Energy and the Built Environment
CRP 470.004 /570.004

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Lecture 6

Energy economics (continued) and life cycle assessment

Outline

- Reading – LCA, Lovins, Renewables
- Review homework (light bulb economics 20 min)
- Economic and energy analysis
  - Simply payback
  - Discount factors
  - Net present value

How can we assess energy choices?

1. Economic impacts
2. Environmental impacts
3. Social impacts

- The triple bottom line

Economic Impacts

Economic evaluation tools

- Simply payback
- Lifetime cost (using discount factor)
- Lifetime cost of energy
- Lifetime cost of emissions

Economic comparison: light bulbs

	 Incandescent	 CFL	 LED
Brand	Phillips	Phillips	Cree
Price ($)	$ 0.41	$ 2.25	$ 8.00
Intensity (lumen)	860	810	815
Efficiency (lm/w)	14.3	62.3	74.1
Power (W)	60	13	11
Lifetime (hr)	1,000	10,000	25,000

Source: Product specs, Home Depot, 2015

How can we compare costs? Apples to apples?

- Total costs = capital cost + variable costs
- Put all of the costs on a $/year basis. Assume that you use the bulb 5 hours/night.

Economic comparison: light bulbs

	 Incandescent	 CFL	 LED
Brand	Phillips	Phillips	Cree
Price ($)	$ 0.41	$ 2.25	$ 8.00
Lifetime (yr)	0.68	6.85	17.12
Capital cost ($/yr)	0.59	0.33	0.47
Electricity costs ($/yr)	13.14	2.85	2.41
Total costs ($/yr)	13.88	3.26	2.99

Source: Product specs, Home Depot, 2015

Simple Payback Period

- Simple payback is the time to recover an investment, through savings, without discounting.
- When you are planning to upgrade an existing technology with a more efficient one, this would tell you how long until you have earned back your investment.

$$\text{Simple Payback (yr)} = \frac{\text{Capital Cost (\$)}}{\text{Annual Energy Savings } \left(\frac{\text{kWh}}{\text{yr}}\right) \text{ x Energy Price } \left(\frac{\$}{\text{kWh}}\right)}$$

Simple Payback Period: CFL vs Incandescent

$$\text{Simple Payback (yr)} = \frac{\text{Capital Cost (\$)}}{\text{Annual Energy Savings } \left(\frac{\text{kWh}}{\text{yr}}\right) \text{ x Energy Price } \left(\frac{\$}{\text{kWh}}\right)}$$

- The capital cost for the CFL is $2.25
- The CFL uses 13 Watts instead of 60 W, which is an energy saving of 47 W. If the light is operated for the 5 hours/day then the annual energy savings = .047kW x 5 hr/day x 365 days/yr = 86 kWh/yr
- Energy price is 0.12$/kWh
- Simple payback (yrs)

  = $2.25/ (86 kWh/yr *$.012/kWh)

  = 0.22yrs (80 days)

Interest rates and discount rates

- The Time-Value of Money: "A bird in hand is worth two in the bush"
- It is more important to have a dollar today than in the future due to lost opportunities, our ability to lend money and collect interest.
- Inflation also changes money's 'value' over time. Usually discount rates reflect both interest rates and inflation:

discount rate (r) = interest rate + inflation

- Discount rates are prices, specifically the relative price, used to compare future and present goods and services in benefit-cost analyses.

Nominal Discount Rates. A forecast of nominal or market interest rates for 2005 based on the economic assumptions from the 2006 Budget are presented below. These nominal rates are to be used for discounting nominal flows, which are often encountered in lease-purchase analysis.

Nominal Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	30-Year
3.7	4.1	4.4	4.6	5.2

Real Discount Rates. A forecast of real interest rates from which the inflation premium has been removed and based on the economic assumptions from the 2006 Budget is presented below. These real rates are to be used for discounting real (constant-dollar) flows, as is often required in cost-effectiveness analysis.

Real Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	30-Year
1.7	2.0	2.3	2.5	3.1

http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html

Future Value

- Future Value: If we put an amount of money, P, in the bank at an interest rate of r, the future value in 1 time period will be:

$$\mathbf{F_1} = P(1+r)$$

- The future value in 2 time periods will be:

$$\mathbf{F_2} = F_1(1+r) = P(1+r)^2$$

- The value in n time periods will be:

$$\mathbf{F} = P(1+r)^n$$

Present Value

- Using the equation for compounding interest, we can rearrange to determine what the present value would be of a future dollar amount:

$$P = \frac{F}{(1+r)^n}$$

Example

- I have access to a lending rate of 5%. If I put \$100 in the bank for 5 years, how much money would I have?

$$\mathrm{F} = P(1+r)^{n} = \$100(1.05)^{5} = \$128$$

- If someone offers to give me \$100 in 5 years, how much would that money be worth today?

$$\mathrm{P} = \frac{\mathrm{F}}{(1+\mathrm{r})^{\mathrm{n}}} = \frac{\$100}{(1.05)^{5}} = \$78$$

Net Present Value

- The Net Present Value (NPV) places all future costs and benefits of a technology or service at the present time. It is the discounted series of costs and benefits:

$$\text{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Example

- Back to our light bulbs…the NPV would look like:

$$\text{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} = -\$2.25 + \frac{-\$2.85}{(1+.07)^1} + \frac{-\$2.85}{(1+.07)^2} + \ldots + \frac{-\$2.85}{(1+.07)^6}$$

Uniform Series Amounts

- To compare costs in a uniform series of payments (e.g., monthly or annual) we assume a payment U is made at each interval against a borrowed amount P

$$U = P\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right] = P\left[\frac{r}{1-(1+r)^{-n}}\right]$$

Uniform Series Amounts

- This can be rearranged to determine the present value of a series of uniform, future payments:

$$P = U\left[\frac{1-(1+r)^{-n}}{r}\right]$$

Summary

Name	Converts	Equation
Present value	F to P	$\frac{1}{(1+i)^n}$
Uniform series present value	U to P	$\frac{1-(1+i)^{-n}}{i}$
Single payment compound amount	P to F	$(1+i)^n$
Compound amount	U to F	$\frac{(1+i)^n-1}{i}$
Capital recovery	P to U	$\frac{i}{1-(1+i)^{-n}}$
Sinking fund	F to U	$\frac{i}{(1+i)^{-n}-1}$

(Table 13.2 on page 554 of Introduction to Engineering and the Environment, Edward S. Rubin, McGraw-Hill, 2001)

Back to our light bulbs…

- Before, we put our costs on an annual basis, but we didn't account for the time value of money. Calculate the capital costs if they are spread out annually over the lifetime of each bulb with a discount rate of 8%.

$$U_{CapitalLED} = P\left[\frac{r}{1-(1+r)^{-n}}\right] = \$8\left[\frac{.08}{1-(1+.08)^{-14}}\right] = \$0.93$$

$$U_{CapitalCFL} = P\left[\frac{r}{1-(1+r)^{-n}}\right] = \$2.25\left[\frac{.08}{1-(1+.08)^{-5.5}}\right] = \$0.51$$

Annualized costs

- Annualized (using discount rate) for CFL/LED

$$U_{LED} = U_{capital} + U_{electricity} = 0.93\$/yr + 2.41\$/yr = 3.34\$/yr$$

$$U_{CFL} = U_{capital} + U_{electricity} = 0.51\$/yr + 2.85\$/yr = 3.36\$/yr$$

Comparing outcomes….

