EE80J/180J
Lecture 2
March 30, 2016

Lectures and Homework

Lecture 1: Introduction and Overview

Lecture 2: Scientific Notation, Energy Overview, Efficiency, Energy Basics

https://courses.soe.ucsc.edu/courses/ee80j/Spring16/01

look at: http://www.youtube.com/watch?v=80hLpNpmCZ8

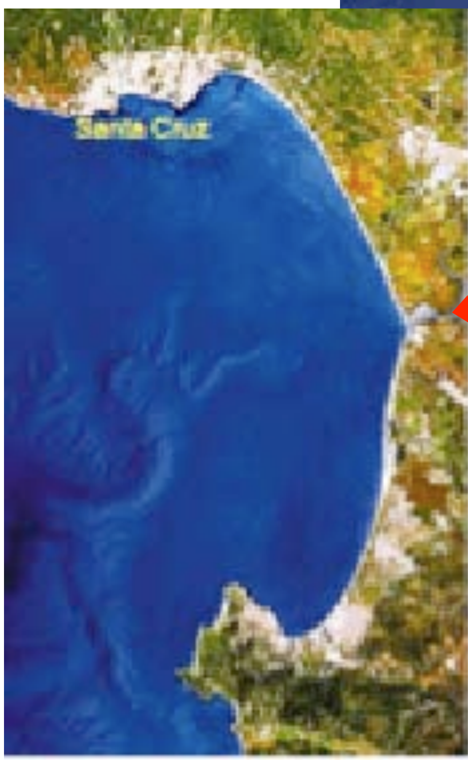
Renewable Energy Sources around the world and in the US

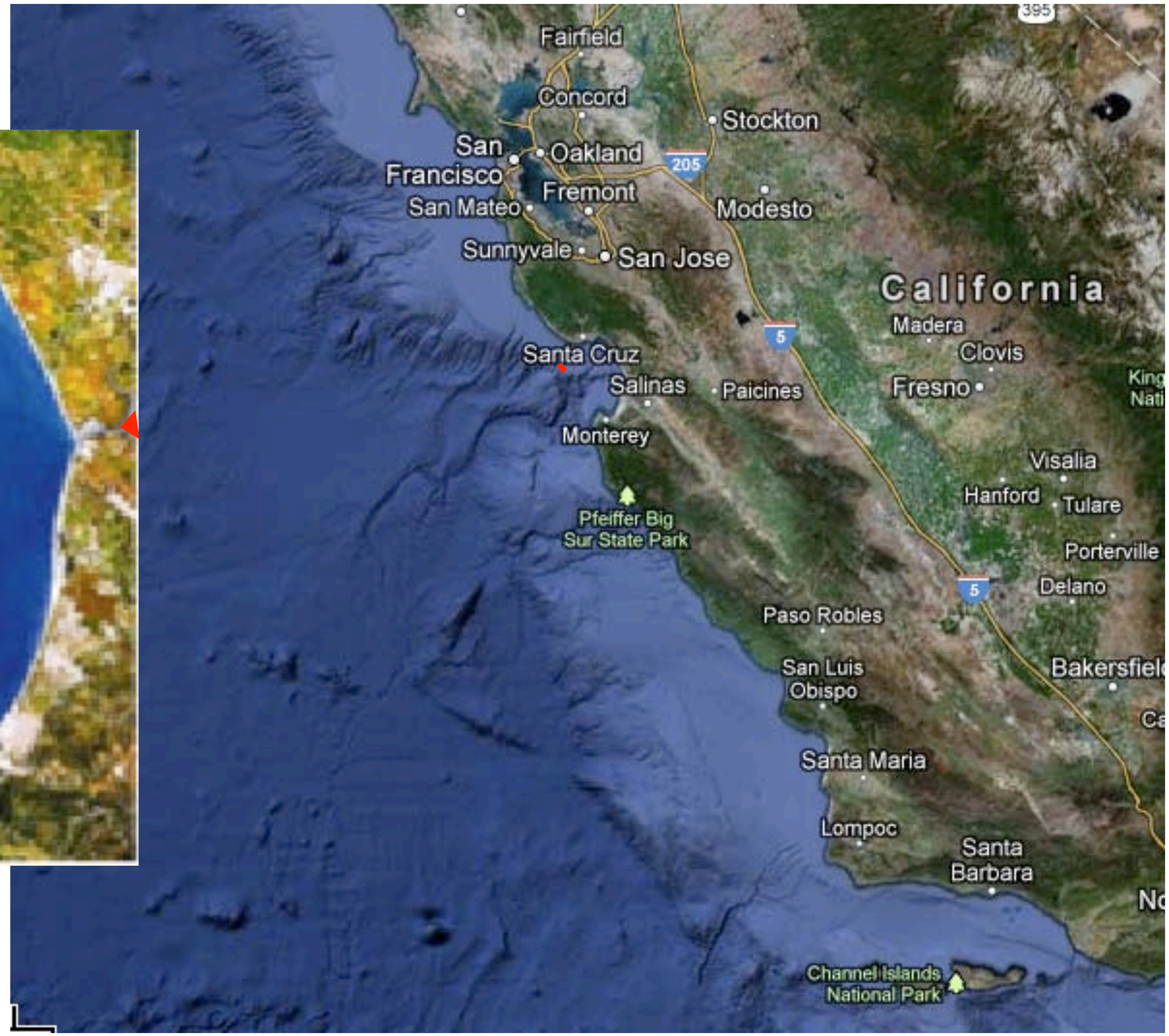
Energy use

Energy resources

Our options

OVERVIEW OF
RENEWABLE ENERGY SOURCES





Why are we interested in the renewable energy?

Why are we interested in the renewable energy?

Depletion of fossil fuel supply

Carbon emissions into the atmosphere

Scientific Notation

❖ Femto	(f)	10^{-15}= 1/1000,000,000,000,000
❖ Pico	(p)	10^{-12}= 1/1000,000,000,000
❖ Nano	(n)	10^{-9}= 1/1000,000,000
❖ Micro	(μ)	10^{-6}= 1/1000,000
❖ Milli (m)	10^{-3}= 1/1000	
❖ Centi	(cm)	10^{-2}= 1/100
❖ Deca	(dm)	10^{1} = 10
❖ Kilo (k)	10^{3}= 1,000	
❖ Mega	(M)	10^{6}= 1,000,000
❖ Giga	(G)	10^{9}= 1,000,000,000
❖ Tera	(T)	10^{12}=1,000,000,000,000
❖ Peta (quad)	(P)	10^{15}=1,000,000,000,000,000
❖ Exa	(E)	10^{18}=1,000,000,000,000,000,000

Energy

- Exa = 10^{18} = 1 quintillion

Example:

2011 Tohoku Earthquake

1.41 Exa Joules of energy (Ejoules)

US uses 94 Ejoules of energy/year

Basic Energy Concepts

- International System of Units
  - Meter
  - Kilogram
  - Second

- What is the unit of energy?

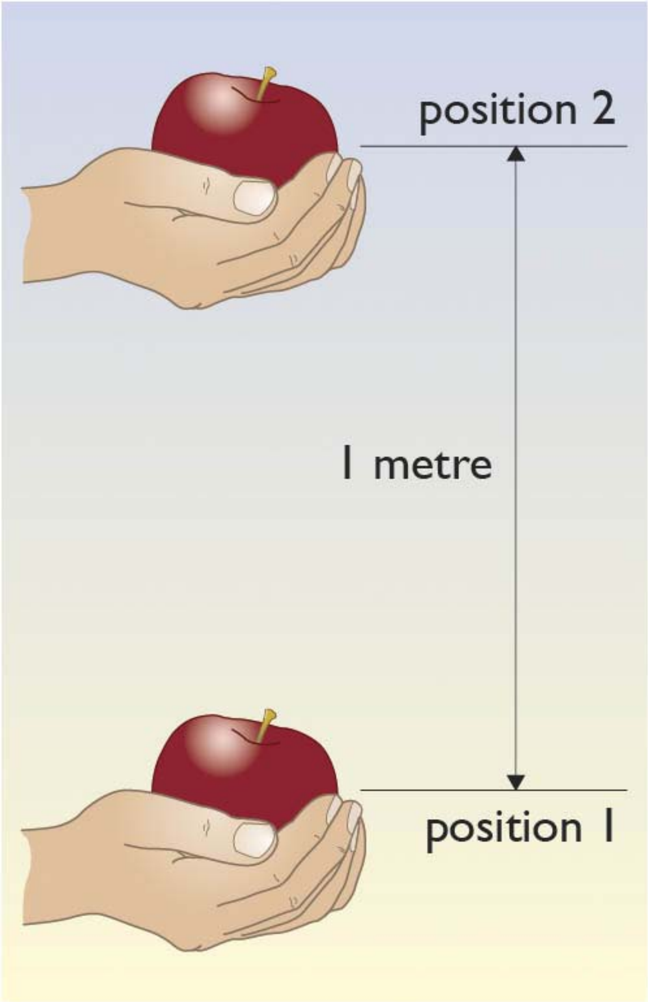
Energy

- The energy supplied by force of one newton in causing movement through a distance of 1 meter.
- Joule (J) - the unit of energy
- Energy (J) = Force (N) x Distance (m)

Power

- The rate at which energy is converted from one form to another or transferred from one place to another.
- Watt (W)
- Power (W) = Energy (J) / Time (sec)

1 joule



Forms of Energy

Kinetic (thermal)

Gravitational

Electrical (chemical)

Nuclear (fission, fusion)

Carnot, Sadi (1824). *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance*. Paris: Bachelier.

