CHAPTER 1 PROBLEM SOLUTIONS

1.1 A combined-cycle, natural-gas, power plant has an efficiency of 52%. Natural gas has an energy density of 55,340 kJ/kg and about 77% of the fuel is carbon.

a. What is the heat rate of this plant expressed as kJ/kWh and Btu/kWh?

SOLN: The heat rate is

$$\text{Heat rate} = \frac{3412 \text{ Btu/kWh}}{\eta} = \frac{3412}{0.52} = 6561 \text{ Btu/kWh}$$

$$\text{Heat rate} = \frac{1\text{kJ/s}}{\text{kW}} \cdot \frac{3600\text{s}}{\text{h}} \cdot \frac{1}{\eta} = \frac{3600}{0.52} = 6923 \text{ kJ/kWh}$$

b. Find the emission rate of carbon (kgC/kWh) and carbon dioxide ($kgCO_2$/kWh). Compare those with the average coal plant emission rates found in Example 1.1.

SOLN: The emission rates are

$$\text{Carbon emission rate} = \frac{6923 \text{ kJ/kWh}}{55{,}340 \text{ kJ/kgfuel}} \cdot \frac{0.77 \text{ kgC}}{\text{kgfuel}} = 0.0963 \text{ kgC/kWh}$$

$$CO_2 \text{ emission rate} = 0.0963 \text{ kgC/kWh x } \frac{44 \text{ kgCO}_2}{12 \text{ kgC}} = 0.353 \text{ kgCO}_2\text{/kWh}$$

$$\frac{52\%\text{-efficient combined cycle gas}}{33\% \text{ efficient coal plant}} = \frac{0.0963 \text{ kgC/kWh}}{0.2673 \text{ kgC/kWh}} = 0.36$$

That is almost a 2/3rds reduction (64%) in emissions.

1.2 In a reasonable location, a photovoltaic array will deliver about 1500 kWh/yr per kW of rated power.

a. What would its capacity factor be?

SOLN: $$CF = \frac{kWh/yr}{P_R(kW)\cdot 8760h/yr} = \frac{1500}{1\cdot 8760} = 17.12\%$$

b. One estimate of the maximum potential for rooftop photovoltaics in the U.S. suggests as much as 1000 GW of PVs could be installed. How many "Rosenfeld" coal-fired power plants could be displaced with full build out of rooftop PVs?

SOLN: At full build out, these PVs could deliver

1000 x 10^6 kW x 1500 kWh/yr/kW = 1500 billion kWh/yr = 1.5 million GWh/yr

(For comparison, the entire U.S. coal generation is about 2 million GWh/yr)

Each Rosenfeld avoids operating a 33%-efficient, 500-MW, 70% CF coal plant that generates 3 billion kWh/yr. So

Coal plants avoided = 1500 billion kWh/yr / 3 billion kWh/yr = 500 Rosenfelds

c. Using the Rosenfeld unit, how many metric tons of CO_2 emissions would be avoided per year?

SOLN: Using Rosenfelds, CO_2 emissions avoided would be

500 Rosenfelds x 3 million MT CO_2/yr = 1500 million metric tons/yr saved

1.3 For the following power plants, calculate the added cost (¢/kWh) that a $50 tax per metric ton of CO_2 would impose. Use carbon content of fuels from Table 1.5.

a. Old coal plant with heat rate 10,500 Btu/kWh.

SOLN: $$\text{Adder} = \frac{10{,}500\text{Btu}}{\text{kWh}} \text{x} \frac{24.5\text{kgC}}{10^6\text{kJ}} \text{x} \frac{1.055\text{kJ}}{\text{Btu}} \text{x} \frac{\text{tonne}}{1000\text{kg}} \text{x} \frac{5000¢/\text{kWh}}{\text{tonne}}$$

$$= 1.36¢/\text{kWh}$$

b. New coal plant with heat rate 8500 Btu/kWh

SOLN: $$\text{Adder} = \frac{8500\text{Btu}}{\text{kWh}} \text{x} \frac{24.5\text{kgC}}{10^6\text{kJ}} \text{x} \frac{1.055\text{kJ}}{\text{Btu}} \text{x} \frac{\text{tonne}}{1000\text{kg}} \text{x} \frac{5000¢/\text{kWh}}{\text{tonne}}$$

$$= 1.10¢/\text{kWh}$$

c. New integrated gasification, combined cycle coal plant with heat rate 9,000 Btu/kWh.

SOLN: $$\text{Adder} = \frac{9{,}000\text{Btu}}{\text{kWh}} \text{x} \frac{24.5\text{kgC}}{10^6\text{kJ}} \text{x} \frac{1.055\text{kJ}}{\text{Btu}} \text{x} \frac{\text{tonne}}{1000\text{kg}} \text{x} \frac{5000¢/\text{kWh}}{\text{tonne}}$$

$$= 1.16¢/\text{kWh}$$

d. Natural gas combined cycle plant with heat rate 7,000 Btu/kWh.

SOLN: $$\text{Adder} = \frac{7000\text{Btu}}{\text{kWh}} \text{x} \frac{13.7\text{kgC}}{10^6\text{kJ}} \text{x} \frac{1.055\text{kJ}}{\text{Btu}} \text{x} \frac{\text{tonne}}{1000\text{kg}} \text{x} \frac{5000¢/\text{kWh}}{\text{tonne}}$$

$$= 0.51¢/\text{kWh}$$

e. Combustion turbine with heat rate 9,500 Btu/kWh.