Discount Rate of 7%

electricity costs ($/yr)	$13.14	$2.85	$2.41
Simple capital cost ($/yr)	$0.74	$0.41	$0.58
Levelized Capital Cost ($/yr)	$0.78	$0.51	$0.93
Simple annual costs ($/yr)	$13.88	$3.26	$2.99
Discounted Annual Cost ($/yr)	$13.92	$3.36	$3.34

Discount Rate of 15%

electricity costs ($/yr)	$13.14	$2.85	$2.41
Simple capital cost ($/yr)	$0.74	$0.41	$0.58
Levelized Capital Cost ($/yr)	$0.82	$0.63	$1.41
Simple annual costs ($/yr)	$13.88	$3.26	$2.99
Discounted Annual Cost ($/yr)	$13.96	$3.48	$3.82

Before moving on....

- Can we add an environmental metric to our comparison?
- What about CO_2 emissions associated with O&M?
- Is this sufficient?

What are the CO_2 savings?

- PNM's generation portfolio is about 60% coal, 20% natural gas, 20% nuclear. The average emission factor was about 0.66 kg of CO_2 per kWh of electricity.
- How many kg of CO_2 emissions are reduced per year by using a CFL?
- Calculate the cost of reducing emissions, from replacing an incandescent w/ a CFL, in $/kg CO_2 reduced.

What are the CO2 savings?

- PNM's generation portfolio is about 60% coal, 20% natural gas, 20% nuclear. The average emission factor was about 0.66 kg of CO2 per kWh of electricity.
- How many kg of CO2 emissions are reduced per year by using a CFL?
- 87 kWh/yr * 0.66kgCO2/kWh = 57 kg CO2/yr
- Calculate the cost of reducing emissions, from replacing an incandescent w/ a CFL, in $/kg CO2 reduced:

$$\frac{(\$/yr3.82 - \$/yr13.96)}{57kgCO2/yr} = -0.18\$/kgCO2$$

Continuous and Discrete Time Analysis

Discount rates are set for different time frames. Most discounting is annual, but we can use any interval, such as monthly discounts or daily discounts.

If we start with a monthly discount rate (r_M) and we want to find out the correspondent annual discount rate (r_A), or vice versa:

$$(1+ r_A) = (1+ r_M)^{12} \quad \text{or,} \quad (1+ r_A)^{1/12} = (1+ r_M)$$

Suppose you keep $10 in the (piggy) bank. Assuming a 7% annual discount rate, after 10 years this amount is worth $5

You can find this value using discrete discounting or you can approximate using continuous discounting.