Use of kinetic energy

Nicolas Léonard Sadi Carnot in 1813 at age of 17 in the traditional uniform of a student of the École Polytechnique

Born	1 June 1796 Palais du Petit-Luxembourg, Paris, France
Died	24 August, 1832 (age 36) Paris, France
Nationality	French
Fields	Physicist and engineer
Institutions	French army
Alma mater	École Polytechnique École Royale du Génie Sorbonne Collège de France
Academic advisors	Siméon Denis Poisson André-Marie Ampère François Arago
Known for	Carnot cycle Carnot efficiency Carnot theorem Carnot heat engine

An aside on energy and power units

1 MJ = 1 million joules = 948 BTU

1 BTU (British Thermal Unit) =
energy needed to raise 1 lb of water
1 degree Fahrenheit.

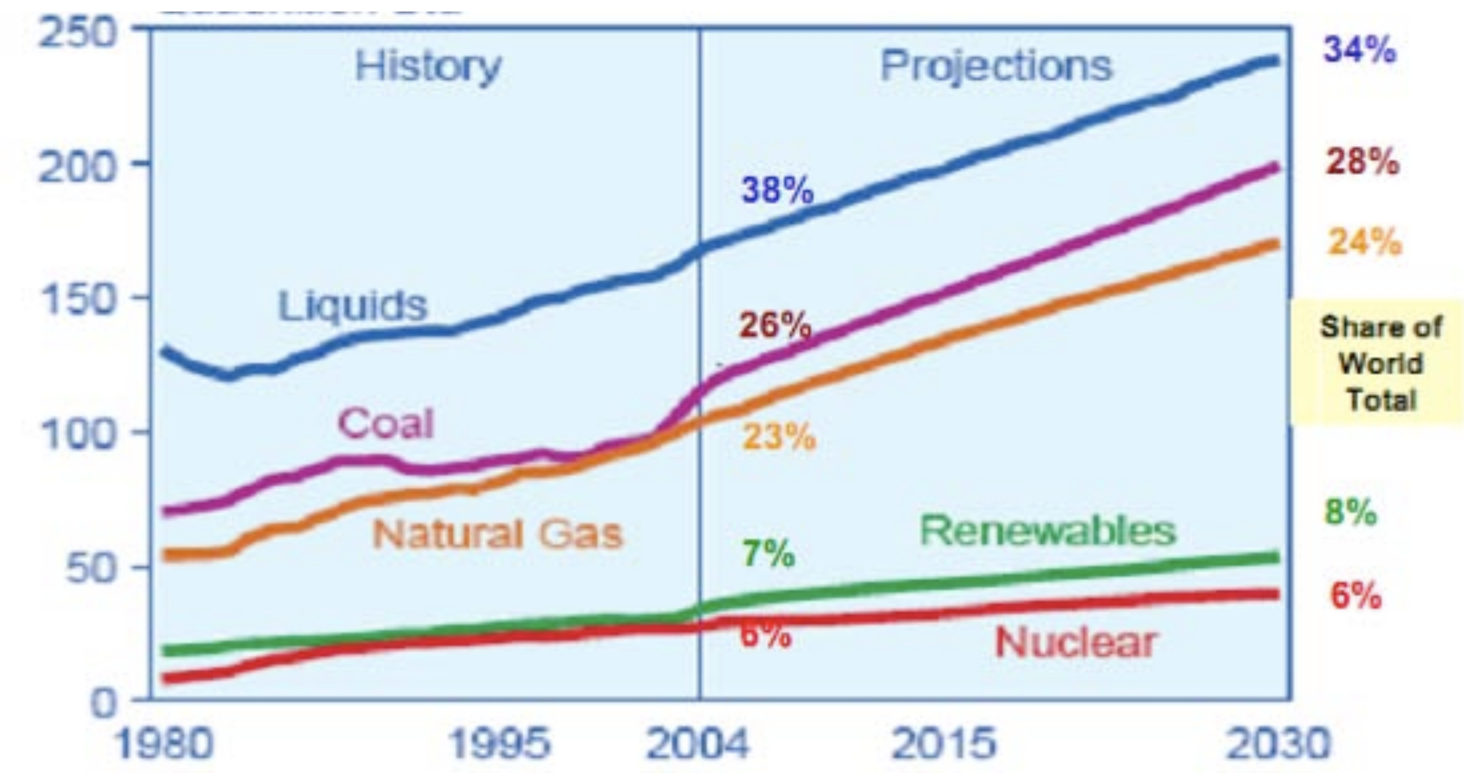
1 horsepower = 1 HP = 745 Watts
= power at which a horse could turn a mill wheel
24 feet in diameter at 2.4 revolutions/minute
with a force of 180 lbs

$$P = 180\text{lbs} \times 2.4\text{rev/min} \times 2\pi \times 12 \text{ ft.}$$
$$= 33{,}000 \text{ ft lbs/min}$$
$$= 745 \text{ kgm m/sec} = 745 \text{ joule/sec} = 745 \text{ watts}$$

Watt devised this unit because his royalties paid for the steam engine were based upon the savings in coal from using earlier steam engines, or for farmers, using a horse, paid based upon the equivalent work his engine could do compared to a horse.

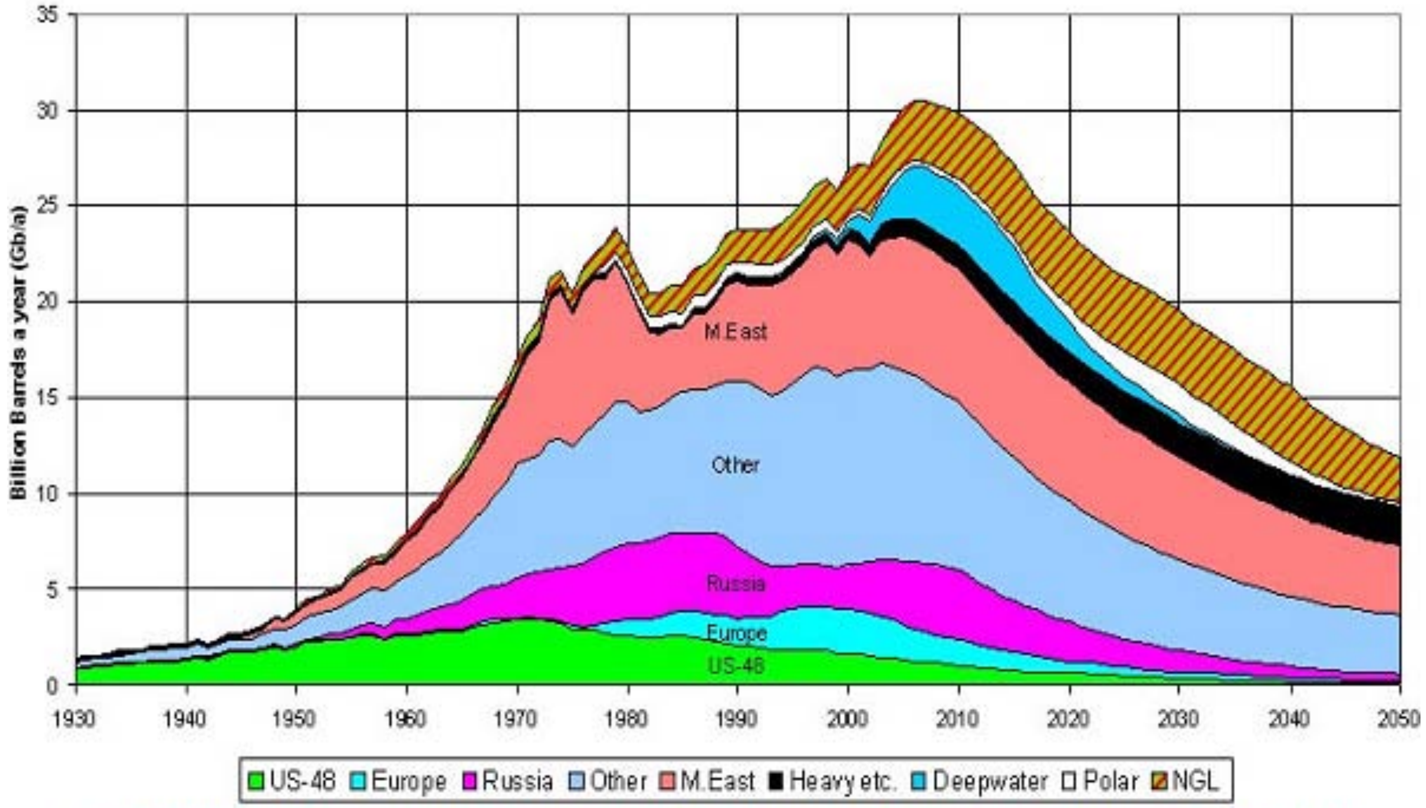
World Marketed Energy Use by Fuel Type 1980-2030

Quadrillion BTU (10^{15})

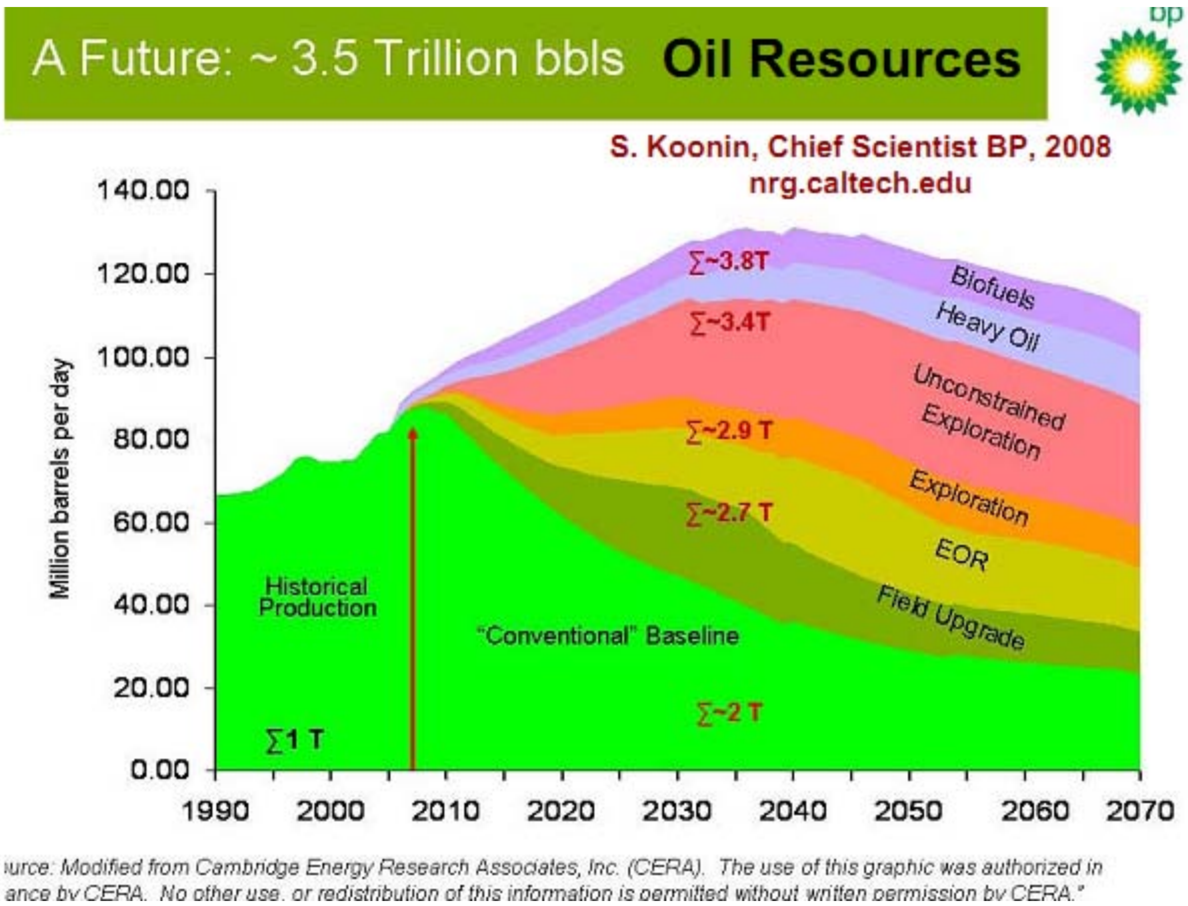


US Department of Energy; Energy Information Administration 2007

OIL AND GAS LIQUIDS
2004 Scenario



C. J. Campbell: "The Essence of Oil & Gas Depletion," Multi-Sci. Publ. Co., Ltd., Essex, UK, 2003


A Future: ~ 3.5 Trillion bbls Oil Resources
bp
S. Koonin, Chief Scientist BP, 2008
nrg.caltech.edu
Million barrels per day
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1990
2000
2010
2020
2030
2040
2050
2060
2070
∑~3.8T
∑~3.4T
∑~2.9 T
∑~2.7 T
∑~2 T
∑1 T
Biofuels
Heavy Oil
Unconstrained Exploration
Exploration
EOR
Field Upgrade
Historical Production
"Conventional" Baseline
urce: Modified from Cambridge Energy Research Associates, Inc. (CERA). The use of this graphic was authorized in
ance by CERA. No other use, or redistribution of this information is permitted without written permission by CERA."

