

Sustainable Energy/Lecture 2

Alternatives for the Future

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Units of Measurement: Energy and Power

- It is important to be familiar with commonly used energy units and their quantitative equivalents.
- Remember...energy content is not to be confused with power.
- Two common units of power are kilowatts (kW) and horsepower (hP); 1000 and 745.7 J/s; 3413 and 2545 Btu/hr; $1W=1.0 J/s$

Energy Conversions

Table 2.1. Various Energy Units and Conversion Factors (continued)

	bbls oil equivalent	tonnes oil equivalent	kg coal equivalent	tonnes coal equivalent	MCF gas equivalent	joules	EJ
Btus	1.82×10^{-7}	2.48×10^{-8}	3.6×10^{-5}	3.6×10^{-8}	10^{-5}	1,055	1.06×10^{-15}
quads	1.82×10^8	2.48×10^7	3.6×10^{10}	3.6×10^7	10^9	1.06×10^{18}	1.06
calories	7.21×10^{-10}	9.82×10^{-11}	1.43×10^{-7}	1.43×10^{-10}	3.97×10^{-9}	4.19	4.19×10^{-18}
kWh	6.20×10^{-4}	8.45×10^{-5}	0.123	1.23×10^{-4}	3.41×10^{-3}	3.6×10^6	3.6×10^{-12}
MWyr	3,435	740	1.08×10^6	1076	2.99×10^4	3.15×10^{13}	3.15×10^{-3}
bbls oil	1	0.136	198	0.198	5.50	5.80×10^9	5.80×10^{-9}
tonnes oil	7.35	1	1,455	1.45	40.4	4.26×10^{10}	4.26×10^{-8}
kg coal	5.05×10^{-3}	6.88×10^{-4}	1	0.001	0.0278	2.93×10^7	2.93×10^{-11}
tonnes coal	1	0.688	1,000	1	27.8	2.93×10^{10}	2.93×10^{-8}
MCF gas	0.182	0.0248	36	0.036	1	1.06×10^9	1.06×10^{-9}
joules	1.72×10^{-10}	9.48×10^{-19}	3.41×10^{-8}	3.41×10^{-11}	9.48×10^{-10}	1	10^{-18}
EJ	1.72×10^8	2.35×10^7	3.41×10^{10}	3.41×10^7	9.48×10^8	10^{18}	1

To convert from the first column units to other units, multiply by the factors shown in the appropriate row (e.g., 1 Btu = 252 calories).

Key: MWyr—Megawatt-years; bbls—barrels; tonnes—metric tons = 1,000 kg = 2,204.6 lb; MCF—thousand cubic feet; EJ—exajoules.

Assumed calorific values; oil—10,180 cal/g; coal—7,000 cal/g; gas—1,000 Btu/ft³ at standard conditions.

Energy Conversions

Table 2.1. Various Energy Units and Conversion Factors

	Btus	quads	calories	kWh	MWy
Btus	1	10^{-15}	252	2.93×10^{-4}	3.35×10^{-11}
quads	10^{15}	1	2.52×10^{17}	2.93×10^{11}	3.35×10^4
calories	3.97×10^{-3}	3.97×10^{-18}	1	1.16×10^{-6}	1.33×10^{-13}
kWh	3,413	3.41×10^{-12}	8.60×10^5	1	1.14×10^{-7}
MWy	2.99×10^{10}	2.99×10^{-5}	7.53×10^{12}	8.76×10^6	1
bbls oil	5.50×10^6	5.50×10^{-9}	1.38×10^9	1,612	1.84×10^{-4}
tonnes oil	4.04×10^7	4.04×10^{-8}	1.02×10^{10}	1.18×10^4	1.35×10^{-3}
kg coal	2.78×10^4	2.78×10^{-11}	7×10^6	8.14	9.29×10^{-7}
tonnes coal	2.78×10^7	2.78×10^{-8}	7×10^9	8,139	9.29×10^{-4}
MCF gas	10^6	10^{-9}	2.52×10^8	293	3.35×10^{-5}
joules	9.48×10^{-4}	9.48×10^{-19}	0.239	2.78×10^{-7}	3.17×10^{-14}
EJ	9.48×10^{14}	0.948	2.39×10^{17}	2.78×10^{11}	3.17×10^4

To convert from the first column units to other units, multiply by the factors shown in the appropriate row (e.g., 1 Btu = 252 calories).

Key: MWy—Megawatt-years; bbls—barrels; tonnes—metric tons = 1,000 kg = 2,204.6 lbs.; MCF—thousand cubic feet; EJ—exajoules.