discrete discounting

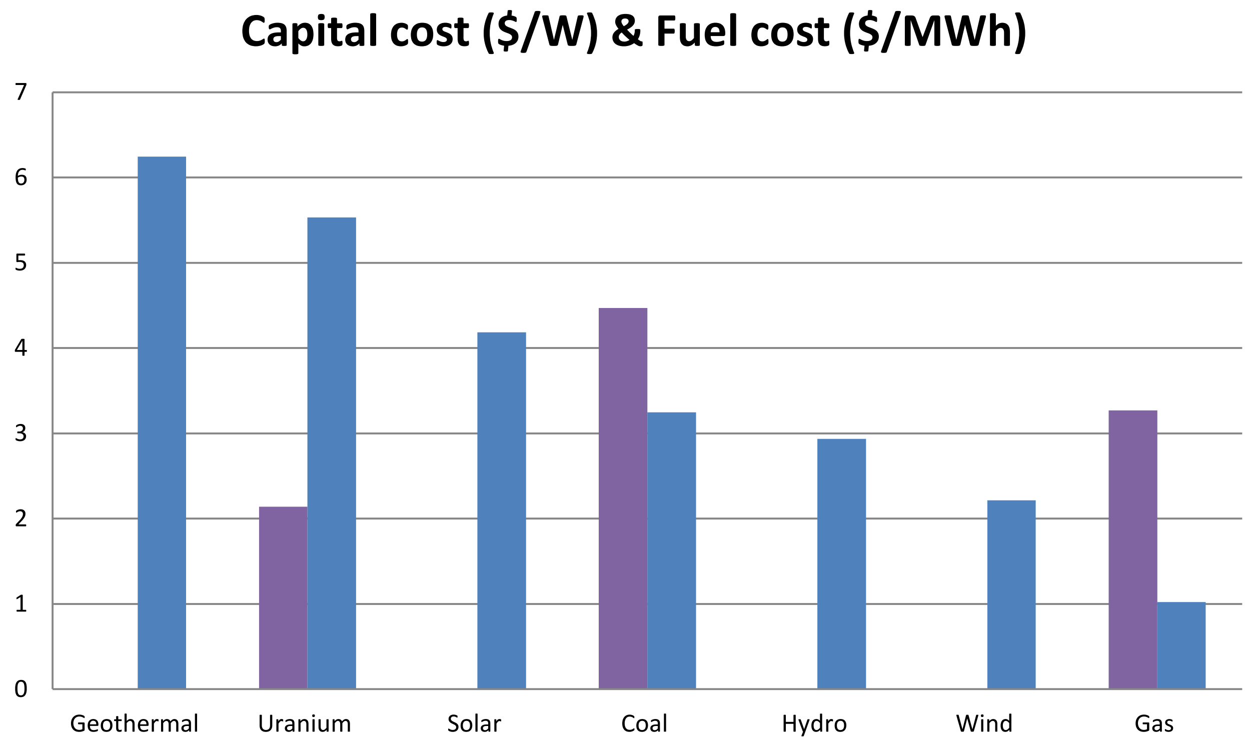
$$= \frac{10}{(1+0.07)^t}$$

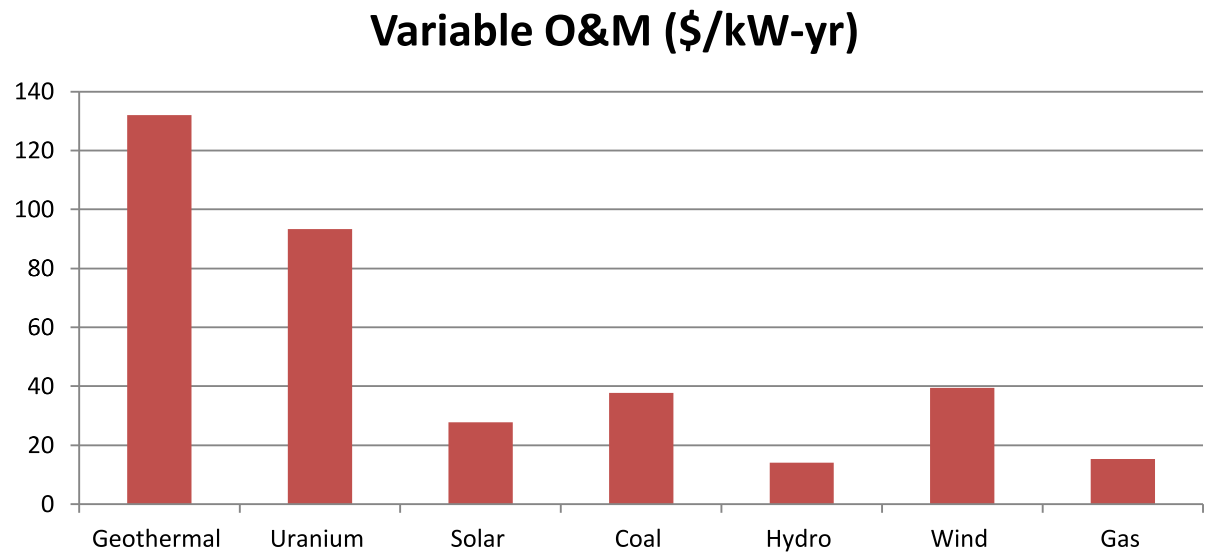
continuous discounting

$$= \frac{10}{e^{rt}}$$

Economic comparison: electricity generation

- Capital cost ($/kW)
  - Civil/structural material and installation,
  - Mechanical equipment supply and installation,
  - Electrical instrumentation and controls
  - Project indirect costs, fees and contingency
  - Owner's costs (excluding project financing costs).
- Fixed O&M ($/kW)
  - expenses that do not vary significantly with generation, such as staffing, admin, routine maintenance,
- Variable O&M ($/kWh)
  - expenses that are production-related costs which vary with electrical generation such as fuel, water, waste disposal, chemicals, etc.





Source: EIA, 2012

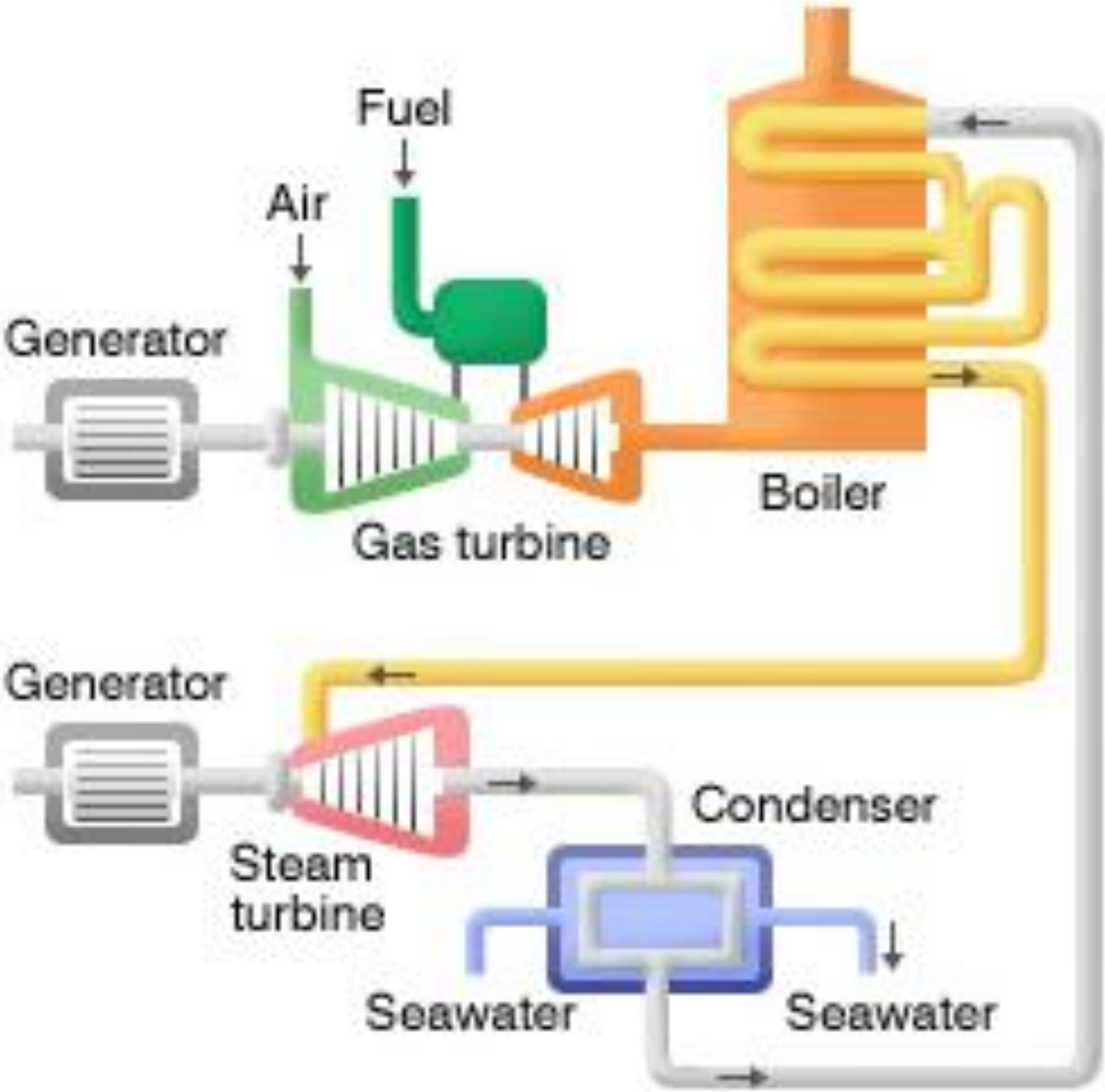
U.S. Capacity Factors by Fuel Type

2013

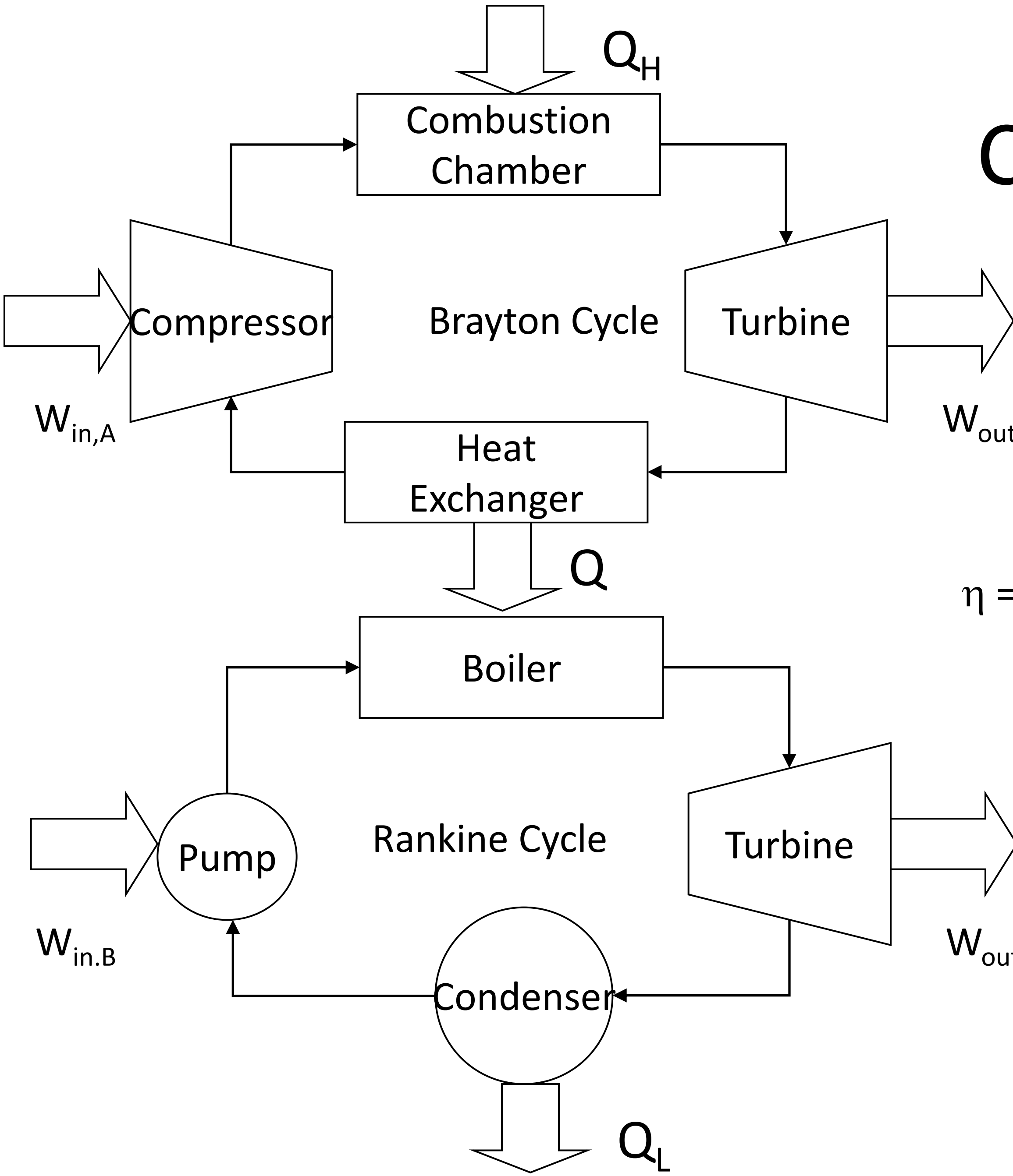
Fuel Type	Average Capacity Factors (%)
Nuclear	90.9
Geothermal	67.2
Biomass	67.1
Coal (Steam Turbine)	58.9
Gas (Combined Cycle)	50.3
Hydro	40.5
Wind	32.3
Solar	24.4
Oil (Steam Turbine)	13.1
Gas (Steam Turbine)	11.9