Climate Change

Climate Forcing

Climate forcing has to do with the amount of energy we receive from the sun, and the amount of energy we radiate back into space. Variances in climate forcing are determined by physical influences on the atmosphere such as orbital and axial changes as well as the amount of greenhouse gas in our atmosphere.

Climate Forcing

Climate forcings are a major cause of climate change. A climate forcing is any influence on climate that originates from outside the climate system itself. The climate system includes the oceans, land surface, cryosphere, biosphere, and atmosphere.

NASA/GISS Climate Forcing & Temperature

Examples of external forcings include:

1. Surface reflectivity (albedo)
2. Human induced changes in greenhouse gases
3. Atmospheric aerosols (volcanic sulfates, industrial output)

These examples all influence the balance of energy entering and leaving the Earth system. These types of forcings are often referred to as radiative forcing and can be quantified in units of the extra energy in watts per meter squared ($W\ m^{-2}$) entering the Earth near the top of the atmosphere (TOA).

http://ossfoundation.us/projects/environment/global-warming/radiative-climate-forcing

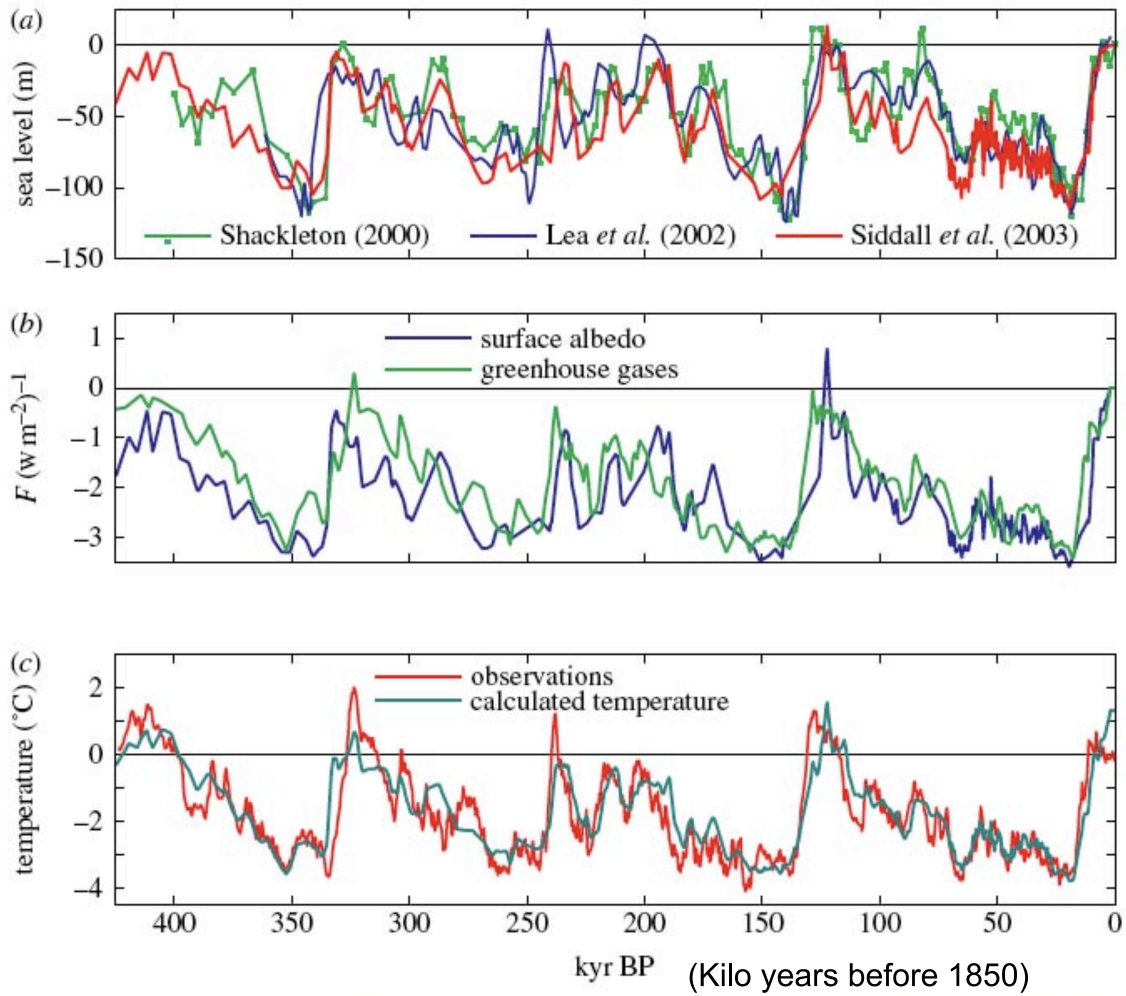
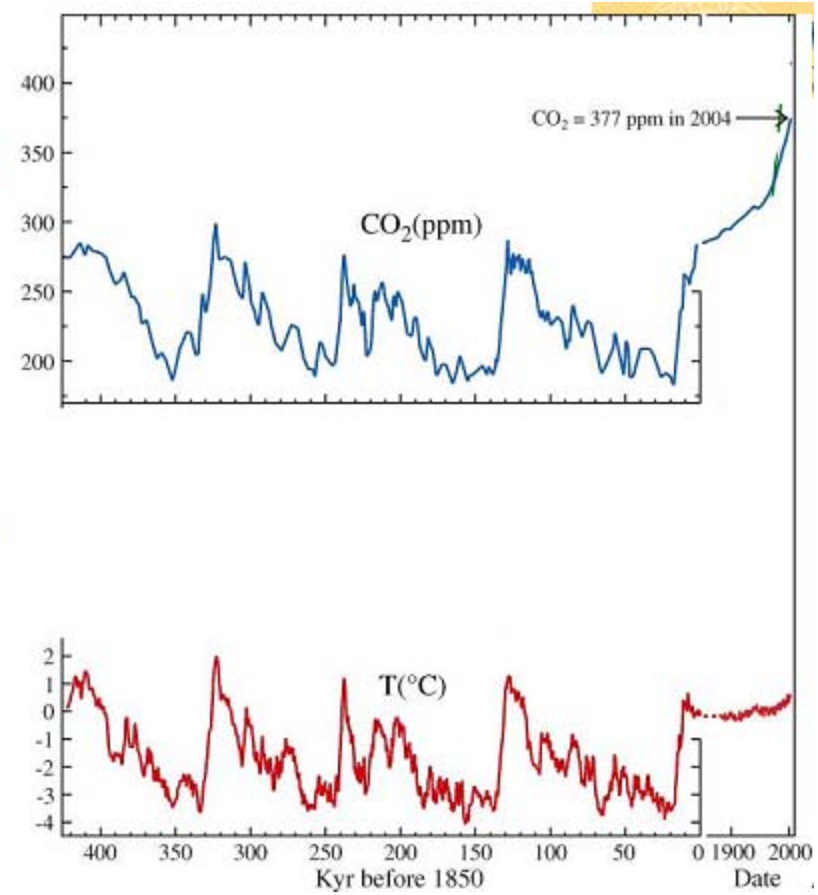


Figure 2. (*a*) Sea-level records of Shackleton (2000; green), Lea *et al.* (2002; blue) and Siddall *et al.* (2003; red), (*b*) climate forcings due to GHGs (CO_2, CH_4 and N_2O) and surface albedo and (*c*) palaeoclimate temperature change: calculated and observed temperature. Calculated temperature is the product of forcing (*b*) and climate sensitivity (3/4°C $(W\ m^{-2})^{-1}$). Observed temperature is Vostok temperature (figure 1) divided by 2.

Hansen, et.al. *Phil. Trans. R. Soc. A* (2007) **365**, 1925–1954

400,000 years of greenhouse-gas & temperature history based on bubbles trapped in Antarctic ice



Last time CO_2 >300 ppm was 25 million years ago.

Source: Hansen, *Clim. Change*, **68**, 269, 2005.

John P. Holdren, 2006

Who was Hansen?