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Efficiency of energy conversions

- Primary sources of energy can be converted to other types: electricity, mechanical energy, heat, etc. .
- All energy conversion steps have inefficiencies that cause loss of energy.
- The overall efficiency of any process is a result of the product of the efficiency of each energy conversion step ($E_1 \times E_2 \times E_3 = E_{\text{Total}}$)

Table 2.2. Efficiencies of Common Anthropogenic and Natural Energy Conversions^{a,c}

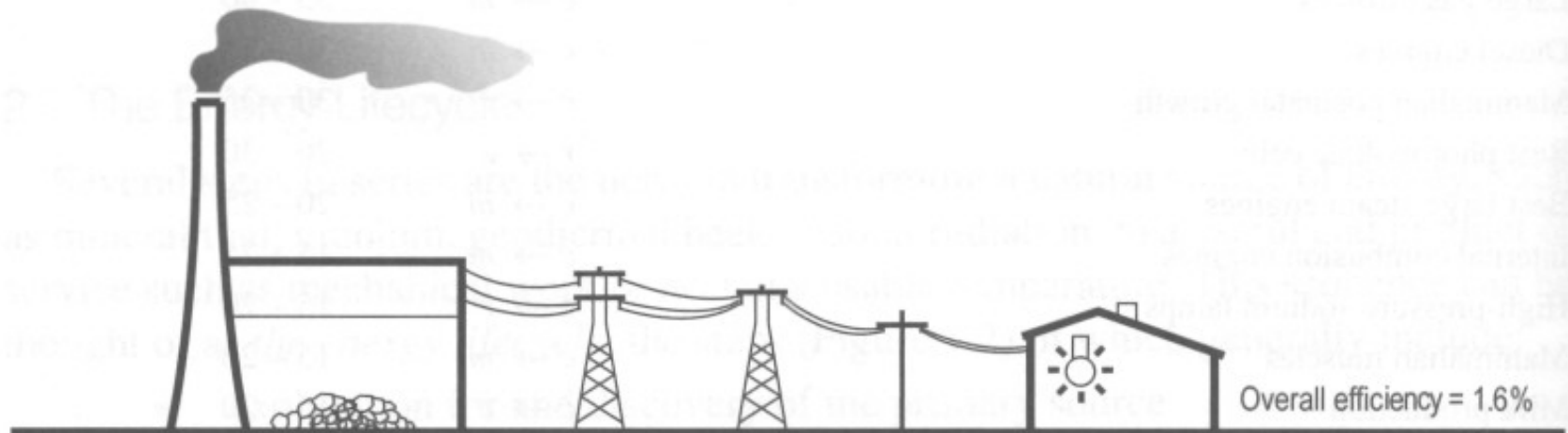
Conversion	Energies ^b	Efficiencies
Large electricity generators	$m \rightarrow e$	98 – 99
Large power plant boilers	$c \rightarrow t$	90 – 98
Large electric motors	$e \rightarrow m$	90 – 97
Best home natural gas furnaces	$c \rightarrow t$	90 – 96
Dry-cell batteries	$c \rightarrow e$	85 – 95
Human lactation	$c \rightarrow c$	75 – 85
Overshot waterwheels	$m \rightarrow m$	60 – 85
Small electric motors	$e \rightarrow m$	60 – 75
Best bacterial growth	$c \rightarrow c$	50 – 65
Glycolysis maxima	$c \rightarrow c$	50 – 60
Large steam turbines	$t \rightarrow m$	40 – 45
Improved wood stoves	$c \rightarrow t$	25 – 45
Large gas turbines	$c \rightarrow m$	35 – 40
Diesel engines	$c \rightarrow m$	30 – 35
Mammalian postnatal growth	$c \rightarrow c$	30 – 35
Best photovoltaic cells	$r \rightarrow e$	20 – 30
Best large steam engines	$c \rightarrow m$	20 – 25
Internal combustion engines	$c \rightarrow m$	15 – 25
High-pressure sodium lamps	$e \rightarrow r$	15 – 20
Mammalian muscles	$c \rightarrow m$	15 – 20
Milk production	$c \rightarrow c$	15 – 20
Pregnancy	$c \rightarrow c$	10 – 20
Broiler production	$c \rightarrow c$	10 – 15
Traditional stoves	$c \rightarrow t$	10 – 15
Fluorescent lights	$e \rightarrow r$	10 – 12
Beef production	$c \rightarrow c$	5 – 10
Steam locomotives	$c \rightarrow m$	3 – 6
Peak field photosynthesis	$r \rightarrow c$	4 – 5
Incandescent light bulbs	$e \rightarrow r$	2 – 5
Paraffin candles	$c \rightarrow r$	1 – 2
Most productive ecosystems	$r \rightarrow c$	1 – 2
Global photosynthetic mean	$r \rightarrow c$	0.3

^aAll ranges are the first-law efficiencies in percentages.