Source: Ventyx Velocity Suite / Energy Information Administration
Updated: 4/14

Combined Cycle Gas Turbine (CCGT)



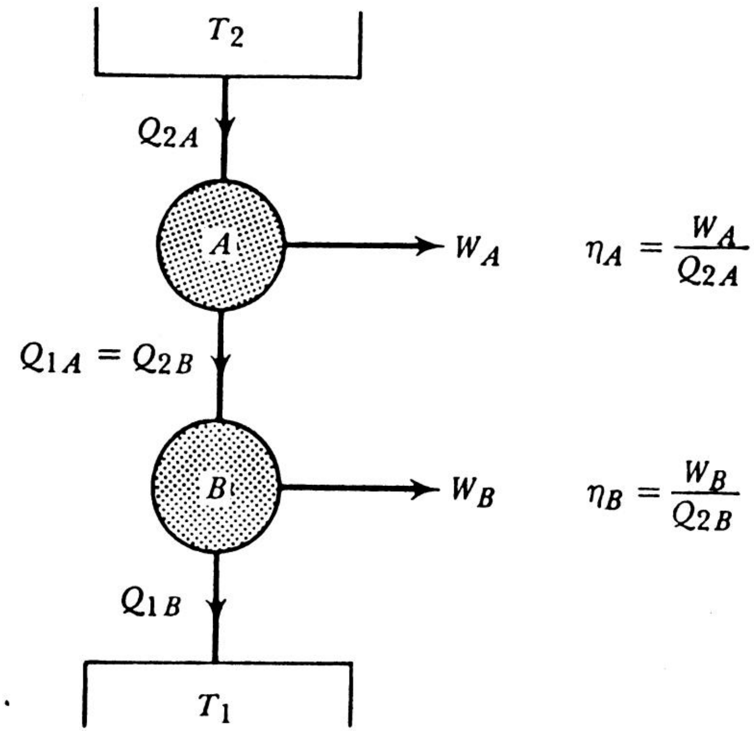
Combined Cycle

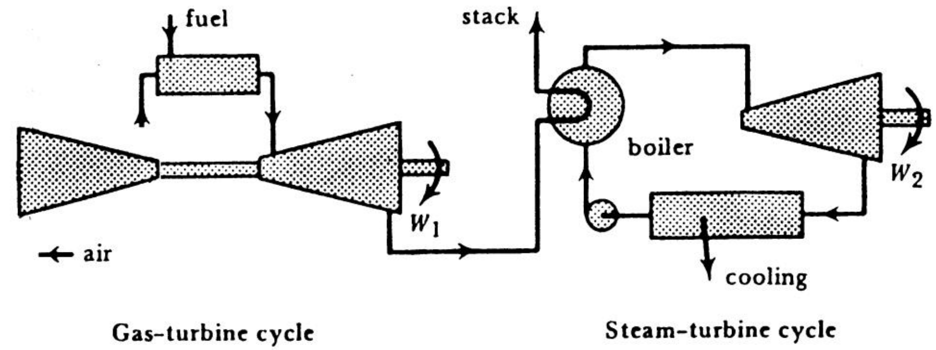


$$\eta = (W_{net,A} + W_{net,B}) / Q_H$$

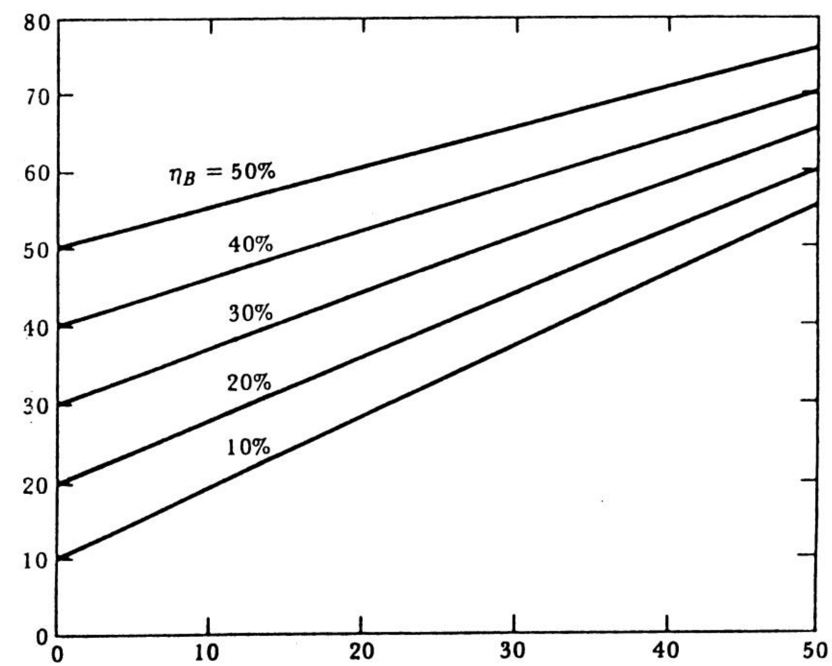
$$\eta = \eta_A + \eta_B(1 - \eta_A) = \eta_A + \eta_B - \eta_A\eta_B$$