James Hansen, NASA Scientist Who Raised Climate Change Alarm, Is Retiring

by **MARK MEMMOTT**

April 02, 2013 1:31 PM

The *Times* notes that:

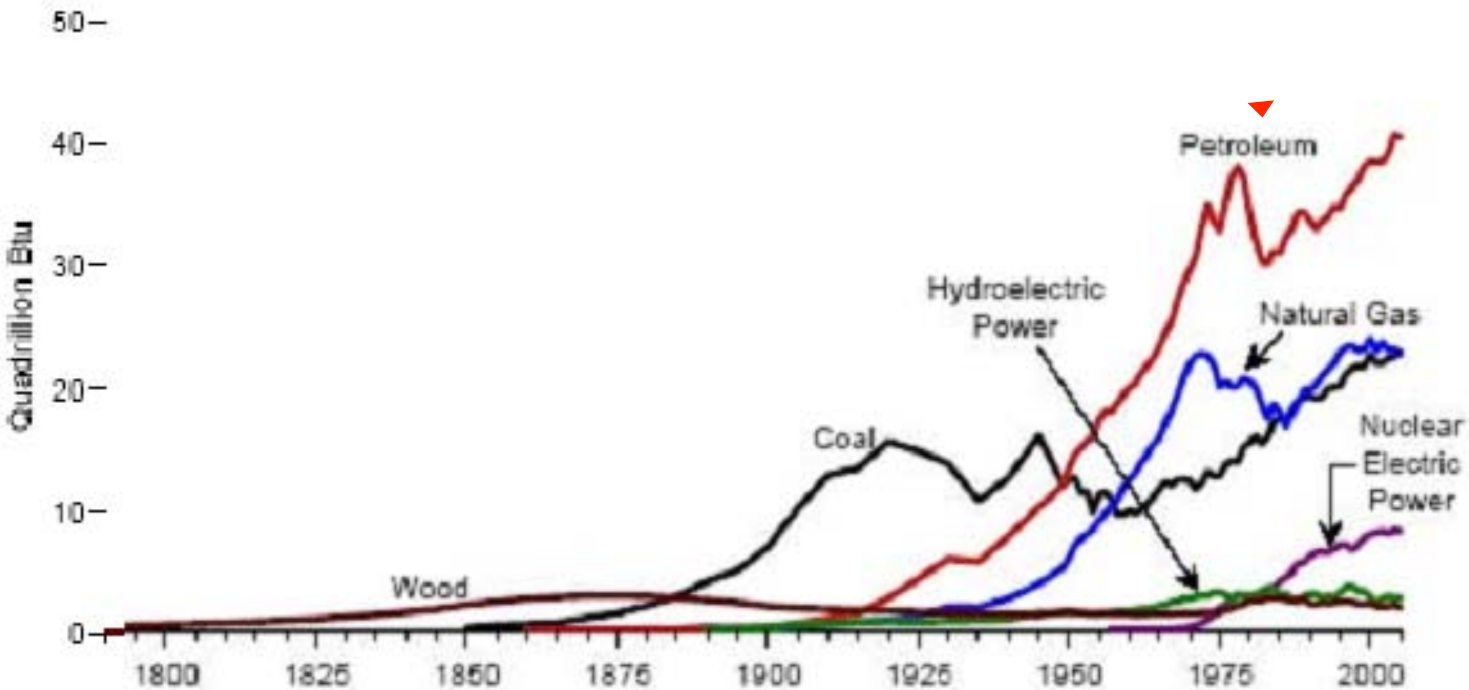
> "Perhaps the biggest fight of Dr. Hansen's career broke out in late 2005, when a young political appointee in the administration of George W. Bush began exercising control over Dr. Hansen's statements and his access to journalists. Dr. Hansen took the fight public and the administration backed down."

NASA scientist and climatologist James Hansen in 2009.

Christopher Furlong/Getty Images

US Energy Consumption

Oil crisis



DOE Energy Information Administration (2007)

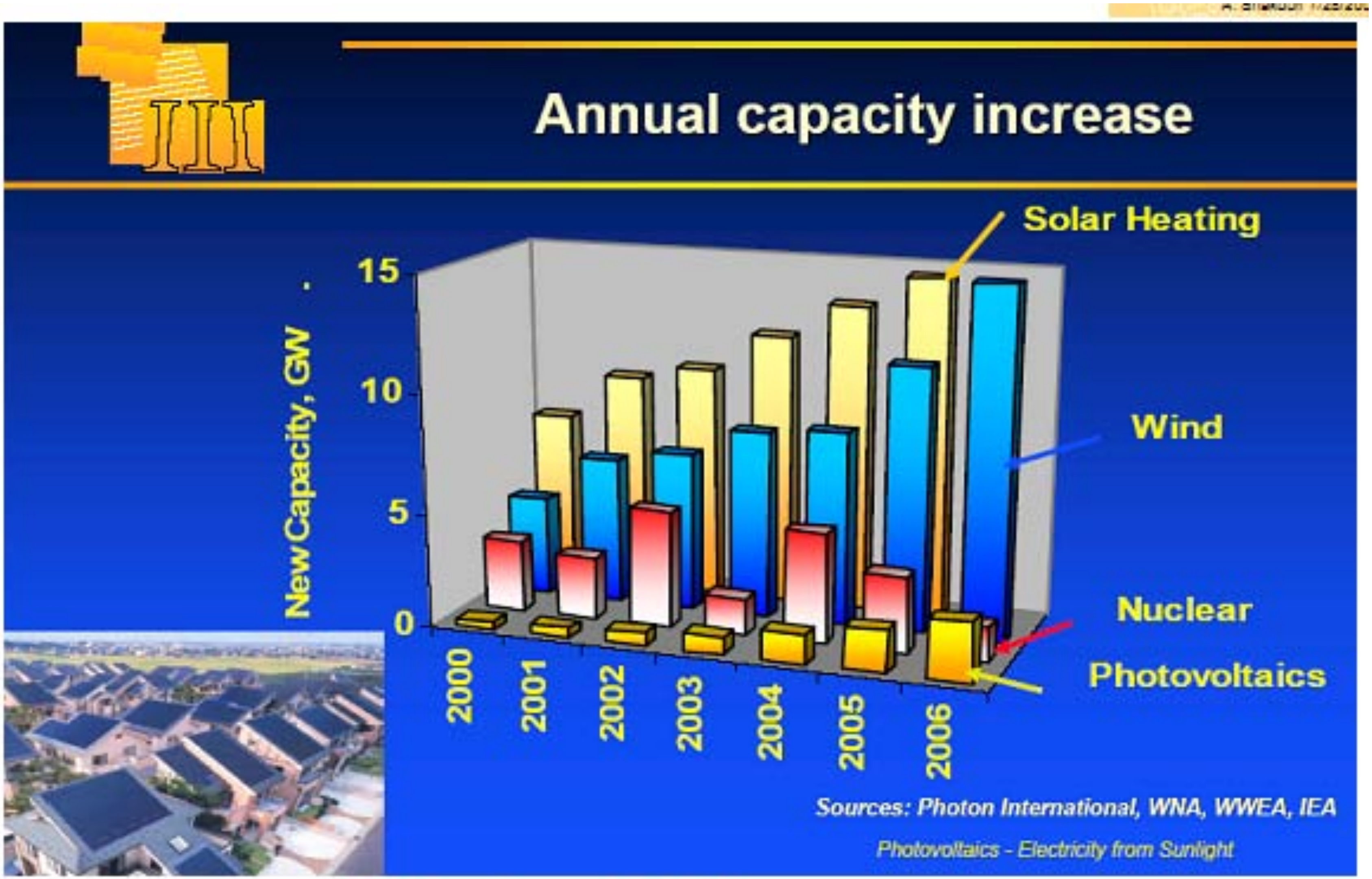
EFFICIENCY AND CAPACITY

Efficiency = useful output/input x 100 (in %)

Capacity = actual energy output over a fixed period or time/ maximum possible output

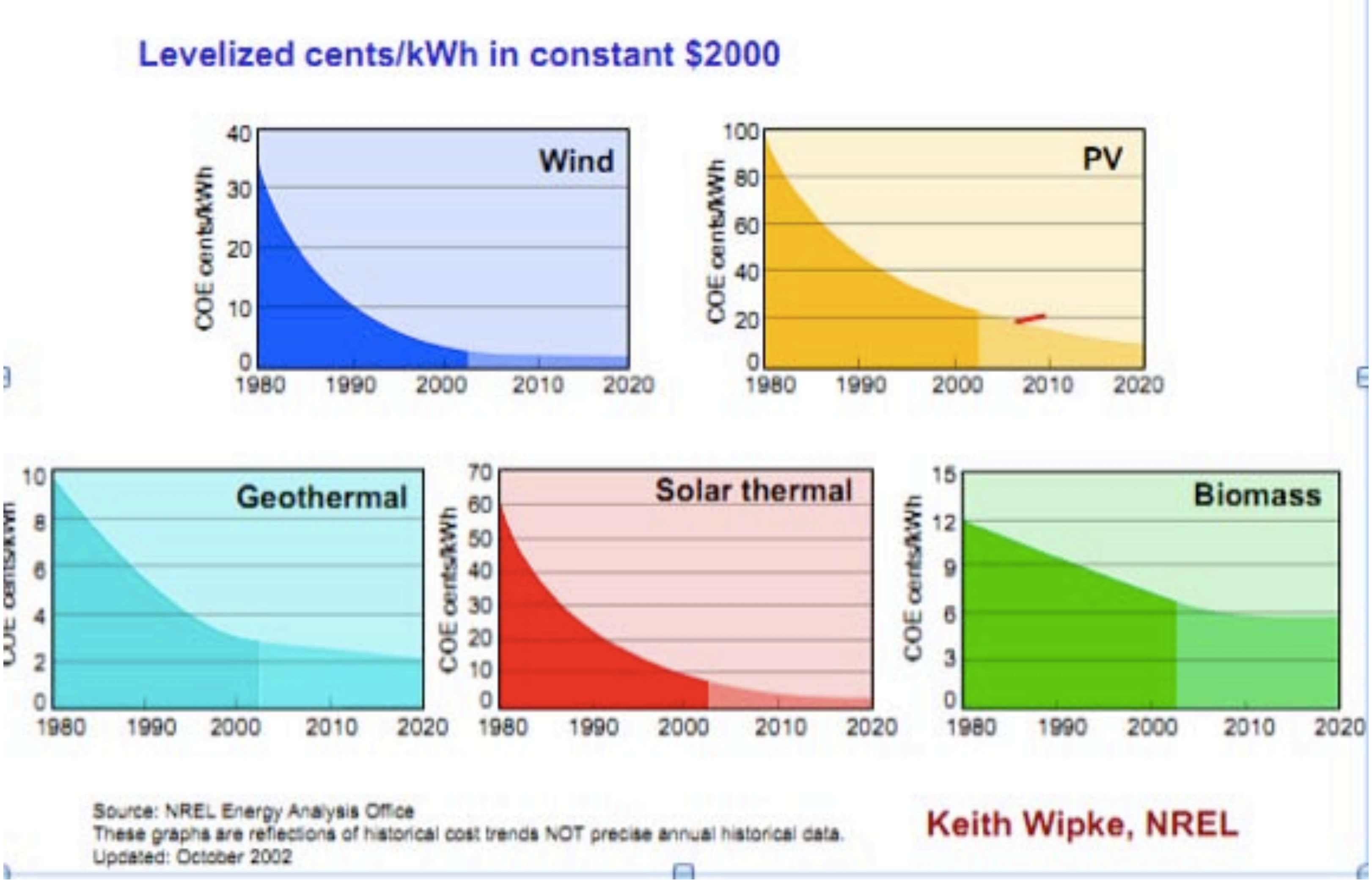
Examples: a 1MW power plant operating at full capacity for 1 year would generate 8760 MWh of output if operating at 100% capacity (capacity factor of 1)

A 1 MW wind turbine might only produce 3000 MWh of output in 1 year since wind doesn't always blow, so its capacity would only be 34.2% (3000/8760)

