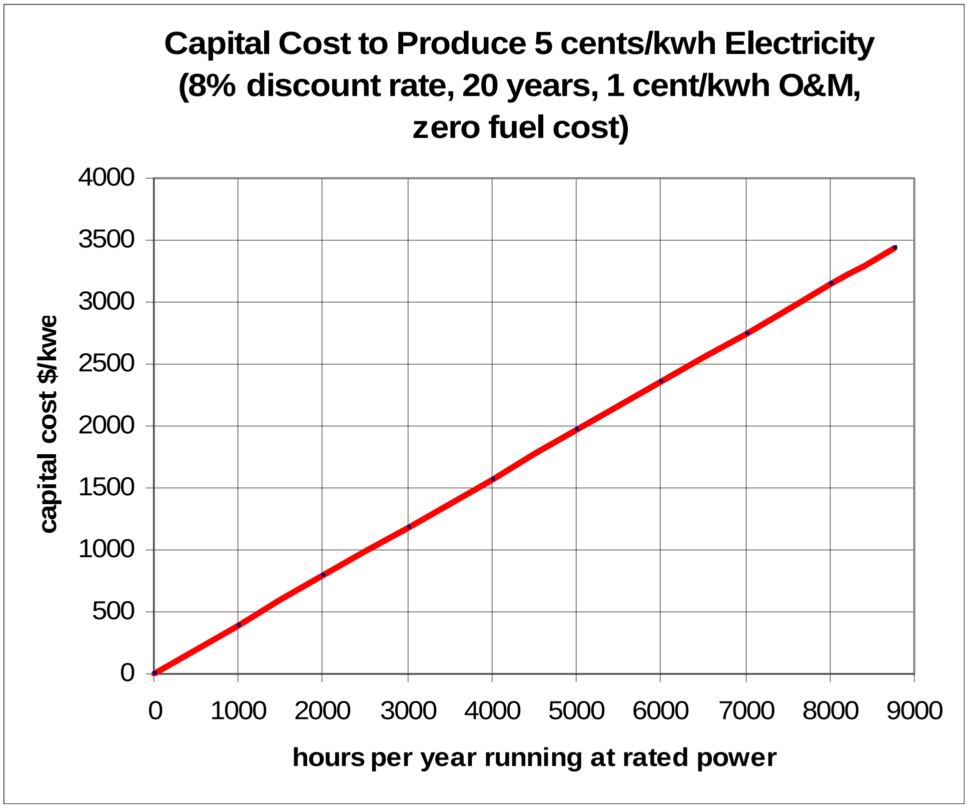
ELECTRICITY GENERATION FOR THE FUTURE (7)

- However, if new long distance transmission lines need to be built to carry the electricity from the windy places to the urban places, then wind energy becomes less attractive.
- If the wind turbine farms are brought close to the urban centers, wind speed may be sacrificed, and public opposition may arise.
- Demark generates about 20% (or more) of its electricity from wind. This requires a careful balancing act with its electricity grid and with its other sources of electricity generation.
- From the technical and economic standpoints, probably 10-20% of the world's electricity could be produced from wind energy. However, greater amounts will require companion energy storage, which is not well developed and integrated with wind yet. A scheme for Iowa uses the wind energy to compress air, which is stored in underground cavities, and then used as needed to drive turbine-generators.
- Wind energy will probably continue to show a rapid growth rate for this decade and into the next.

- There are two possibilities for solar generated electricity:
    - Solar photovoltaic (PV)
    - Solar thermal electricity – solar heat running a steam-electric power plant or assisting a combined cycle power plant.

ELECTRICITY GENERATION FOR THE FUTURE (8)

- The following plot illustrates the challenge solar faces for generating electricity.



- This plot shows the tradeoff between system installed capital cost (as $/kw-capacity) and operating hours per year. For example, a wind turbine running 3000 hours per year (at capacity) needs to have an installed capital cost of no more than $1100-1200/kw in order to complete in a 5 cent/kwh electricity market. This condition can be met, even without the PTC. Solar runs no more than about 2000 hours per year at capacity – think of this as equivalent to about 6 hours of full (1000 w/m^2) sunlight per day. Thus, the installed capital cost of solar has to be under $1000/kw.

ELECTRICITY GENERATION FOR THE FUTURE (9)

- The current installed capital cost of solar PV is about \$5000/kw – about double this for small systems.
- So where are its opportunities?
    - Off-grid applications, rural sectors of developing nations – solar PV cost is less than new grid lines.
    - Peak electricity – electricity for daytime office building air conditioning load in southwestern US (for example).
    - In countries with large subsidies for solar PV – Germany for example.
- Will the cost come down? Most likely:
    - Manufacturing advancements.
    - Economy of scale.
    - Organic (plastic) PV.
    - Government incentives and R&D spending.
    - Building integrated PV.

- Solar thermal electric may be attractive for utility-scale solar electricity generation in regions with strong direct sunlight.
    - Large (0.3 GW) system at Kramer Junction, Mojave Desert, CA. This sells electricity into the southern California grid for meeting peak demand (10-15 cents/kwh) Concentrating trough collectors heat oil to about 400 degrees C, which flows to a steam power plant, where the heat of the hot oil is transferred to the steam.

ELECTRICITY GENERATION FOR THE FUTURE (10)

- Other solar thermal electricity generating systems, in RD&D, are based on:
    - Power towers
    - Dish collectors driving a Stirling engine-generator.
    - Solar heated gas turbine engine.
- Cost projections indicate the power tower may offer the best chance of reaching 5 cents/kwh electricity.

- European research and development is beginning to out pace US research on solar energy.

- Compared to the billions of dollars spent annually worldwide on subsidies to the conventional energy industries and on fuel cell RD&D, solar energy RD&D receives relatively little funding.

- It should also be noted that use of solar energy to passively heat and light homes and buildings may offer the best opportunity for cost effective application of solar energy – since this is mainly a matter of getting smarter on how we design buildings, putting to use what we know already, and doing this cost effectively as an integrated part of the design and construction.