Combined Cycle Heat Engine





Overall efficiency for a combined cycle



η percentage

η_A percentage

$\eta = W/Q_{2A} = (W_A + W_B)/Q_{2A}$

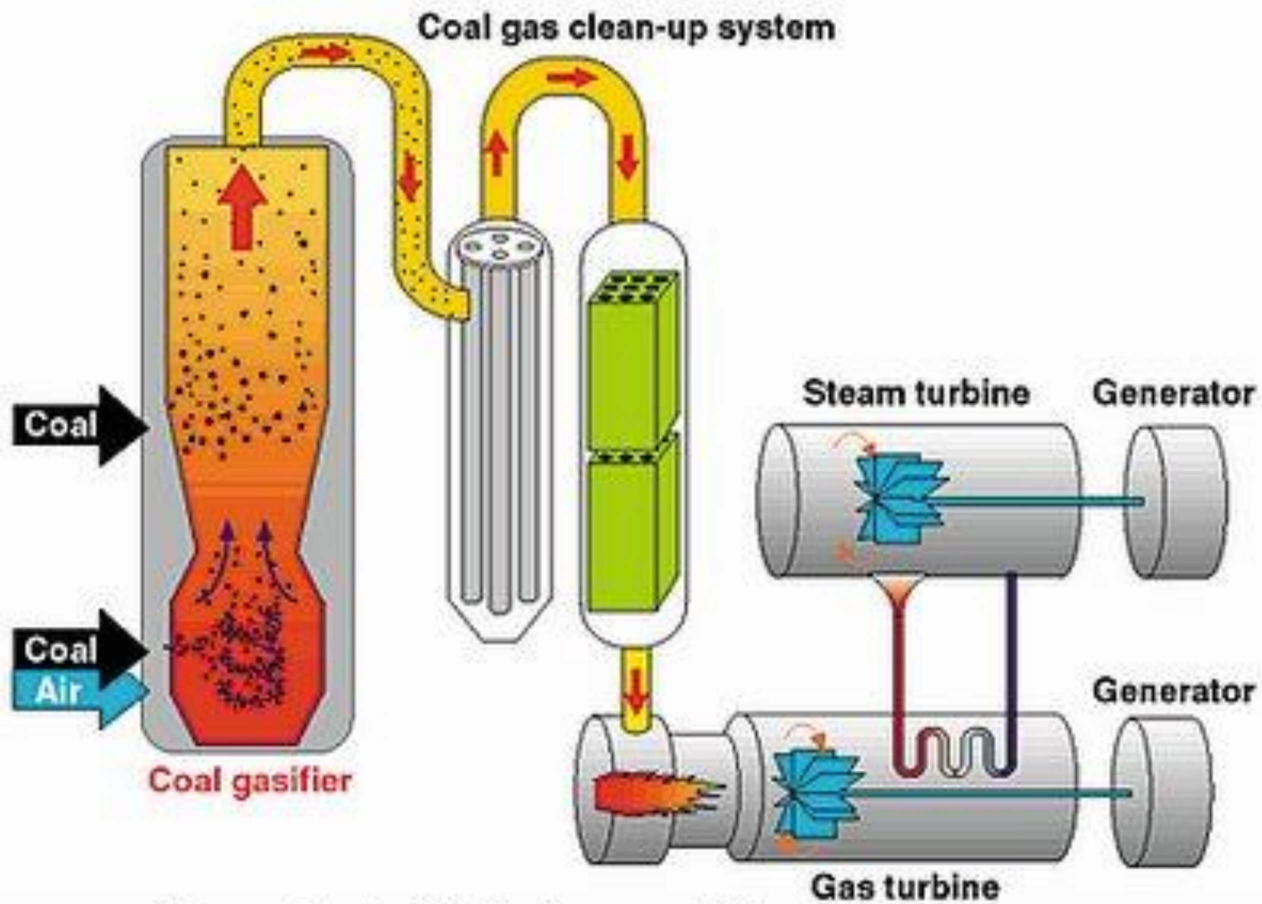
$W_A = \eta_A Q_{2A}$

$W_B = \eta_B Q_{2B} = \eta_B Q_{1A} = \eta_B(Q_{2A} - W_A) = \eta_B(1 - \eta_A)Q_{2A}$

$\eta = \eta_A + \eta_B(1 - \eta_A) = \eta_A + \eta_B - \eta_A\eta_B$

IGCC

- Integrated gasification combined cycle



Source: Center for Environment, Commerce & Energy

Cost and emissions of various technologies

				Costs			Emissions		
Technology	Lifetime	Capacity factor	Nominal Capacity (MW)	Capital Cost $/W	Fixed O&M ($/kW-yr)	Variable O&M ($/MWh)	SO2 (kg/kWh)	NOX (kg/kWh)	CO2 (kg/kWh)
Geothermal – Dual Flash	40	0.67	50	6.2	132	0	0.000310	0	0.186
Advanced Nuclear	40	0.9	2,234	5.5	93.28	2.14	0	0	0
Photovoltaic	25	0.25	20	4.2	27.75	0	0	0	0
Advanced Pulverized Coal	40	0.6	650	3.2	37.8	4.47	0.000155	0.000093	0.320
Hydroelectric	40	0.4	500	2.9	14.13	0	0.0	0.0	0.0
Onshore Wind	20	0.32	100	2.2	39.55	0	0.0	0.0	0.0
Advanced Natural Gas CC	20	0.5	400	1	15.37	3.27	0.000002	0.000012	0.182

Source: EIA, 2012

Lifetime cost of energy

- How can we compare the economics of different generation technologies?
- We first need to put all of their costs either at the net present value, or uniform payments.
- It turns out that annualizing (uniform payments) tends to be more convenient.

$$\mathrm{LCE} = \frac{\text{Discounted annual costs}}{\text{annual energy production}} = \frac{\$}{kWh}$$

Example: Calculating costs for a coal power plant

- Assumptions:
  - Planned capacity: 650 MW
  - Capital cost: 3,200 $/kW
  - Fixed O&M: 40 $/kW per year
  - Variable O&M: fuel costs are 4.50 $/MWh
  - Capacity Factor: 0.65
  - Efficiency: 35%
  - Lifetime: 30 years
  - Discount rate 8%

Annualized Capital Cost

- Present value of capital cost:
  - 650,000 kW x 3,200 $/kW = $2080 (millions)
- Annualizing (uniform payments – in millions)

$$U_{capital} = P\left[\frac{r}{1-(1+r)^{-n}}\right] = \$2080\left[\frac{.08}{1-(1+.08)^{-30}}\right] = 185\$/yr$$

Variable costs

- Variable O&M – fuel costs are 4.50 $/MWh
  - 650 MW * 0.65 *8760 hrs = 3701100 MWh/yr
  - 3701100 MWh/yr * 4.50 $/MWh = 16.7 $/year (millions)
- Fixed O&M: 40 $/kW per year
  - 40 $/kW-yr * 650,000 kW = 26 $/yr (millions)

LCE
(ignoring fixed O&M for now)

$$\mathrm{LCE} = \frac{\text{Discounted annual costs}}{\text{annual energy production}} = \frac{\$}{kWh}$$

$$\mathrm{LCE} = \frac{(16.7 + 26 + 185)\mathrm{x}\,1\mathrm{e}6\,\$}{3.7\mathrm{e}9\mathrm{kWh}} = 0.062\,\frac{\$}{kWh}$$