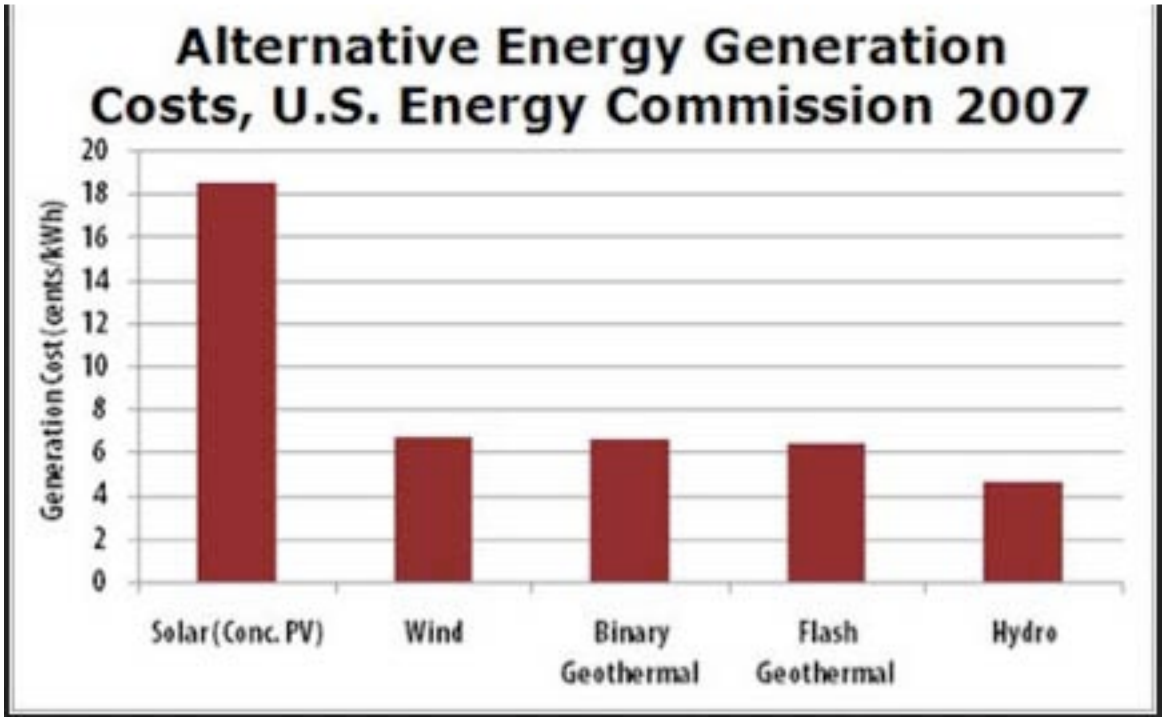


Martin Green, UNSW

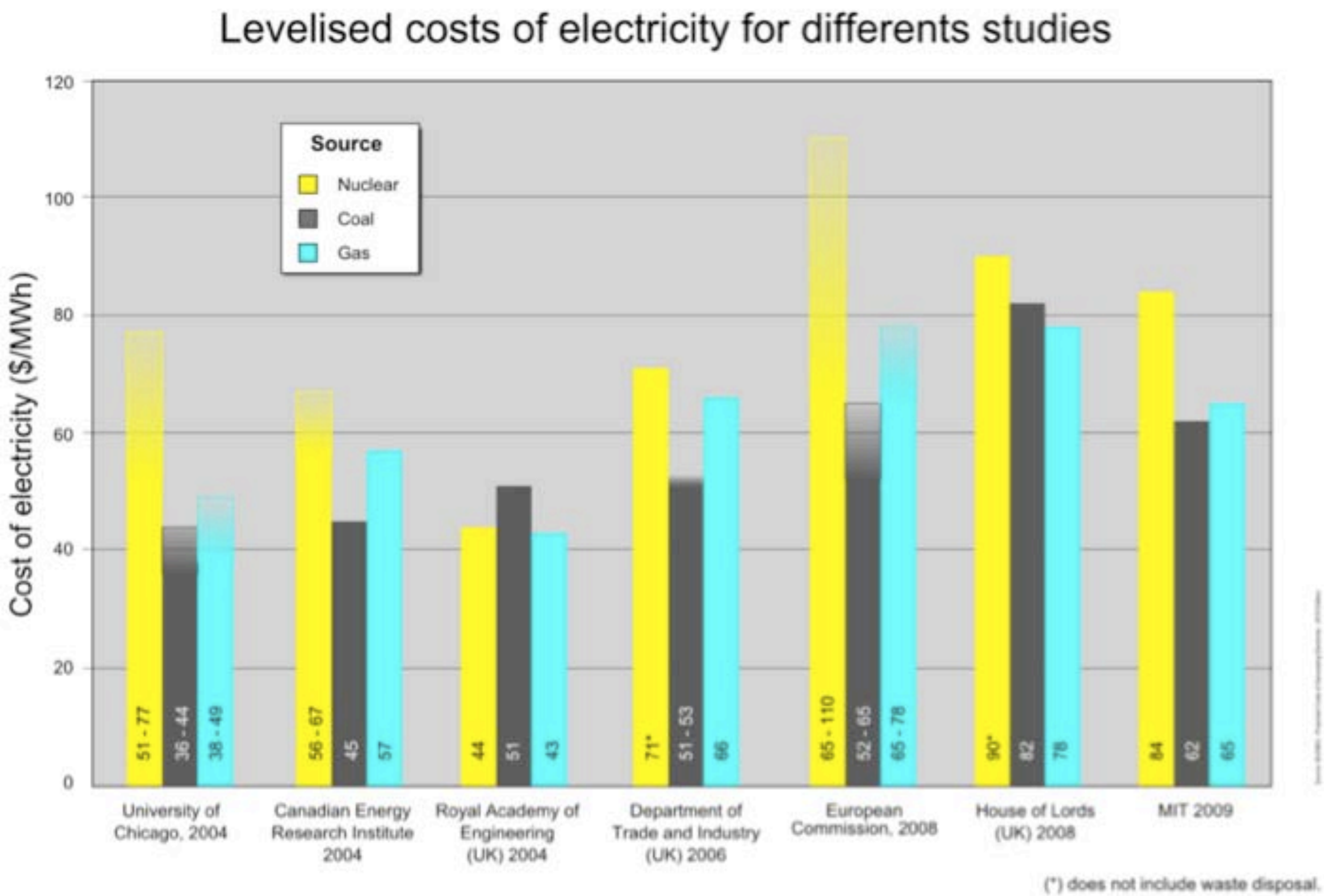
What is the cost of renewable energy? (2002)



Compared to fossil fuels how has cost changed in last decade? .



Alternative Energy Generation Costs, U.S. Energy Commission 2007
Generation Cost (cents/kWh)
20
18
16
14
12
10
8
6
4
2
0
Solar (Conc. PV)
Wind
Binary Geothermal
Flash Geothermal
Hydro



Size of this preview: 800 × 541 pixels. Other resolutions: 320 × 216 pixels | 640 × 432 pixels | 1,024 × 692 pixels | 1,280 × 865 pixels.

Estimated Levelized Cost of New Generation Resources, 2017[10]

		U.S. Average Levelized Cost for Plants Entering Service in 2017 (2010 USD/MWh)				
Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Conventional Coal	85	65.8	4.0	28.6	1.2	99.6
Advanced Coal	85	75.2	6.6	29.2	1.2	112.2
Advanced Coal with CCS	85	93.3	9.3	36.8	1.2	140.7
Natural Gas Fired						
Conventional Combined Cycle	87	17.5	1.9	48.0	1.2	68.6
Advanced Combined Cycle	87	17.9	1.9	44.4	1.2	65.5
Advanced CC with CCS	87	34.9	4.0	52.7	1.2	92.8
Conventional Combustion Turbine	30	46.0	2.7	79.9	3.6	132.0
Advanced Combustion Turbine	30	31.7	2.6	67.5	3.6	105.3
Advanced Nuclear	90	88.8	11.3	11.6	1.1	112.7
Geothermal	92	76.6	11.9	9.6	1.5	99.6
Biomass	83	56.8	13.8	48.3	1.3	120.2
Wind[1]	34	83.3	9.7	0.0	3.7	96.8
Solar PV[1,2]	25	144.9	7.7	0.0	4.2	156.9
Solar Thermal[1]	20	204.7	40.1	0.0	6.2	251.0
Hydro[1]	53	76.9	4.0	6.0	2.1	89.9

[1]Non-dispatchable (Hydro is dispatchable within a season, but nondispatchable overall-limited by site and season)

[2]Costs are expressed in terms of net AC power available to the grid for the installed capacity

10. ^ a b c d e Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011. Released January 23, 2012. Report of the US Energy Information Administration (EIA) of the U.S. Department of Energy (DOE).

For interested readers

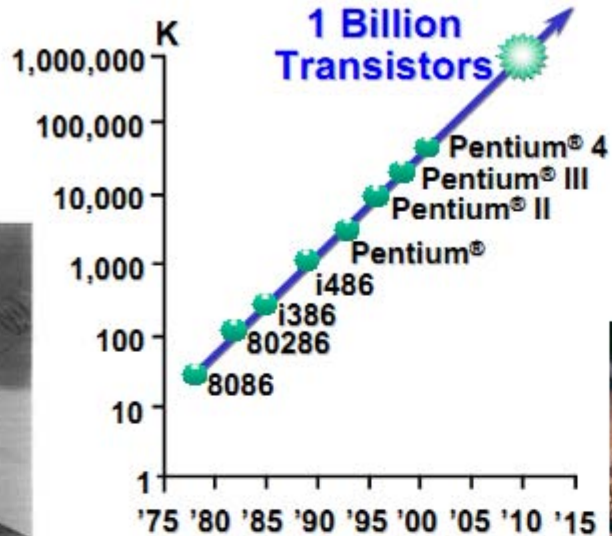
ei.haas.berkeley.edu/pdf/newsletter/2012Spring.pdf

Economic discuss of comparative costs of electricity generation that includes subsidies, etc.

Microprocessor Evolution

scaling

FIGURE 1.1 The world's first transistor, developed in 1947. It was a point-contact device roughly one centimeter across. (Courtesy of Lucent Technologies Bell Laboratories.)