SOLN: $$\text{Adder} = \frac{9500\text{Btu}}{\text{kWh}} \text{x} \frac{13.7\text{kgC}}{10^6\text{kJ}} \text{x} \frac{1.055\text{kJ}}{\text{Btu}} \text{x} \frac{\text{tonne}}{1000\text{kg}} \text{x} \frac{5000¢/\text{kWh}}{\text{tonne}}$$

$$= 0.687¢/\text{kWh}$$

1.4 An average pulverized-coal power plant has an efficiency of about 33%. Suppose a new ultra-supercritical coal plant increases that to 42%. Assume coal burning emits 24.5 kgC/GJ.

a. If CO_2 emissions are eventually taxed at $50 per metric ton, what would the tax savings be for the supercritical plant ($/kWh)?

SOLN: From (1.1), the conventional-plant carbon heat rate would be

$$\text{Heat rate(conventional)}=\frac{3600\text{ kJ/kWh}}{\eta}=\frac{3600}{0.33}=10{,}909\text{ kJ/kWh}$$

It's CO_2 emission rate would be

$$CO_2(conventional)=\frac{24.5kgC}{10^6kJ}x\frac{10{,}909kJ}{kWh}x\frac{44kgCO_2}{12kgC}=0.980kgCO_2/kWh$$

The ultra-supercritical plant emission rate would be

$$\text{Heat rate(ultra-crit)}=\frac{3600\text{ kJ/kWh}}{\eta}=\frac{3600}{0.42}=8{,}571\text{ kJ/kWh}$$

$$CO_2\left(\text{ultra-critical}\right)=\frac{8571kJ}{kWH}x\frac{24.5kgC}{10^6kJ}x\frac{44kgCO_2}{12kgC}=0.770kgCO_2/kWh$$

Carbon tax savings would be

$$Tax\ savings=\frac{(0.980-0.770)kgCO_2}{kWh}x\frac{\$50}{10^3kg}=\$0.0105/kWh=1.05¢/kWh$$

b. If coal that delivers 24 million kJ of heat per metric ton costs $40/tonne what would be the fuel savings for the ultra-supercritical plant ($/kWh)?

SOLN:

$$Conventional=\frac{\$40}{10^3kg}x\frac{10^3kg}{24x10^6kJ}x\frac{10{,}909kJ}{kWh}=\$0.0182/kWh$$

$$Ultra=\frac{\$40}{10^3kg}x\frac{10^3kg}{24x10^6kJ}x\frac{8571kJ}{kWh}=\$0.0143/kWh$$

Savings = (1.82 - 1.43)¢/kWh = 0.39¢/kWh

1.5 The United States has about 300 GW of Coal-fired power plants that in total emit about 2 gigatonnes of CO_2/yr while generating about 2 million GWh/yr of electricity.

a. What is their overall capacity factor?

SOLN: Overall capacity factor

$$CF=\frac{GWh/yr}{P_R(GW)\cdot 8760h/yr}=\frac{2x10^6GWh/yr}{300GW\cdot 8760}=76.1\%$$

b. What would be the total carbon emissions (Gt CO_2/yr) that could result if all of coal plants with 50%-efficient natural gas combined-cycle (NGCC) plants that emit 13.7 kgC per gigajoule of fuel?

SOLN:

$$\text{Heat rate}=\frac{3600\text{ kJ/kWh}}{\eta}=\frac{3600}{0.50}=7{,}200\text{ kJ/kWh}$$

$$\text{NGCC emissions} = \frac{7200 kJ}{kWh} x \frac{13.7 kgC}{10^6 kJ} x \frac{2x10^{12} kWh}{yr} x \frac{44 kgCO_2}{12 kgC}$$
$$= \frac{0.723x10^{12} kgCO_2}{yr} x \frac{tonne}{1000 kg} x \frac{Gt}{10^9 tonne} = 0.723 \text{ GtCO}_2\text{/yr}$$

c. Total U.S. CO_2 emissions from all electric power plants about 5.8 Gt/yr. What percent reduction would result from switching all the above coal plants to NGCC?

$$\text{Reduction} = \frac{(2-0.723)}{5.8} = 22\%$$

CO_2 savings = 2 - 0.723 = 1.28 Gt/yr (a 64% decrease !)

1.6 Consider a 55%-efficient, 100-MW, NGCC merchant power plant with capital cost of $120 million. It operates with a 50% capacity factor (CF). Fuel currently costs $3 per million Btu (MMBtu) and current annual O&M is 0.4¢/kWh. The utility uses a levelizing factor LF = 1.44 to account for future fuel and O&M cost escalation (see Problem 1.6).

The plant is financed with 50% equity at 14% and 50% debt at 6%. For financing purposes, the "book life" of the plant is 30 years. The fixed charge rate, which includes insurance, fixed O&M, corporate taxes, etc., includes an additional 6% on top of finance charges.

a. Find the annual fixed cost of owning this power plant ($/yr).