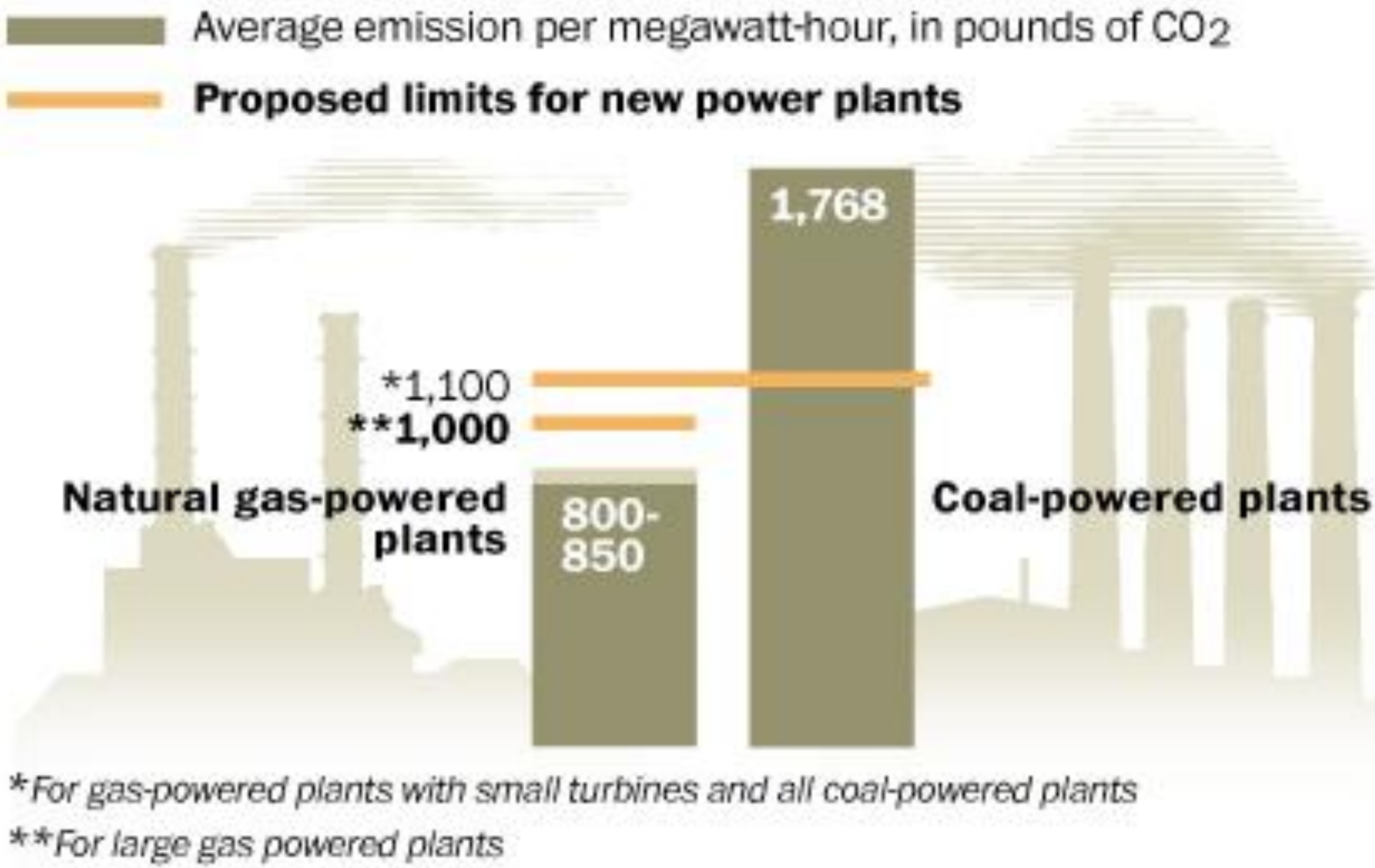
San Juan Generating Station

San Juan Generating Station

Unit 1	**340 MW**	**1976**
Unit 2	**340 MW**	**1973**
Unit 3	**496 MW**	**1979**
Unit 4	**507 MW**	**1982**
TOTAL	**1,683 MW**	

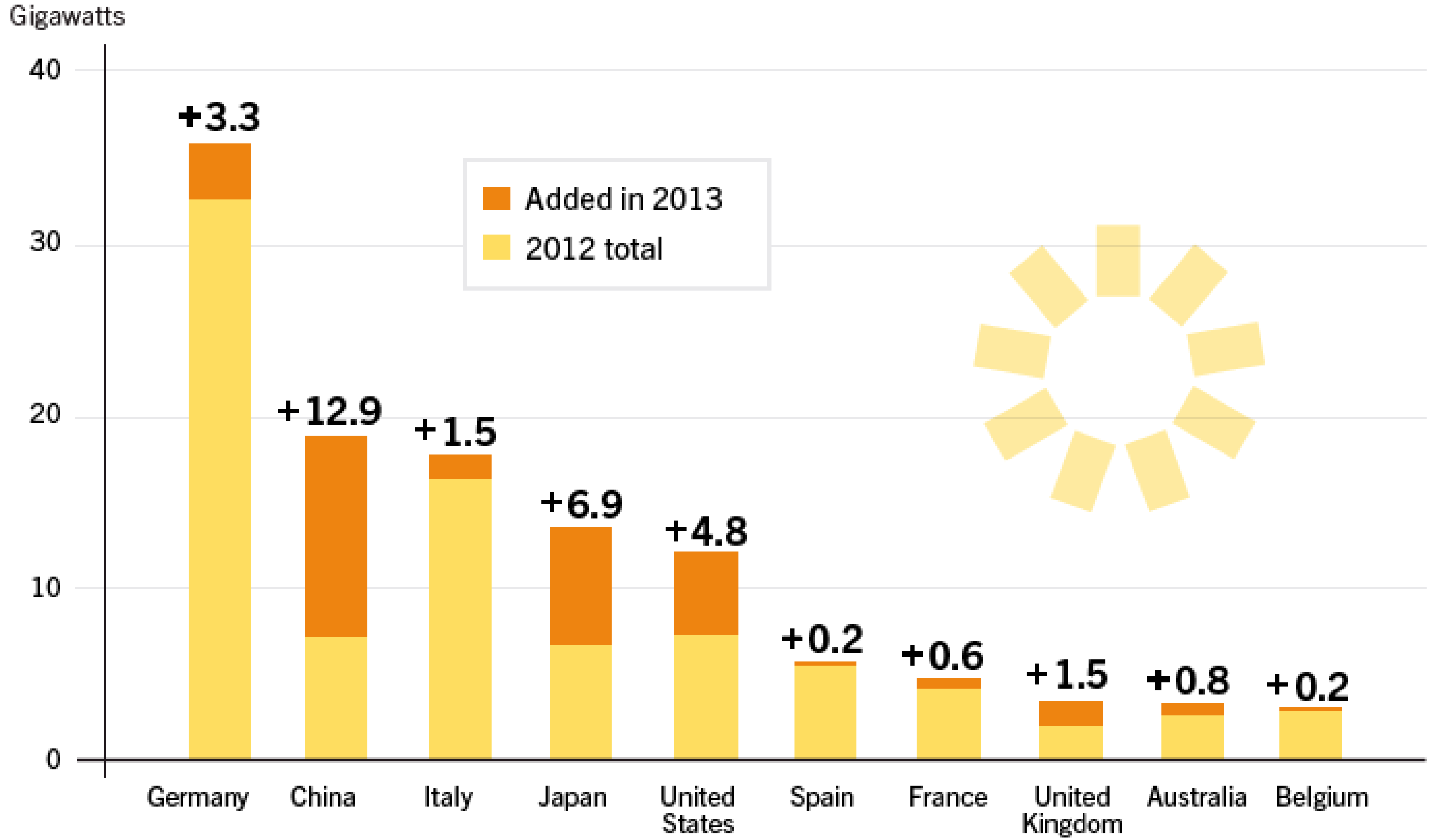
Will retire units 2 and 3 (836 MW) by 2017.