Airplane Speed/Efficiency Evolution

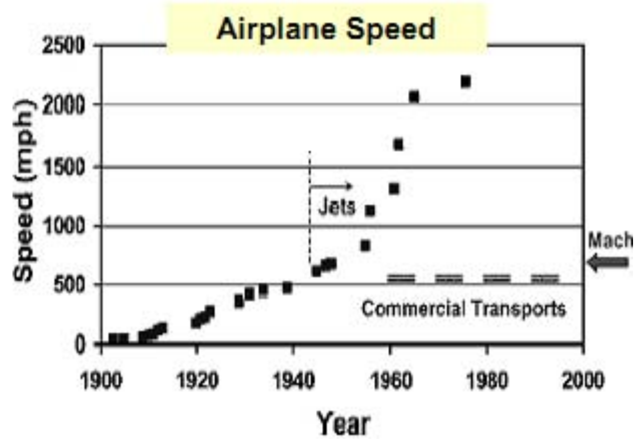
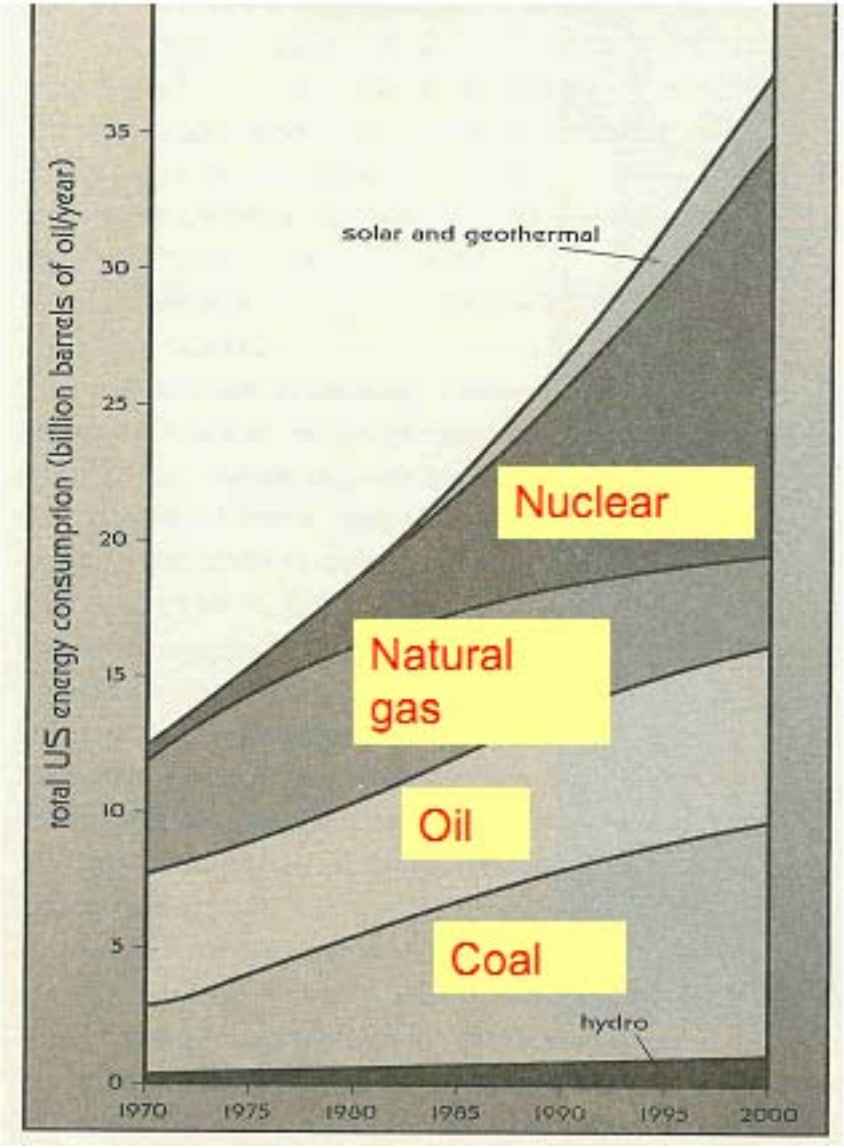


Fig. 6 Absolute airplane speed record (Refs. 10 and 11).

McMasters & Cummings, Journal of Aircraft, Jan-Feb 2002

Prediction is very hard, especially about the future - Yogi Berra



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A. Shakouri 7/28/20

Felix's forecasts of US energy consumption in year 2000 (early 1970's)

Vaclav Smil,
Energy at the Crossroads,
2005

Potential Energy in Renewable Sources

We need to look at the “potential” of renewable energy resources.

Electric Potential of Wind

- Significant potential in US Great Plains, inner Mongolia and northwest China

- U.S.:
  Use 6% of land suitable for wind energy development; practical electrical generation potential of ≈0.5 TW

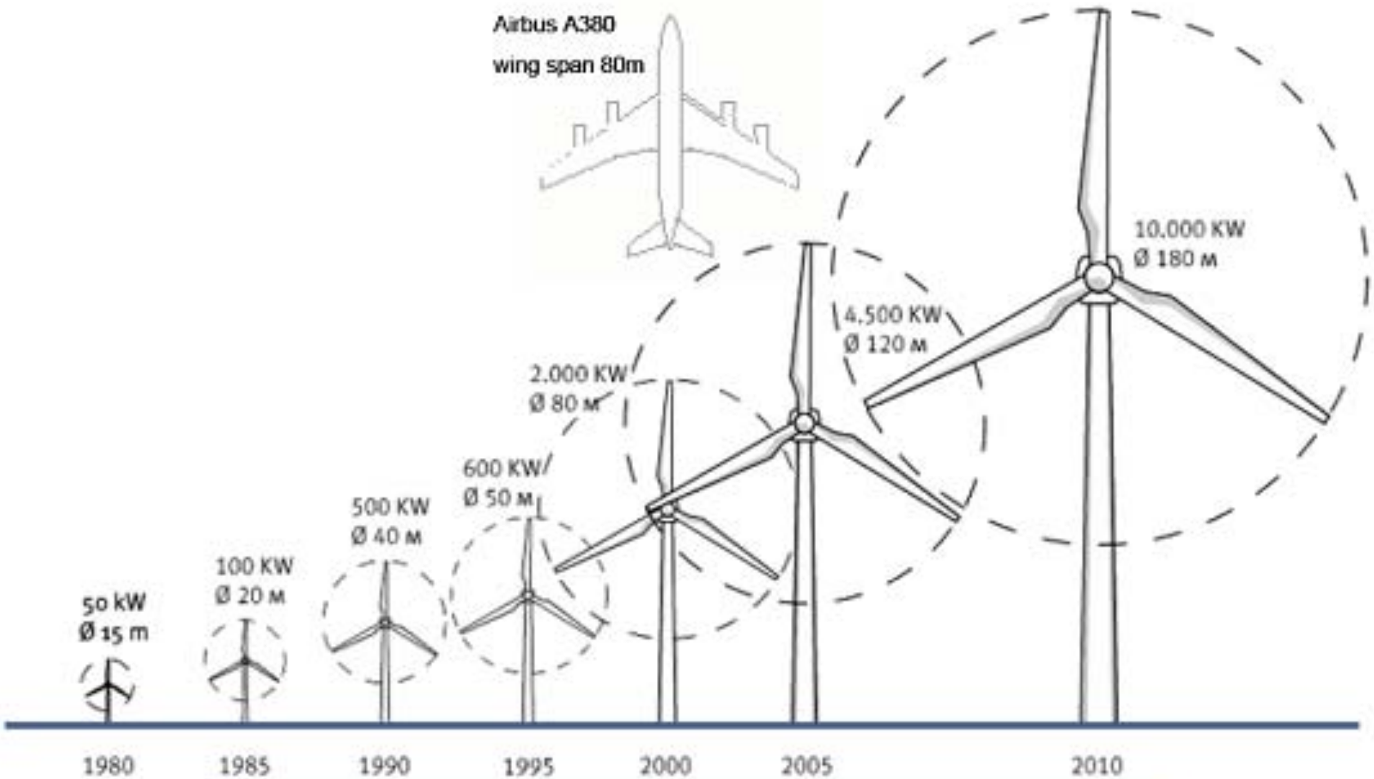
- Globally:
  Theoretical: 27% of earth's land is class >3 => 50 TW
  Practical: 2 TW potential (4% utilization)

  Off-shore potential is larger but must be close to grid to be interesting; (no installation > 20 km offshore now)

Nate Lewis, Caltech

Turbine Sizes

Horizonal axis (HAWT)