SOLN: First, find the weighted average cost of capital (WACC)

WACC = 0.5 x 14% + 0.5 x 6% = 10%

$$\text{CRF}(10\%, \text{30-yr}) = \frac{0.10(1+0.10)^{30}}{(1.10)^{30}-1} = 0.1061/yr$$

FCR = CRF + 0.06 = 0.1061 + 0.06 = 0.1661/yr

Annualized Fixed Cost = 0.1661/yr x $120 million = $19.93 million/yr

b. Find the levelized cost of fuel and O&M for the plant.

SOLN:

$$\text{Heat rate} = \frac{3412 \text{ Btu/kWh}}{\eta} = \frac{3412}{0.55} = 6204 \text{ Btu/kWh}$$

Electricity Generated=100,000 kW x 8760 hr/yr x (CF=0.5)= 438×10^6 kWh/yr

$$\text{Initial Fuel Cost} = \frac{\$3}{10^6 \text{Btu}} \text{ x } \frac{6204 \text{Btu}}{\text{kWh}} \text{ x } 438 \text{x} 10^6 \text{ kWh/yr} = \$8.15 \text{x} 10^6\text{/yr}$$

Initial O&M = $0.004/kWh x 438x10^6 kWh = $1.752x10^6/yr

Levelized Cost of (Fuel + O&M) = 1.44 x (1.752 + 8.15) x10^6 = $14.26 x 10^6 /yr

c. Find the levelized cost of energy (LCOE).

$$\text{LCOE} = \frac{\$(19.93+14.26)\text{x}10^6/\text{yr}}{438\text{x}10^6\text{kWh/yr}} = \$0.078/\text{kWh}$$

1.7 The levelizing factors shown in Fig. 1.28 that allow us to account for fuel and O&M escalations in the future are derived in Appendix A and illustrated in Example A.5.

a. Find the levelizing factor for a utility that assumes its fuel and O&M costs will escalate at an annual rate of 4% and which uses a discount factor of 12%.

SOLN:

$$\text{Equivalent discount rate } (A.14) = d' = \frac{d-e}{1+e} = \frac{0.12-0.04}{1+0.04} = 0.07692$$

$$\text{Levelization Factor, } LF(A.25) = \frac{\left[(1+d')^n - 1\right]}{d'(1+d')^n} \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

$$LF = \frac{(1.07692^{30}-1)}{(0.07692x1.07692^{30})} \cdot \frac{(0.12x1.12^{30})}{(1.12)^{30}-1} = \frac{8.237}{0.710} x \frac{3.595}{28.96} = 1.44$$

b. If natural gas now costs $4 per million Btu ($4/MMBtu), use the levelization factor just found to estimate the life-cycle fuel cost ($/kWh) for a power plant with a heat rate of 7,000 Btu/kWh.

SOLN:

$$\text{Levelized fuel cost} = \frac{\$4}{10^6\text{Btu}} \text{x} \frac{7{,}000 \text{ Btu}}{\text{kWh}} \text{x}1.44 = \$0.0403/\text{kWh} \approx 4¢/\text{kWh}$$

1.8 Consider the levelizing factor approach derived in Appendix A as applied to electricity bills for a household. Assume the homeowner's discount rate is the 6%/yr interest rate that can be obtained on a home equity loan, the current price of electricity is $0.12/kWh, and the time horizon is 10 years.

a. Ignoring fuel price escalation (*e* = 0), what is the 10-yr levelized cost of electricity ($/kWh)?

SOLN:

$$\text{Equivalent discount rate } (A.14) = d' = \frac{d-e}{1+e} = \frac{0.06}{1} = 0.06$$

$$\text{Levelization Factor, } LF(A.25) = \frac{\left[(1+d')^n - 1\right]}{d'(1+d')^n} \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

$$LF = \frac{(1.06^{10} - 1)}{(0.06x1.06^{10})} \cdot \frac{(0.06x1.06^{10})}{(1.06)^{10} - 1} = 1.0$$

LCOE = Current Price x LF = $0.12 x 1.0 = $0.12 = 12¢/kWh
(Could have just written that down without any calcs)

b. If fuel escalation is the same as the discount rate (6%), what is the levelization factor and the levelized cost of electricity?

SOLN:

$$\text{Equivalent discount rate } (A.14) = d' = \frac{d-e}{1+e} = \frac{0.06-0.06}{1+0.06} = 0$$

$$\text{Levelization Factor, } LF(A.25) = \frac{\left[(1+d')^n - 1\right]}{d'(1+d')^n} \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

$$LF = \frac{(1^{10} - 1)}{(0x1.0)} \cdot \frac{(0.06x1.06^{10})}{(1.06)^{10} - 1} = \frac{0}{0} x \frac{(0.06x1.06^{10})}{(1.06)^{10} - 1} = ?\text{blows up}$$

From Eq. A.12, when d = e, the present value function PVF = *n*.

$$LF = PVF(d',n) \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right] = n \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

$$LF = 10 \cdot \frac{(0.06x1.06^{10})}{(1.06)^{10} - 1} = 10x\frac{(0.06x1.06^{10})}{(1.06)^{10} - 1} = 10x0.1359 = 1.359$$

c. With a 6% discount rate and 4% electricity rate increases projected into the future, what is the levelizing factor and LCOE?