^bEnergy labels: c = chemical, e = electrical, m = mechanical (kinetic), r = radiant (electromagnetic, solar), t = thermal

^cAdapted from Smil (1998).

Energy efficiency of Electrical Transmission System



Fuel = Coal
 $E_0 = 1.00$

Power Plant
 $E_1 = 0.35$

Transmission Lines
 $E_2 = 0.90$

Light
 $E_3 = 0.05$

Overall efficiency = 1.6%

Overall Efficiency for Converting Chemical Energy To Light Energy = $E_1 \times E_2 \times E_3 = 0.35 \times 0.90 \times 0.05 = 0.016$

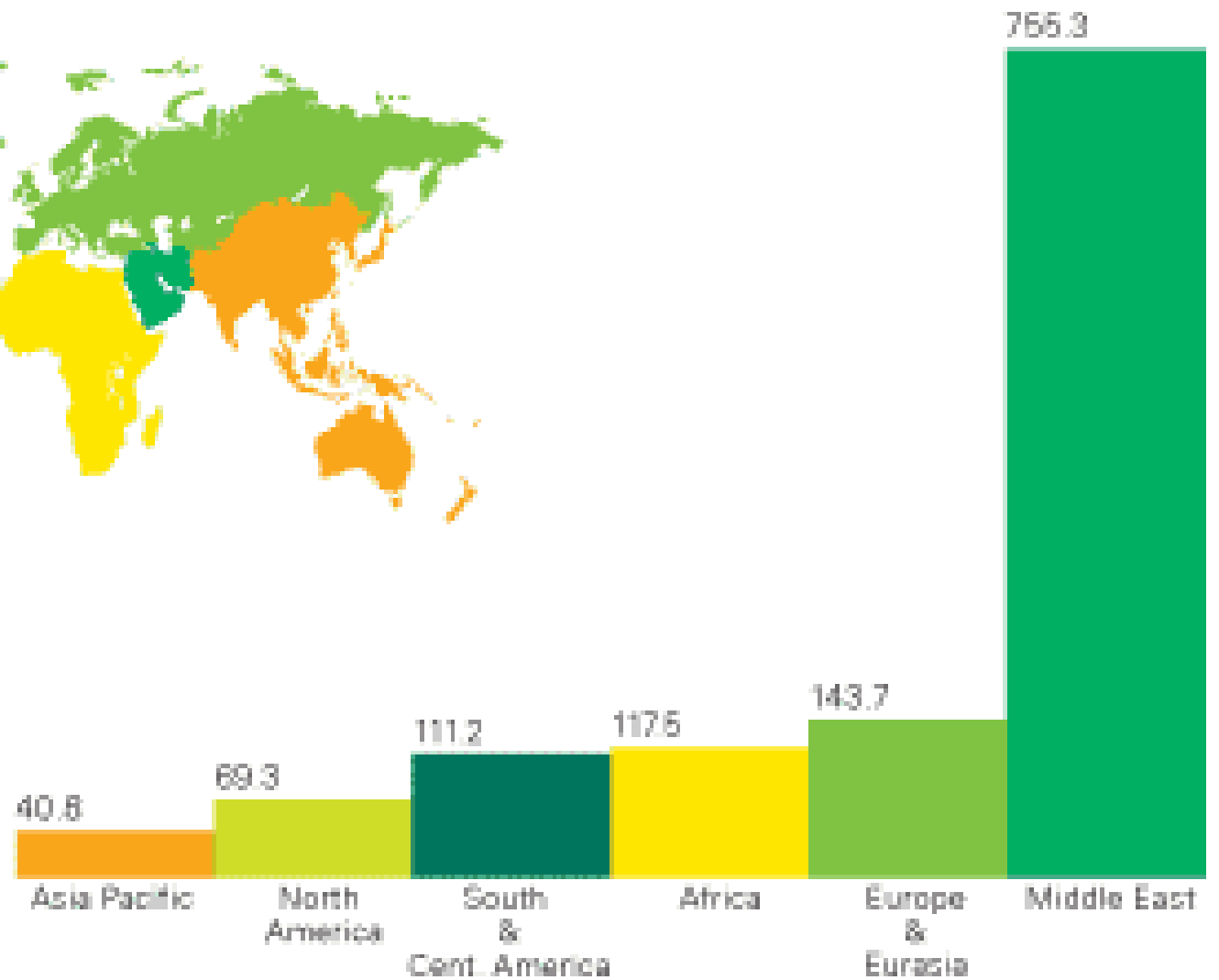
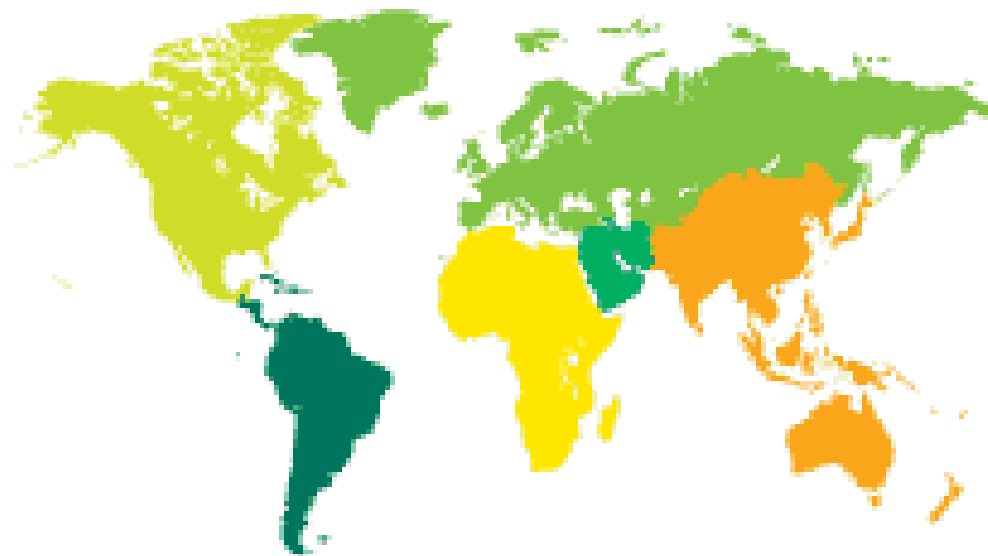
The Energy Life Cycle