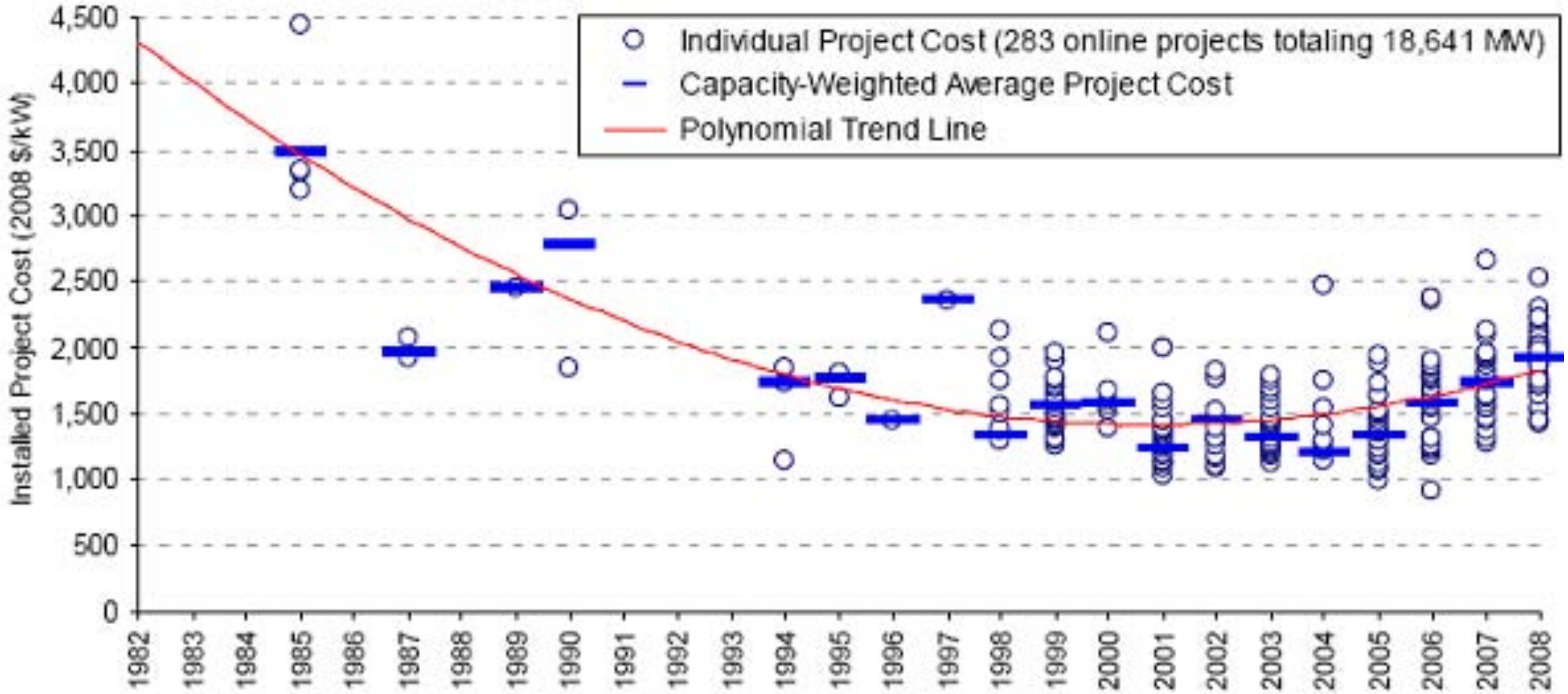
Trend toward bigger turbine sizes

Helge Aagaard Madsen, DTU Riso

The Center for Sustainable Energy and Power Systems

CENSEPS

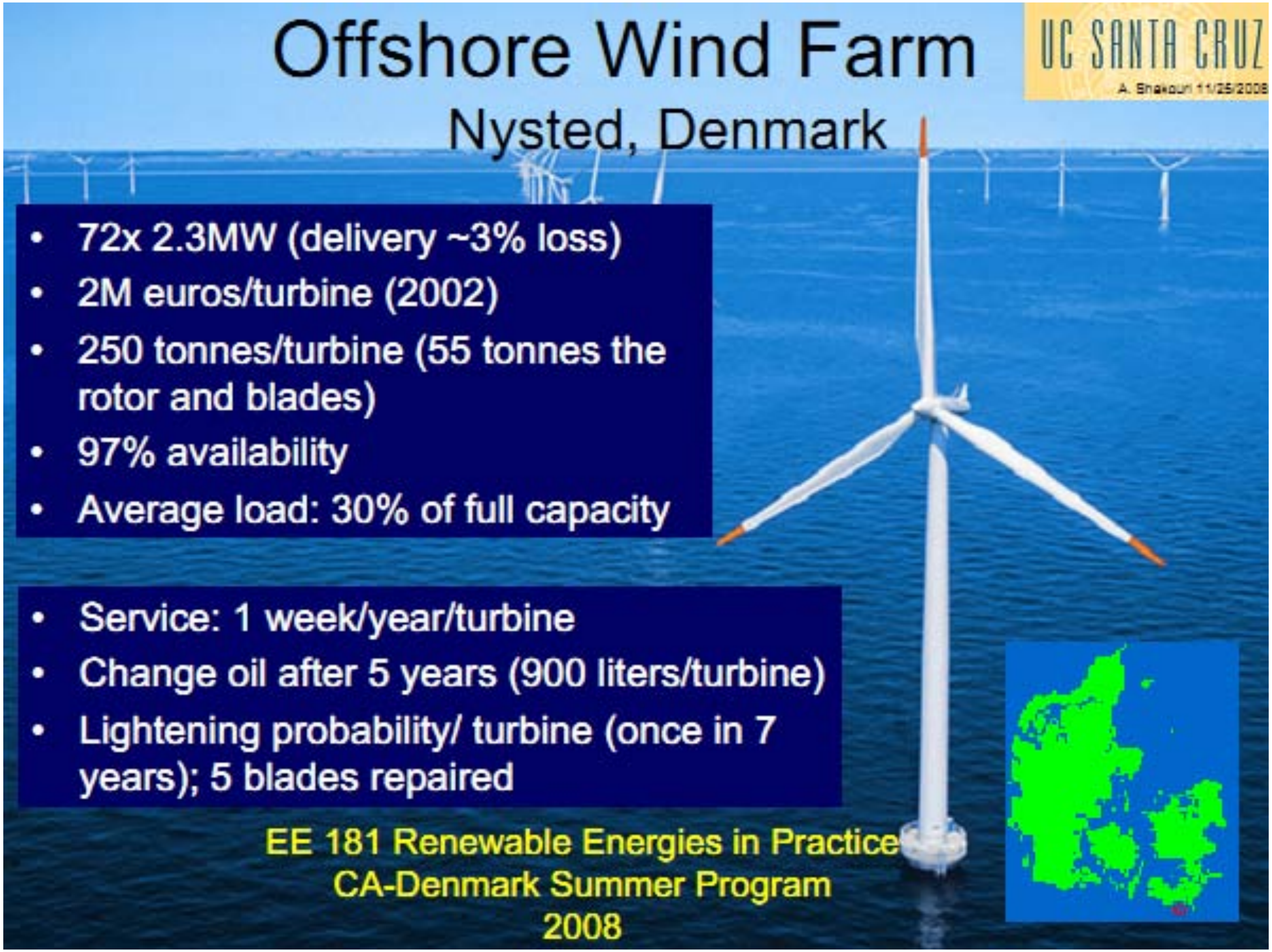
HAWT



Source: Berkeley Lab database (some data points suppressed to protect confidentiality)

http://www.eere.energy.gov/

2008 Wind Technologies Market Report


Offshore Wind Farm
Nysted, Denmark
UC SANTA CRUZ
A. Shakouri 11/25/2008
• 72x 2.3MW (delivery ~3% loss)
• 2M euros/turbine (2002)
• 250 tonnes/turbine (55 tonnes the rotor and blades)
• 97% availability
• Average load: 30% of full capacity
• Service: 1 week/year/turbine
• Change oil after 5 years (900 liters/turbine)
• Lightening probability/ turbine (once in 7 years); 5 blades repaired
EE 181 Renewable Energies in Practice
CA-Denmark Summer Program
2008

Geothermal Energy Potential

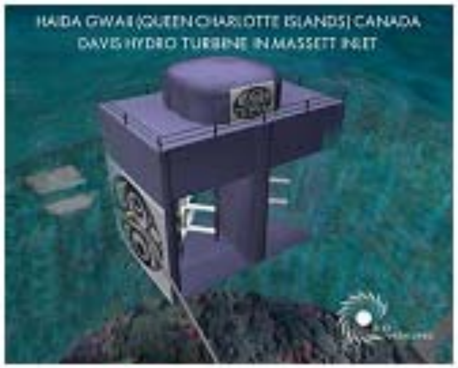
Cal-Den summer school

- Mean terrestrial geothermal flux at earth's surface 0.057 W/m^2
- Total continental geothermal energy potential 11.6 TW
- Oceanic geothermal energy potential 30 TW

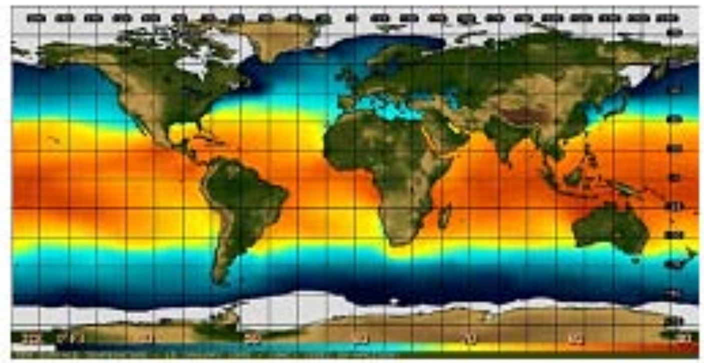
- Wells "run out of steam" in 5 years
- Power from a good geothermal well (pair) 5 MW
- Power from typical Saudi oil well 500 MW
- Needs drilling technology breakthrough
  (from exponential \$/m to linear \$/m) to become economical)

Nate Lewis, Caltech

Energy from the Oceans?

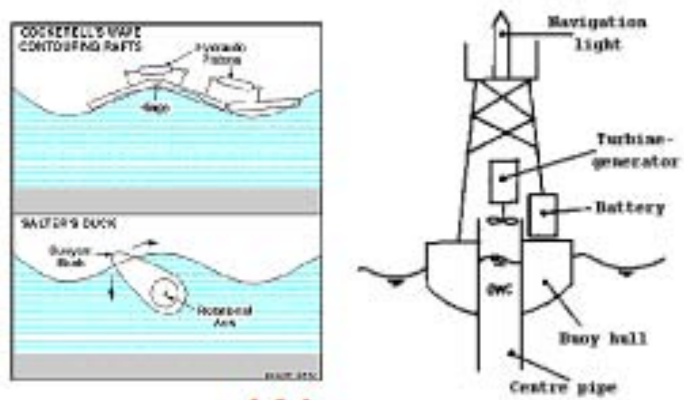


Currents



Thermal Differences

Tides

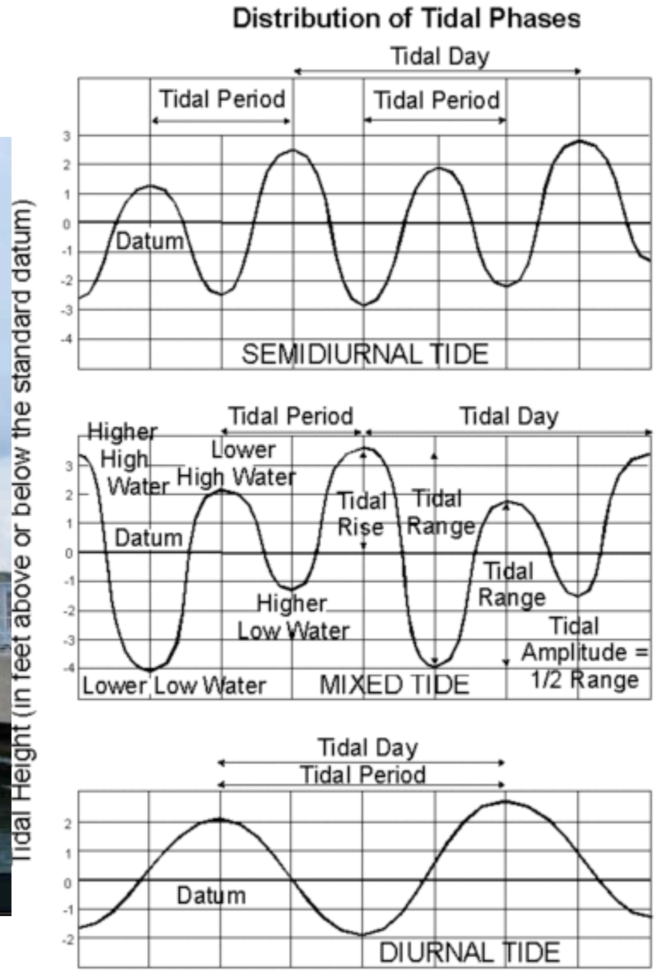


Waves

Ken Pedrotti, UCSC

Tidal Power


The Rance Tidal Power Station bridges the Rance River in Brittany, France. The


Distribution of Tidal Phases
Tidal Day
Tidal Period
Tidal Period
Datum
SEMIDIURNAL TIDE
Tidal Height (in feet above or below the standard datum)
Tidal Period
Tidal Day
Higher High Water
Lower High Water
Datum
Tidal Rise
Tidal Range
Tidal Range
Higher Low Water
Tidal Amplitude = 1/2 Range
Lower Low Water
MIXED TIDE
Tidal Day
Tidal Period
Datum
DIURNAL TIDE

