



Figure by MIT OCW.

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SUSTAINABLE ENERGY

IAP 2007

PROBLEM SET #2

Due January 19, 2007

Energy Conversion and Economic Analysis

In class example problems:

1. **“Forest fires for electricity”**-- The United States has a lot of federally owned land. Unfortunately, and uncontrolled natural forest fires destroy large areas in the Western US every summer. Last year alone about 1,000,000 acres of standing timber in National forests were consumed. Some consideration is being given to improved management practices that could produce electric power from residual forest thinnings. Estimate the lost energy content of burned US forests during 2002. Assuming the US average electricity demand load is about 300,000 MWe, how much forested land would be needed to produce all the country’s power? Is this a sustainable alternative? A few facts to consider:

(i) the total forested area on US Federal lands in the lower 48 states is about 600 million acres with a standing stock density of about 100 dry metric tonnes of wood per acre

(ii) woody plants and trees capture solar energy via photosynthesis at an average rate of about 0.8 W/m² which corresponds to producing about 5 to 10 dry tons of biomass per acre annually with an average heating value of 8000 BTU/dry lb. Note that 1 acre = 43,560 ft² = 0.405 hectare = 4047 m²

(iii) the average heat to work conversion efficiency of a biomass-fired electric power plant is about 35%

2. **“Batteries for families”** What weight of lead acid batteries are needed to power a family sized electric car with a range of 200 miles. You can assume that the power needed is 50 hp for speeds up to 60 mph with regenerative on board flywheel storage for additional acceleration when needed.

3. **“Hydrogen versus gasoline”** If the US converts to a hydrogen economy to replace its current energy system, how much natural gas would be needed per year to produce the hydrogen required for all our transportation fuels? Currently the US consumes about 45 quads/year in energy for transportation and the worldwide production rate of natural gas is 90 trillion SCF per year.

4. **“Economic discounting of human life”** A Performance Assessment (actually a probabilistic risk assessment) for a high-level waste (HLW) repository estimates that the mean radioactive dose rate to a member of the public living in the vicinity (i.e. within 50 miles) of the repository is negligible for <5000 years and then equal to 5 mRem/year

thereafter [actually it increases somewhat at much longer time scales]. Assume that 1000 people live within 50 miles of the facility.

If a human life is valued in constant dollars, V , at \$4.0 million, how much money can we justify spending today in order to prevent a future HLW-related fatality? Use an annual monetary discount rate of 3%, assume that a collective population dose of 1 million person-rem will result in a mean of 800 excess cancers, of which half will be fatal.

- a) Identify important factors of uncertainty that could affect your answer.
- b) The annual monetary discount rate is 3%.

5. **“Policy impact on process economics”** A 1000 MWe power plant has an “overnight” cost of \$2 billion (i.e. the cost of hardware). In different political jurisdictions the treatments of the funds invested in the plant differ. Contrast the following two cases in terms of the total capital charge values incurred during construction. In each case assume that the plant is built over a 10-year interval, at a constant annual spending rate of \$200 million/year. A return to the utility company of 3.0% of the invested capital is allowed by the government. The annual rate of inflation is 4%.

Case 1:

The national government guarantees the loans used to finance the plant, resulting in a reduction of the interest rate charged by lenders of 2.0%. Also, the national government permits any funds expended to go into the electricity rate base immediately. This results in an additional 1.0% reduction in the interest rate charged by lenders.

Case 2:

The plant is financed with commercial loans at a nominal annual interest rate of 12%, and no capital investments are allowed into the rate base until the plant enters into operations. To what extent does the national guarantee of the construction loans in Case 1 constitute a subsidy? Explain why.

Homework problems

1. **“Gasoline power”** How much power in MW are you delivering to your car when you fill it up at a self-service gas station?

2. **“It’s hard to beat an oil well”** A good oil well in the Persian Gulf produces about 100,000 bbl of oil per day. What would the mass flow rate of steam from a geothermal well located at the Larderello field in Northern Italy required to provide the same rate of energy production? Are there any practical limitations to achieving this production rate? The Larderello field produces saturated steam at about 20 bar, 212.4°C. Assume a typical Larderello well is about 28 cm in diameter and is about 2500 m deep.