SOLN:

$$\text{Equivalent discount rate } (A.14) = d' = \frac{d-e}{1+e} = \frac{0.06-0.04}{1+0.04} = 0.019231$$

$$\text{Levelization Factor, } LF(A.25) = \frac{\left[(1+d')^n - 1\right]}{d'(1+d')^n} \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

$$LF = \frac{(1.019231^{10} - 1)}{(0.019231x1.019231^{10})} \cdot \frac{(0.06x1.06^{10})}{(1.06)^{10} - 1} = 9.0188x0.13587 = 1.225$$

LCOE = Current Price x LF = $0.12 x 1.225 = $0.1470 = 14.7¢/kWh

1.9 Consider the levelizing factor approach derived in Appendix A as applied to electricity bills for a household. Assume the homeowner's discount rate is the

5%/yr interest rate that can be obtained on a home equity loan, the current price of utility electricity is \$0.12/kWh, price escalation is estimated at 4%/yr, and the time horizon is 20 years.

a. What is the levelized cost of utility electricity for this household (\$/kWh) over the next 20 years?

$$\text{Equivalent discount rate } (A.14) = d' = \frac{d-e}{1+e} = \frac{0.05-0.04}{1+0.04} = 0.00962$$

$$\text{Levelization Factor, } LF(A.25) = \frac{\left[(1+d')^n - 1\right]}{d'(1+d')^n} \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

$$LF = \frac{(1.00962^{20} - 1)}{(0.00962x1.00962^{20})} \cdot \frac{(0.05x1.05^{20})}{(1.05)^{20} - 1} = 18.1156x0.0.08024 = 1.454$$

LCOE = \$0.12/kWh x 1.454 = \$0.174/kWh

b. Suppose the homeowner considers purchasing a rooftop photovoltaic system that costs \$12,000 and delivers 5,000 kWh/yr. Assume the only costs for those PVs are the annual loan payments on a \$12,000, 5%, 20-yr loan that pays for the system (we're ignoring tax benefits associated with the interest portion of the payments). Compare the LCOE (\$/kWh) for utility power vs these PVs.

$$\text{CRF(5\%, 20yr)} = \frac{i(1+i)^n}{(1+i)^n - 1} = \frac{0.05(1.05)^{20}}{(1.05)^{20} - 1} = 0.08024$$

Annual loan payments A = 0.08024 x \$12,000 = \$962.88/yr

Photovoltaic electricity cost = \$962.44/yr / 5,000 kWh/yr = \$0.193/kWh

1.10 Using the representative power plant heat rates, capital costs, fuels, O&M, levelizing factors, and fixed charge rates factors given in Table 1.4, compute the cost of electricity from the following power plants. For each, assume a fixed charge rate of 0.167/yr.

a. Pulverized-coal steam plant with capacity factor CF = 0.70.

SOLN:

$$\text{Annualized fixed costs} = \frac{\text{\$2300/kW x 0.167/yr}}{\text{8760 h/yr x 0.70}} = \text{\$0.0626/kWh}$$

$$\text{Levelized energy cost} = \left(\frac{\$2.50}{10^6\text{Btu}} \text{x} \frac{\text{8750 Btu}}{\text{kWh}} + \frac{\$0.004}{\text{kWh}}\right) x1.5 = \text{\$0.03881/kWh}$$

$$\text{LCOE} = (\$0.0626 + \$0.0388)\text{/kWh} = \text{\$0.1014/kWh} = 10.14¢\text{/kWh}$$

b. Combustion turbine with CF = 0.20.

SOLN:

$$\text{Annualized fixed costs} = \frac{\$990/\text{kW x } 0.167/\text{yr}}{8760 \text{ h/yr x } 0.20} = \$0.0944/\text{kWh}$$

$$\text{Levelized energy cost} = \left(\frac{\$6.00}{10^6\text{Btu}} \text{x} \frac{9300 \text{ Btu}}{\text{kWh}} + \frac{\$0.004}{\text{kWh}} \right) x1.5 = \$0.0897/\text{kWh}$$

$$\text{LCOE} = (\$0.0944 + \$0.0897)/\text{kWh} = \$0.1841/\text{kWh} = 18.41¢/\text{kWh}$$

c. Combined cycle natural gas plant with CF = 0.5.

SOLN:

$$\text{Annualized fixed costs} = \frac{\$1300/\text{kW x } 0.167/\text{yr}}{8760 \text{ h/yr x } 0.50} = \$0.0496/\text{kWh}$$

$$\text{Levelized energy cost} = \left(\frac{\$6.00}{10^6\text{Btu}} \text{x} \frac{6900 \text{ Btu}}{\text{kWh}} + \frac{\$0.004}{\text{kWh}} \right) x1.5 = \$0.068/\text{kWh}$$

$$\text{LCOE} = (\$0.0496 + \$0.068)/\text{kWh} = \$0.1177/\text{kWh} = 11.77¢/\text{kWh}$$

d. Nuclear plant with CF = 0.85.

SOLN:

$$\text{Annualized fixed costs} = \frac{\$4500/\text{kW x } 0.167/\text{yr}}{8760 \text{ h/yr x } 0.85} = \$0.1009/\text{kWh}$$

$$\text{Levelized energy cost} = \left(\frac{\$0.60}{10^6\text{Btu}} \text{x} \frac{10{,}500 \text{ Btu}}{\text{kWh}} + \frac{\$0.004}{\text{kWh}} \right) x1.5 = \$0.0155/\text{kWh}$$

$$\text{LCOE} = (\$0.1009 + \$0.0155)/\text{kWh} = \$0.1164/\text{kWh} = 11.64¢/\text{kWh}$$

e. A wind turbine costing \$1600/kW with CF = 0.40, O&M \$60/yr-kW, LF = 1.5, FCR = 0.167/yr.