- The steps of the energy life cycle are:
 - Exploration
 - Extraction/production
 - Processing/refining/conversion
 - Utilization
 - Restoration/decontamination/waste removal

Life cycle continued...

- Environmental impacts of energy use must take into consideration the impacts at each stage of the energy life cycle.
- The fossil fuel with the lowest environmental impacts is natural gas.
- Coal has the largest environmental impacts associated with its life cycle.
- Renewable energy sources have the lowest environmental impacts.

Proved reserves at end 2007
Thousand million barrels



Summary of Reserve Data as of 2007

Country	Reserves ¹		Production ²		Reserve life ³ years
	10 ⁹ bbl	10 ⁹ m ³	10 ⁶ bbl/d	10 ³ m ³ /d	
<u>Saudi Arabia</u>	260	41	8.8	1,400	81
<u>Canada</u>	179	28.5	2.7	430	182
<u>Iran</u>	136	21.6	3.9	620	96
<u>Iraq</u>	115	18.3	3.7	590	85
<u>Kuwait</u>	99	15.7	2.5	400	108
<u>United Arab Emirates</u>	97	15.4	2.5	400	106
<u>Venezuela</u>	80	13	2.4	380	91
<u>Russia</u>	60	9.5	9.5	1,510	17
<u>Libya</u>	41.5	6.60	1.8	290	63
<u>Nigeria</u>	36.2	5.76	2.3	370	43
<u>United States</u>	21	3.3	4.9	780	11
<u>Mexico</u>	12	1.9	3.2	510	10
Total of top twelve reserves	1,137	180.8	48.2	7,660	65