The enthalpy of vaporization is 1890.7 kJ/kg at 20 bar. Assume an average liquid phase heat capacity for water of 4100 J/kg K. Note that the energy content of a bbl of oil which is about 5 million Btu is referenced to its heat of combustion at 25°C.

3. **“US versus Japan”** American drivers are often criticized for not being as conservative as Japanese drivers. But let’s take a closer look. The most popular car in the US is a Japanese car - the Toyota Camry - and it’s very likely that the Japanese drive as many Toyotas as we do, but they might be smaller cars. How would the US compare to Japan if we somehow scaled the amount of driving done in each country according to the size of the country? Are the results that you calculate different? Roughly speaking Japan is the size of California with 128 million people. You should explicitly state all your assumptions and cite all sources of data. Please include several paragraphs explaining differences in your calculations, if any, in the amount of driving done in each country. Also please identify uncertainties in both your analysis and conclusions.

| Attribute | World | US | Japan | India |
|--|--------|--------|-------|-------|
| Population m | 6,378 | 297 | 128 | 1,081 |
| Area (10⁶)km² | 148 | 9.37 | 0.378 | 3.29 |
| % arable | 10.8% | 19% | 12% | 54% |
| Urban pop % | 49.2% | 80.8% | 65.7% | 28.7% |
| GDP \$bn | 41,300 | 11,712 | 4,623 | 691 |
| Pop <15 % | 28.2% | 20.8% | 14.0% | 32.1% |
| Pop >60 % | 10.4% | 16.7% | 26.3% | 7.9% |
| Energy mTOE | | | | |
| Total output | 10,672 | 1,631 | 85 | 453 |
| Total consumption | 10,544 | 2,281 | 517 | 553 |
| Net Imports as % consumption | -1% | 28% | 84% | 18% |

Statistics from “Pocket World in Figures, 2007 Edition, The Economist, Profile Books, London.

From <http://www.infoplease.com/ipa/A0004587.html>

Average Daily Temperatures (°F) in Selected Cities

| Location | January | | April | | July | | October | |
|-------------|---------|-----|---------|-----|---------|-----|---------|-----|
| | High | Low | High | Low | High | Low | High | Low |
| Tokyo | 48 | 31 | 64 | 48 | 84 | 71 | 70 | 56 |
| Bombay | 83 | 67 | 89 | 76 | 85 | 77 | 89 | 76 |
| New York | 32 avg. | | 53 avg. | | 77 avg. | | 57 avg. | |
| Los Angeles | 57 avg. | | 61 avg. | | 69 avg. | | 67 avg. | |
| | | | | | | | | |

4. **“Inflation effects on financial planning”** A 1000 MWe coal-fired power plant accumulates toxic ash wastes that must be secured from the biosphere when the plant is decommissioned at the end of its 50-year operational life, at a constant dollar cost of \$10/ton. The annual monetary discount rate is 4.0%. The plant capacity factor is 0.80, it consumes 3 million tons of coal annually, having an ash content of 2.0%.

An ash disposal fund is established over the operational life of the plant. How large should this fund be in the following cases? At what annualized rate should funds be accumulated over the plant’s operational life?

Case 1: The annual rate of monetary inflation is equal to zero.

Case 2: The annual rate of monetary inflation is equal to 5%.

5. **“Carbon taxes on CO₂ emissions”** A “carbon” tax is proposed upon coal consumption of \$50 per tonne-coal. What are the justifications of such a tax? What would be its likely influence upon the uses of:

Case 1: Natural gas (CH₄) if it were applied in proportion to a fuel’s carbon intensity (assume it to be half that of coal)?

Case 2: Nuclear power? In what ways is such a tax a subsidy for less carbon-intensive technologies?

Note -- List all assumptions and approximations made in arriving your answers. You can use the textbook as a source for conversion factors and other needed data to solve these problems. Feel free to use other sources but make sure that you list the sources in your solution.