SOLN:

$$\text{Annualized fixed costs} = \frac{\$1600/\text{kW x } 0.167/\text{yr}}{8760 \text{ h/yr x } 0.40} = \$0.0763/\text{kWh}$$

$$\text{Levelized variable cost} = \left(\frac{\$60/\text{kW/yr}}{8760 x 0.4 kWh/yr/kW} \right) x1.5 = \$0.0257/\text{kWh}$$

$$\text{LCOE} = (\$0.0763 + \$0.0257)/\text{kWh} = \$0.10199/\text{kWh} = 10.2¢/\text{kWh}$$

Alternative approach to the solution (assume 1 kW source):

$$\text{Fixed costs} = 1 \text{ kW x } \frac{\$1600}{\text{kW}} \text{ x } 0.167 = \$267.2/\text{yr}$$

$$\text{Levelized Variable costs} = 1 \text{ kW} \cdot \frac{\$60/yr}{kW} \text{x} 1.5 = \$90/\text{yr}$$

$$\text{LCOE} = \frac{\$267.2/\text{yr} + \$90/\text{yr}}{1 \text{ kWx } 8760 \text{ h/yr x } 0.40} = \$0.102/\text{kWh} = 10.2¢/\text{kWh}$$

1.11 Consider the following very simplified load duration curve for a small utility:

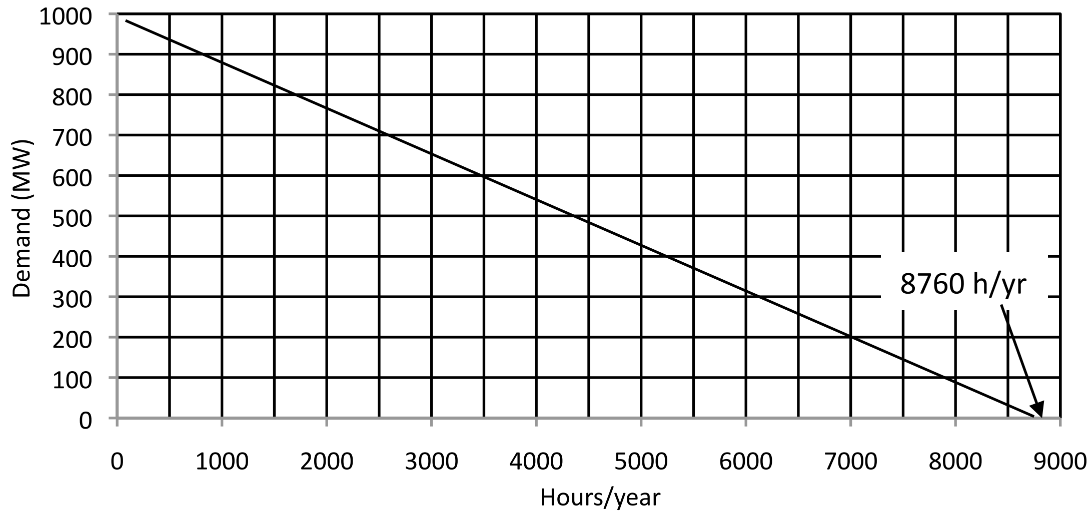


Figure P1.10

a. How many hours per year is the load less than 200 MW?

SOLN: 8760 hrs – 7000 hrs = 1760 hrs with P < 200 MW

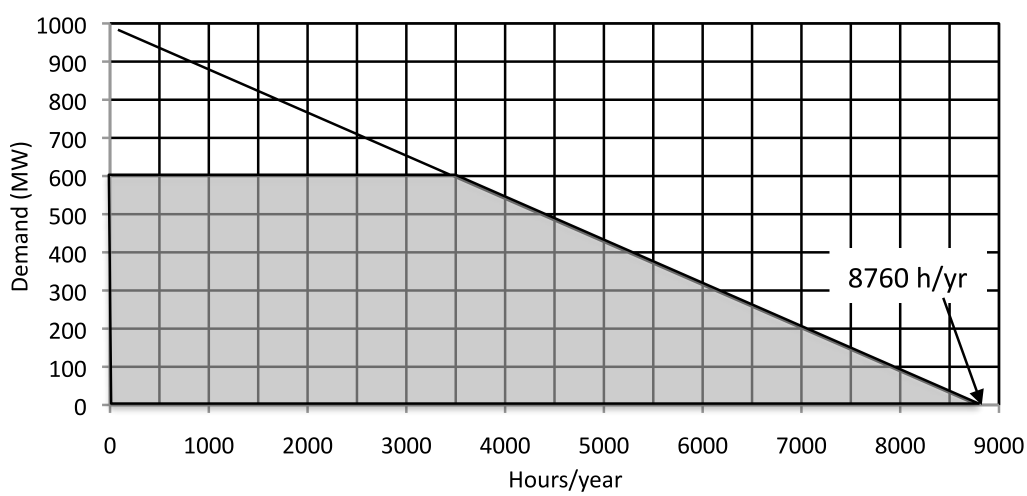
b. How many hours per year is the load between 200 MW and 600 MW?