Impacts of proposed EPA new carbon rules

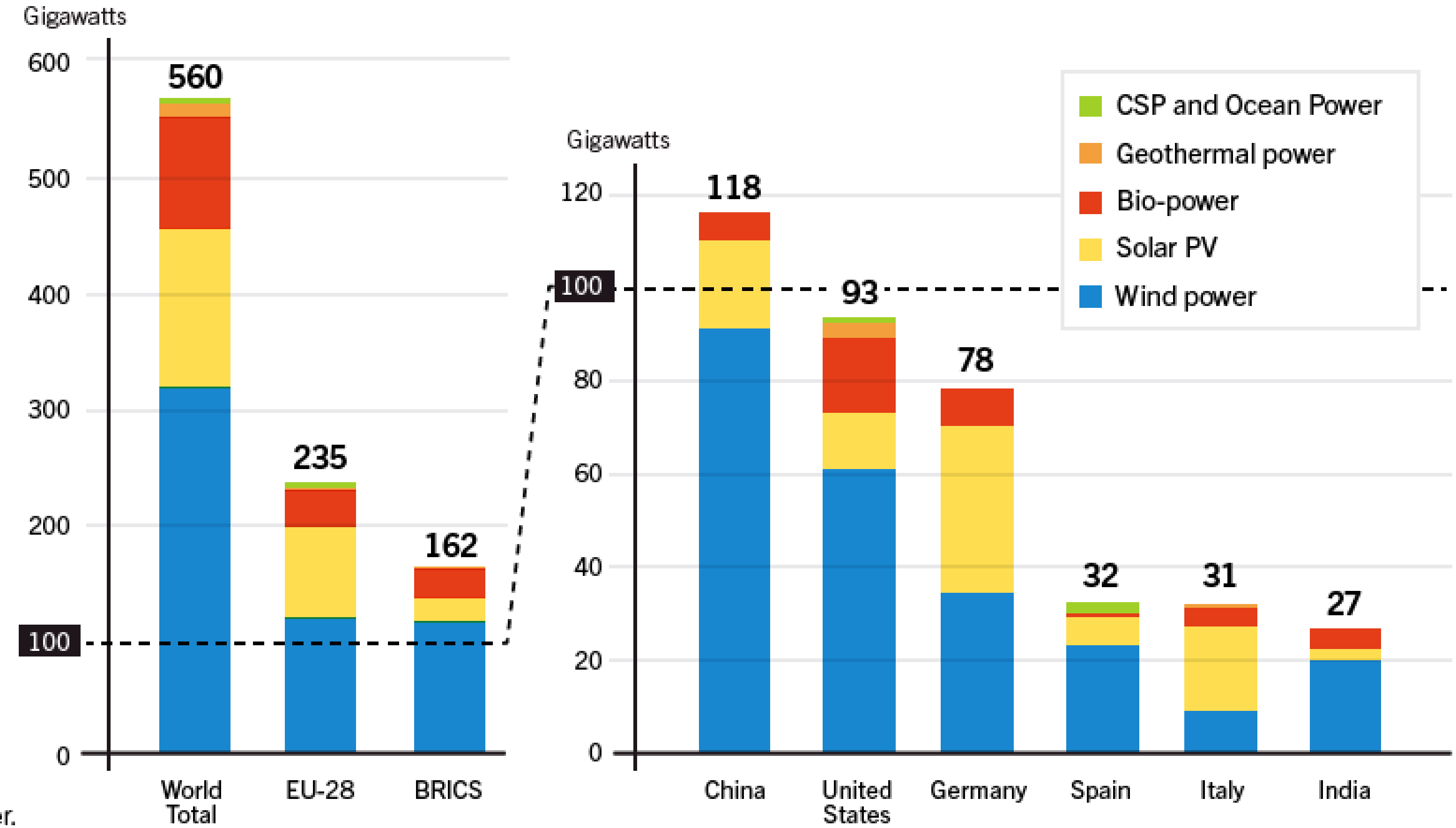


Source: Staff reports, EPA. Patterson Clark / The Washington Post. Published on September 19, 2013,

Solar PV Capacity and Additions, Top 10 Countries, 2013



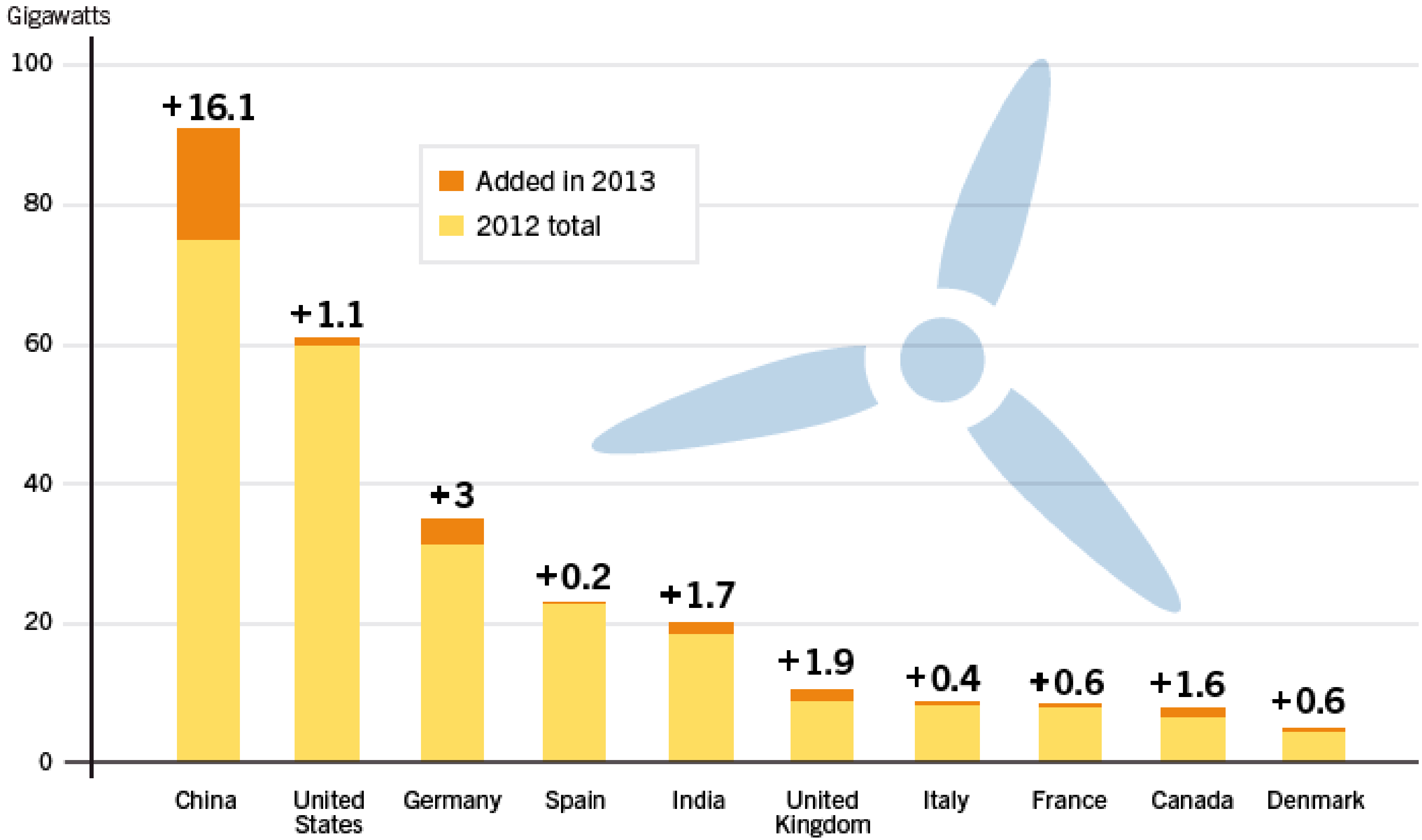
Renewable Power Capacities EU-28, BRICS, and Top Six Countries, 2013