Estimation and Valuation of Fossil Fuels

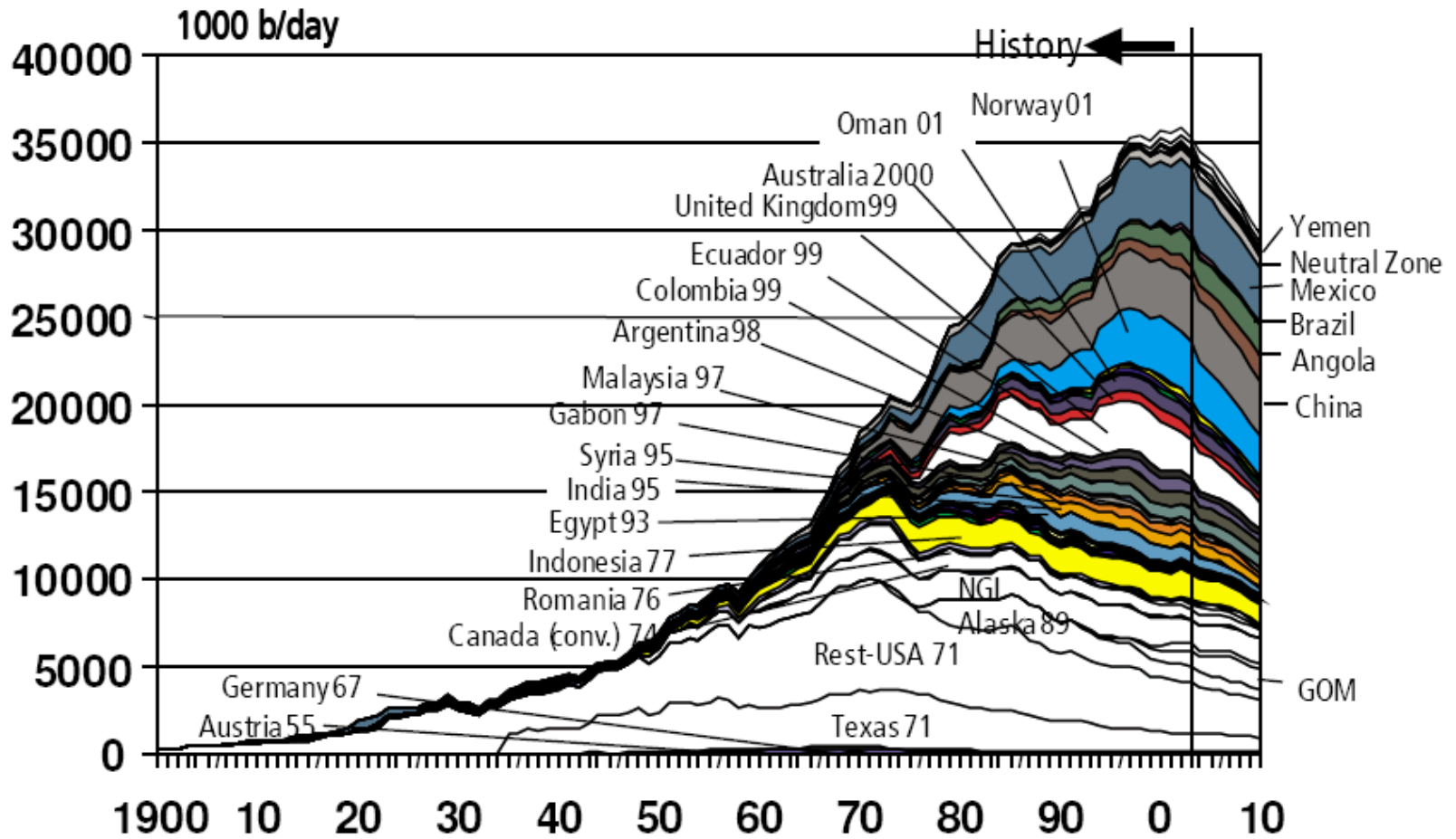
- Resources – the amount of fuels that is estimated to be recoverable under current economic/technological conditions.
- Reserves – the amount of fuel that has been identified in a position to produce it for the market under current conditions.

Fixed Stock Scarcity Theory

- Fossil fuels are nonrenewable and in limited supply.
- Recovery cost and resultant price will increase as reserves dwindle.
- What factors might invalidate this theory?
 - Technological developments in exploration/extraction?
 - The availability and use of other energy sources.

Types of Reserves

- Proved developed reserves
- Proved undeveloped reserves
- Probable, possible, speculative and “undiscovered” reserves
- Unconventional reserves



Source: Industry database, 2003 (IHS 2003)
OGJ, 9 Feb 2004 (Jan-Nov 2003)

Conclusions

- The environmental impacts of fossil fuels are substantial.
- Questions concerning the long-term availability/price of fossil fuels is reason enough to consider alternatives.
- Recent information on the impacts of global warming make changes in our energy policy imperative.
- Recent prices of oil make renewable energy alternatives economically feasible.