SOLN: Above 200 MW for 7000 hrs; Above 600 MW for 3500 hrs

Between 200 and 600 MW for 7000 – 3500 = 3500 hrs

c. If the utility has 600 MW of base-load coal plants, what would their average capacity factor be?

SOLN:



CF is the fraction of the 600-MW rectangle that is shaded.

$$CF = \frac{600x3500 + 0.5x600(8760 - 3500)}{600x8760} = 0.70$$

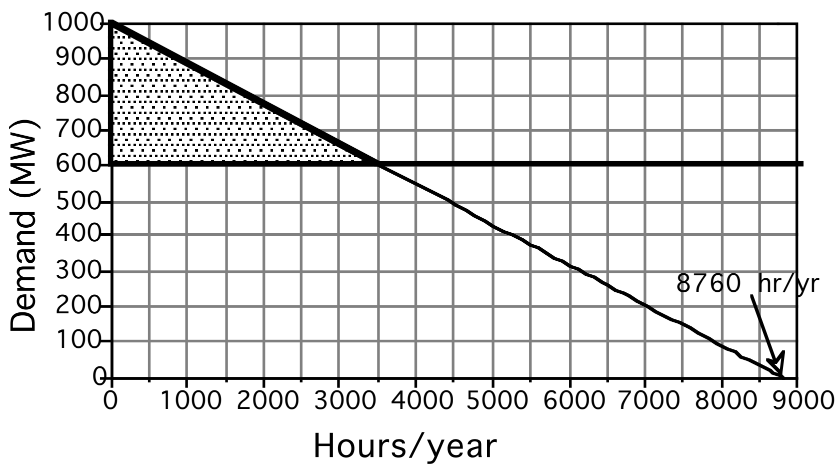
d. Energy delivered by the coal plants

SOLN: Energy = 8760 h/yr x 600 MW x 0.70 = 3.68 x 10^6 MWh/yr

1.12 Suppose the utility in Problem 1.11 has 400 MW of combustion turbines operated as peaking power plants.

a. How much energy will these turbines deliver (MWh/yr)?

SOLN: CF for the 400 MW of peakers is the dark triangular area out of the rectangular area:



$$CF = \frac{0.5x400MWx3500h/yr}{400MWx8760h/yr} = 0.20$$

Energy = 8760 h/yr x 400 MW x 0.20 = 0.70 x 10^6 MWh/yr

b. If these peakers have the "revenue required" curve shown below, what would the selling price of electricity from these plants (¢/kWh) need to be?

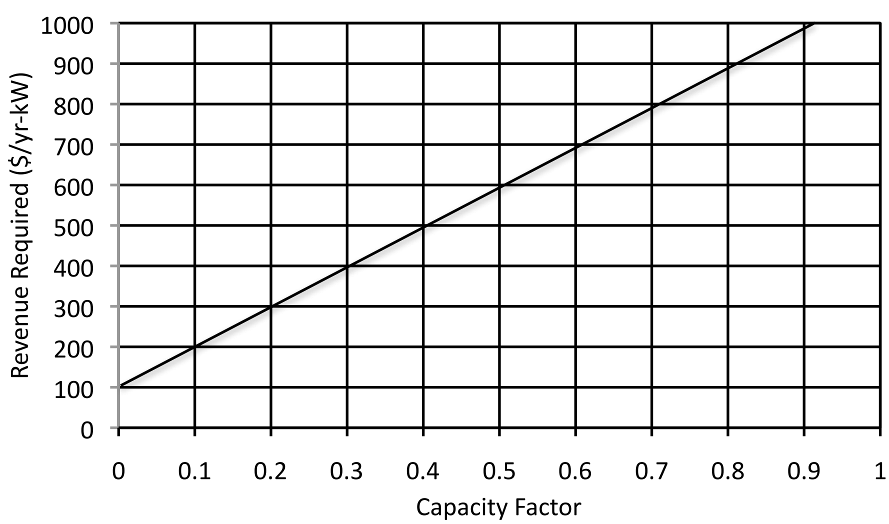


Figure P 1.11

SOLN: At a capacity factor of 0.2,

Revenue required = \$300/yr/kW x 400,000 kW = 120 x 10^6 \$/yr

$$\text{Revenue/kWh} = \frac{\$120x10^6 \ / \ yr}{0.7x10^9 \ kWh \ / \ yr} = \$0.171 \ / \ kWh$$

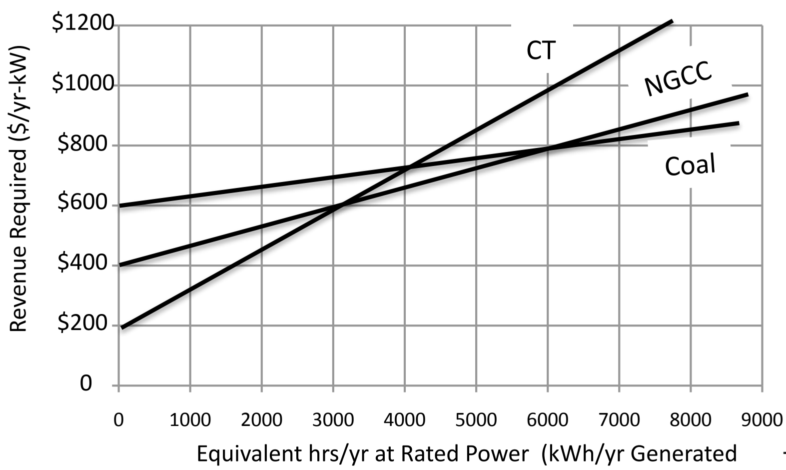
1.13 As shown below, on a per kW of Rated Power basis, the costs to own and operate a combustion (gas) turbine (CT), a natural-gas combined cycle (NGCC), and a coal plant have been determined to be:

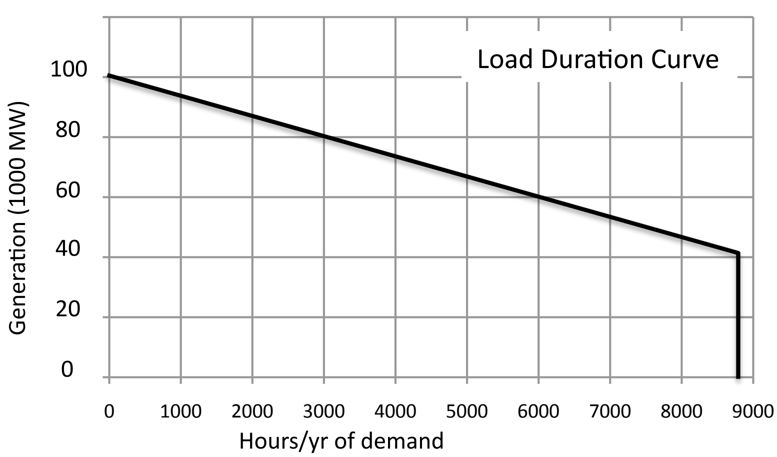
CT (\$/yr) = \$200 + \$0.1333 x hrs/yr

NGCC (\$/yr) = \$400 + \$0.0666 x hrs/yr

Coal (\$/yr) = \$600 + \$0.0333 x hrs/yr

Also shown is the Load Duration Curve for an area with a peak demand of 100 GW.





a. How many megawatts (MW) of each type of plant would you recommend?

SOLN: For < 3000 hrs, CT is cheapest, so use (100 - 80) = 20 MW of CT

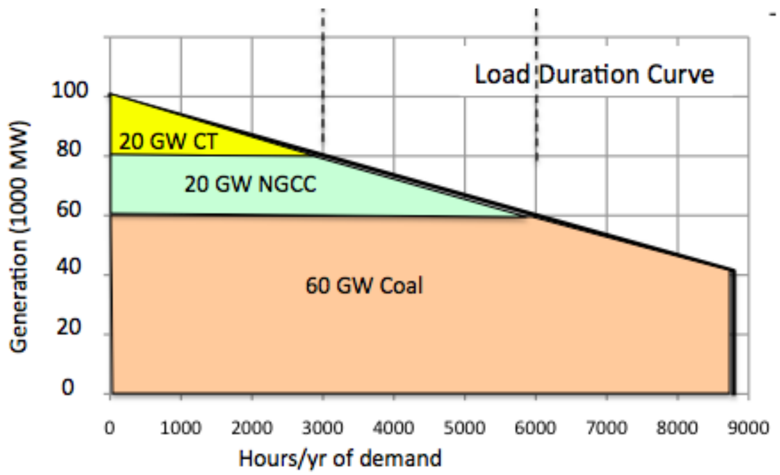
For > 6000 hrs, Coal is the cheapest, so use 60 GW of Coal

Load between 3000 - 6000 hrs, NGCC is cheapest, so use 20 GW of NGCC

b. What would be the capacity factor for the NGCC plants?

SOLN: From the ratio of areas shown in the load duration curve

$$\text{CF(NGCC)} = \frac{20x3000 + 0.5x20x3000}{20x8760} = \frac{90{,}000}{175{,}200} = 0.514$$



c. What would be the average cost of electricity from the NGCC plants?

SOLN:

$$\text{Costing NGCC (\$/yr)} = \frac{\$400 + \$0.0666 \text{ x } 0.514 \text{ x } 8760 \text{ hrs/yr}}{1kWx0.514x8760hr/yr} = \frac{\$700\text{/yr}}{4503kWh/yr} = \$0.155/kWh$$

d. What would be the average cost of electricity from the CT plants?

$$\text{CF(CT)} = \frac{\text{Triangular Area}}{\text{Rectangle Area}} = \frac{0.5 \text{ x } 20\text{x}10^6\text{kW x3000 h/yr}}{20\text{x}10^6\text{kW x 8760 h/yr}} = 0.171$$

which is equivalent to 0.171 x 8760 h/yr = 1498 h/yr

$$\text{Costing CT (\$/yr)} = \frac{\$200 + \$0.1333 \text{ x } 1498 \text{ h/yr}}{1 \text{ kW x } 0.171 \text{ x } 8760 \text{ h/yr}} = \$0.267\text{/kWh}$$

e. What would be the average cost of electricity from the coal plants?

$$\text{CF(CT)} = \frac{\text{Shaded Area}}{\text{Rectangle Area}}$$

$$= \frac{60\text{x}8760\text{-}0.5\text{x}(8760\text{-}6000)\text{x}20}{60 \text{ x } 8760} = 0.9479$$