Not including hydropower.

REN21 Global Status Report 2014

Wind Power Capacity and Additions, Top 10 Countries, 2013



REN21 Global Status Report 2014

Power plant economics worksheet

- PNM will retire 836 MW of generation in 2017 at San Juan Generation Station. If the generation station currently has a capacity factor of 0.6, how much energy is produced by these units each year?
- 836 MW x 0.6 x 8760 hrs/yr = 4394016 MWh/yr

- How many tons of CO2 is released each year (assume coal has an emission of 0.32 kgCO2/kWh). Assume a power plant efficiency of 0.35.
- 4294016 MWh/yr x1000 kWh/MWh x 0.32 kg CO2/kWh / 0.35 x 1 ton/1000kg = 4017386 tCO2/yr

Power plant economics worksheet

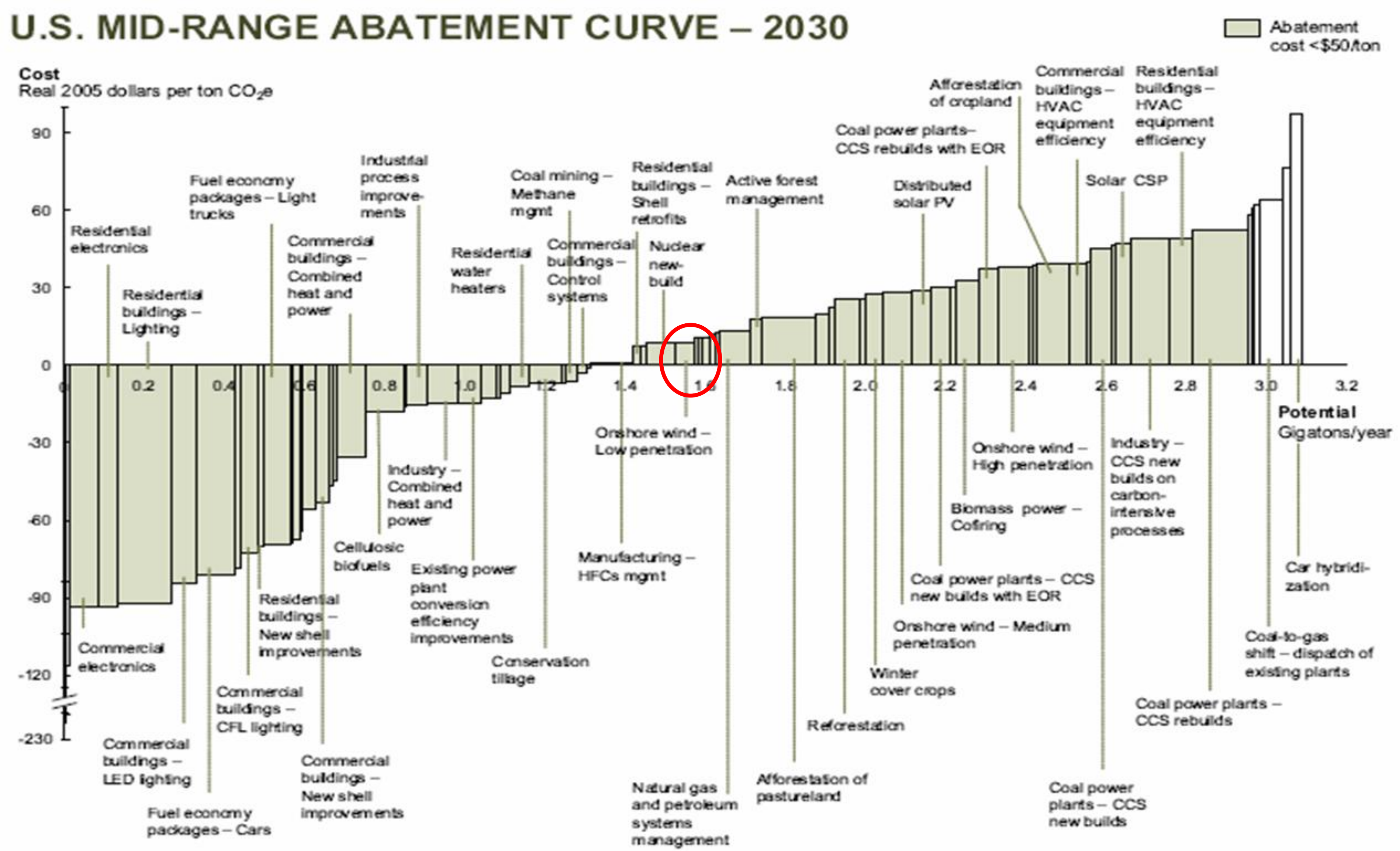
- If PNM found a wind site that would have wind turbines operating with a capacity factor of 0.32, what installed capacity would be needed to replace the lost generation?
- CF = Total energy generated / nameplate * 8760 hrs
- Nameplate = 4394016 MWh/yr / 0.32 / 8760 hrs = 1568 MW
- This would be 627 wind turbines each with a capacity of 2.5 MW
- An engineering company tells PNM that it can build the needed wind farm at a capital cost of 2.2 $/W, and O&M costs of 39.55 $/kW-yr. Find the annualized project cost, if it is assumed that PNM can borrow money at 8% over the expected 20 year lifetime of the project.
- Annualized capital cost = 3.51e8 $/yr
- Annual O&M = 6.2e7 $/yr
- Total annualized cost ($/yr) = 4.13 e8 $/yr

Power plant economics worksheet

- Find the lifetime cost of energy for the project.
- LCE = 4.13 e8 \$/yr / 4394016000 kWh = 0.09\$/kWh
- Calculate the cost for the emission reduction, in terms of \$/tCO2

$$\frac{.09\$/kWh - .06\$/kWh}{\frac{0.32kgCO2/kWh}{0.35} x \frac{1ton}{1000kg}} = 33\$/tCO2$$

Marginal Abatement Cost (MAC) curve



Source: McKinsey analysis