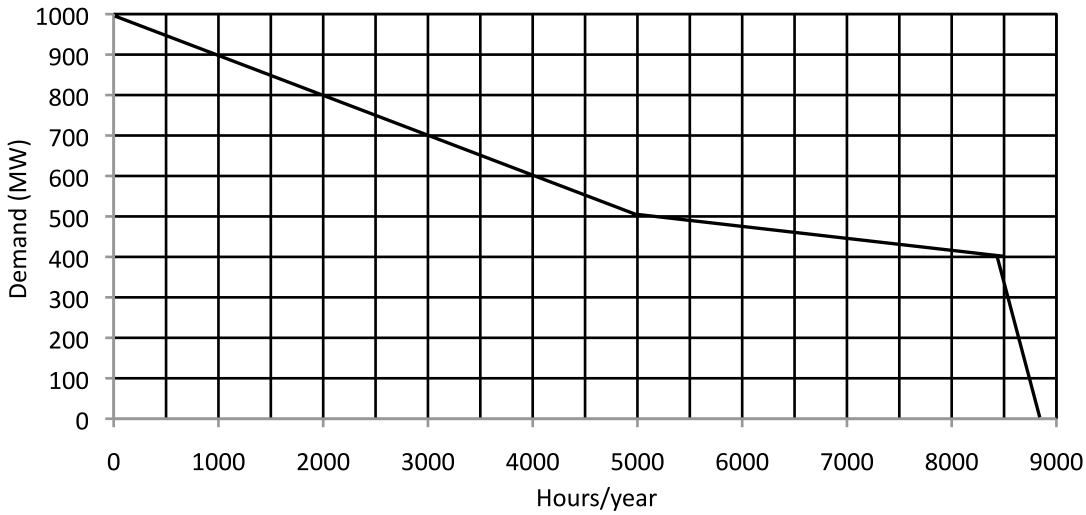
which is equivalent to 0.9479 x 8760 h/yr = 8300 h/yr

$$\text{Costing Coal (\$/yr)} = \frac{\$600 + \$0.0333 \text{ x } 8300 \text{ h/yr}}{1 \text{ kW x } 0.9479 \text{ x } 8760 \text{ h/yr}} = \$0.1055\text{/kWh}$$

1.14 The following table gives capital costs and variable costs for coal plants, a natural gas combined-cycle plants, and natural-gas-fired combustion turbines:

	COAL	NGCC	CT
Capital cost ($/kW)	$2,000	$1,200	$800
Variable cost (¢/kWh)	2.0	4.0	6.0

This is a municipal utility with a low fixed charge rate of 0.10/yr for capital costs. Its load duration curve is shown below.

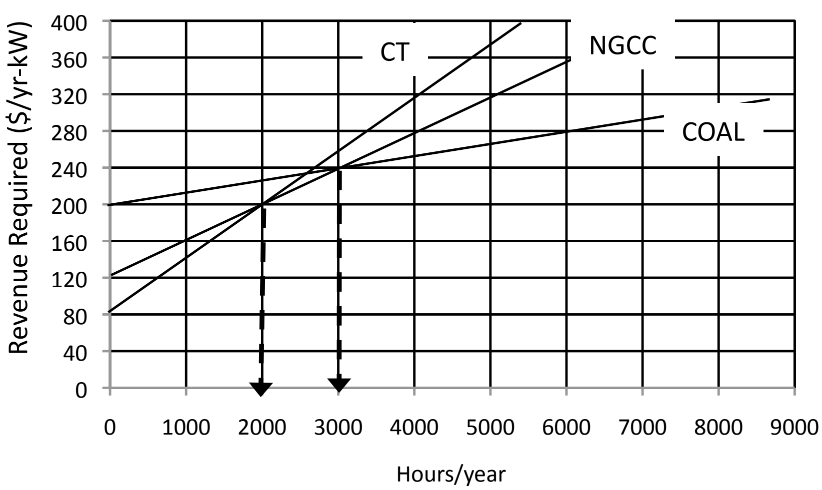


a. On a single graph, draw the screening curves (Revenue Required $/yr-kW vs h/yr) for the three types of power plants (like Fig. 1.29).

SOLN: Coal $/yr-kW = $2000/kW x 0.10/yr + 0.02$/kWh x H (h/yr) = 200+0.02 H

CC $/yr = $1200 x 0.10/yr + 0.04 $/h x H (h/yr) = 120 + 0.04 H

GT $/yr = $800 x 0.10/yr + 0.06 $/h x H h/yr = 80 + 0.06 H



b. For a least-cost system, what is the maximum number of hours a combustion turbine should operate, the minimum number of hours the coal plant should operate, and the range of hours the NGCC plants should operate. You can do this algebraically or graphically.

SOLN: Solving the above equations algebraically (or you could use the graph)

CT-CC Intersection: 120 + 0.04 H = 80 + 0.06 H…. H = 2000 hrs

CC-Coal Intersection: 200 + 0.02 H = 80 + 0.06 H…. H = 3000 hrs

CT operate < 2000 hrs; 2000<CC<3000 hrs; Coal > 3000 hrs.

c. How many MW of each type of power plant would you recommend?

SOLN: Demand is greater than 700 MW for 3000 h/yr, so 700 MW of coal plants will run at least 3000 hours. Demand is between 800 MW and 1000 MW for less than 2000 h/yr, so use 200 MW of CT. That leaves 100 MW of NGCC that will run at least 2000 h/yr and no more than 3000 h/yr.