Biomass Energy Potential

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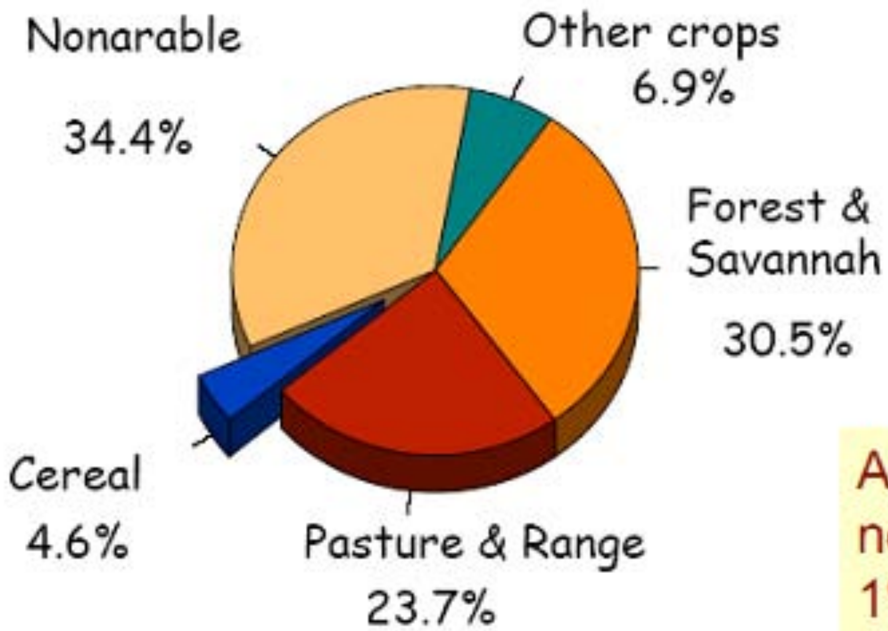
Global: Top Down

- Requires Large Areas Because Inefficient (0.3%)
- 3 TW requires ≈ 600 million hectares = 6×10^{12} m^2
- 20 TW requires ≈ 4×10^{13} m^2
- Total land area of earth: 1.3×10^{14} m^2
- Hence requires 4/13 = 31% of total land area

Nate Lewis, Caltech

Land Usage

Does not include the ocean/algae based



Amount of land needed for 20 TW at 1% efficiency:

9% of land

AMBIO 23,198 (Total Land surface 13,000 M Ha)

Chris Somerville, UC Berkeley

Biofuels

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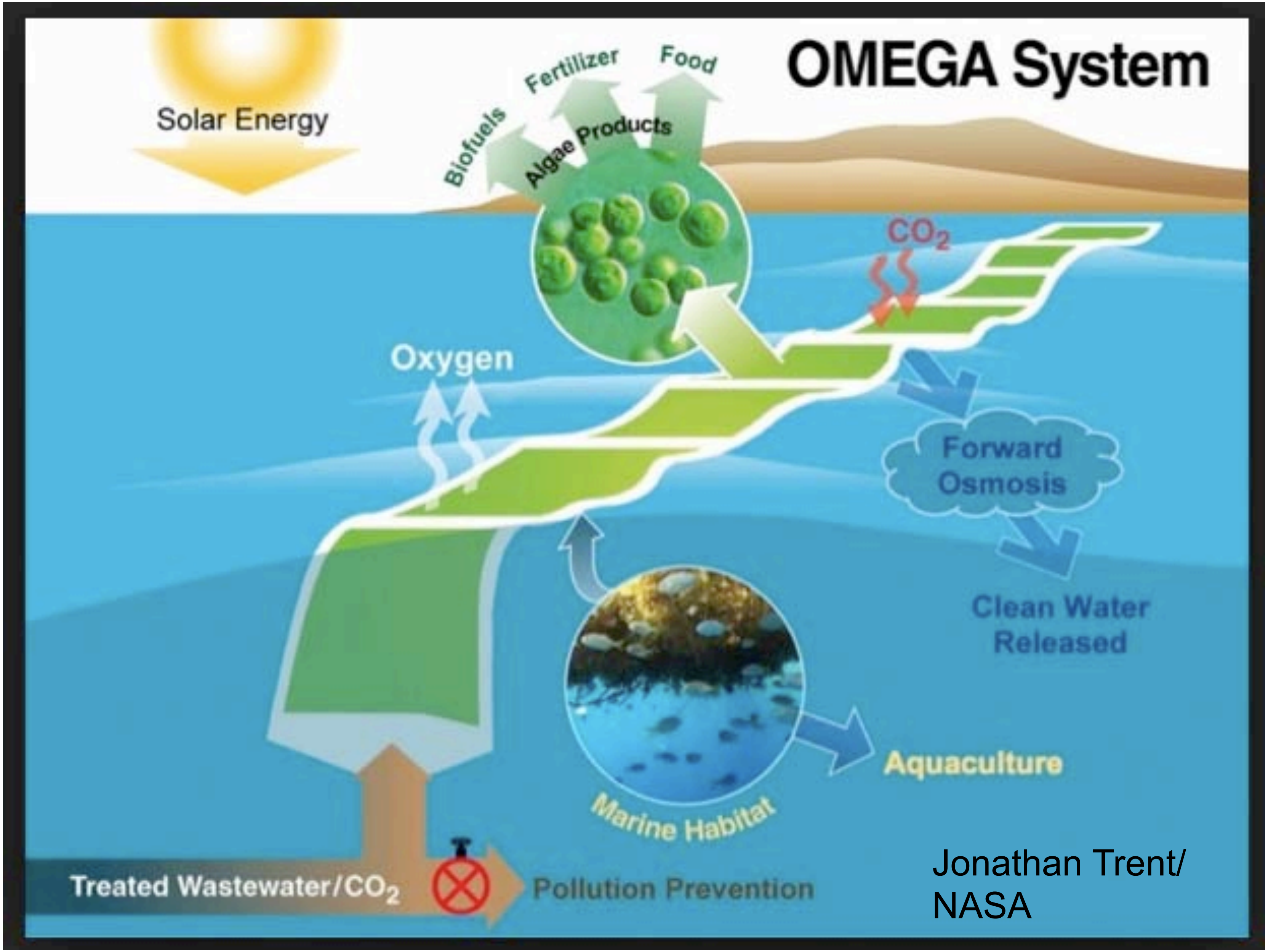
CROP	Harvest-able Biomass (tons/ acre)	Ethanol (gal/t)	Million acres needed for 35 billion gallons of ethanol	% 2006 harvested US cropland needed
Corn grain	4	500	70	25.3
Corn stover	3	300	105	38.5
Corn Total	7	800	40	15.3
Prairie	2	200	210	75.1
Sorghum	2	200	210	75.1
Switch-grass	6	600	60	20.7
Miscanthus	17	1700	18	5.8
Tank Algae*	80+	600+	< 10	< 2

*assumes CO_2 input

Dan Kammen, Berkeley

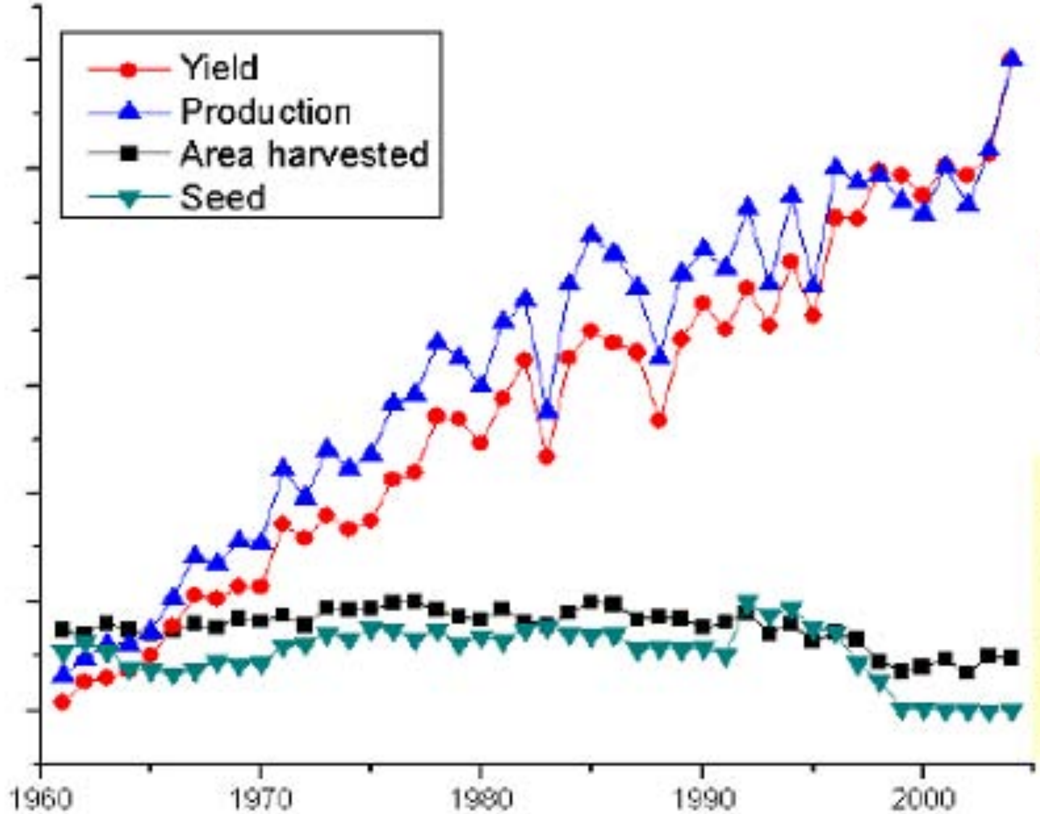


Jonathan Trent/
NASA

Algae Growing Facility Testbed at NOAA Labs in Santa Cruz

Jonathan Trent

World Production of Grain (1961 – 2004)



Steven Chu, 2007

Energy Input (Fertilizer, etc.)

Ecosystem Impact

1960:
Population = 3 B

2005:
Population = 6.5 B

Source: Food and Agriculture Organization (FAO), United Nations

Solar Energy Potential

- Theoretical: $1.2x10^5$ TW solar energy potential
- Practical: ≈ 600 TW solar energy potential
- Onshore electricity generation potential of ≈60 TW (10% conversion efficiency):
- *Photosynthesis*: 90 TW

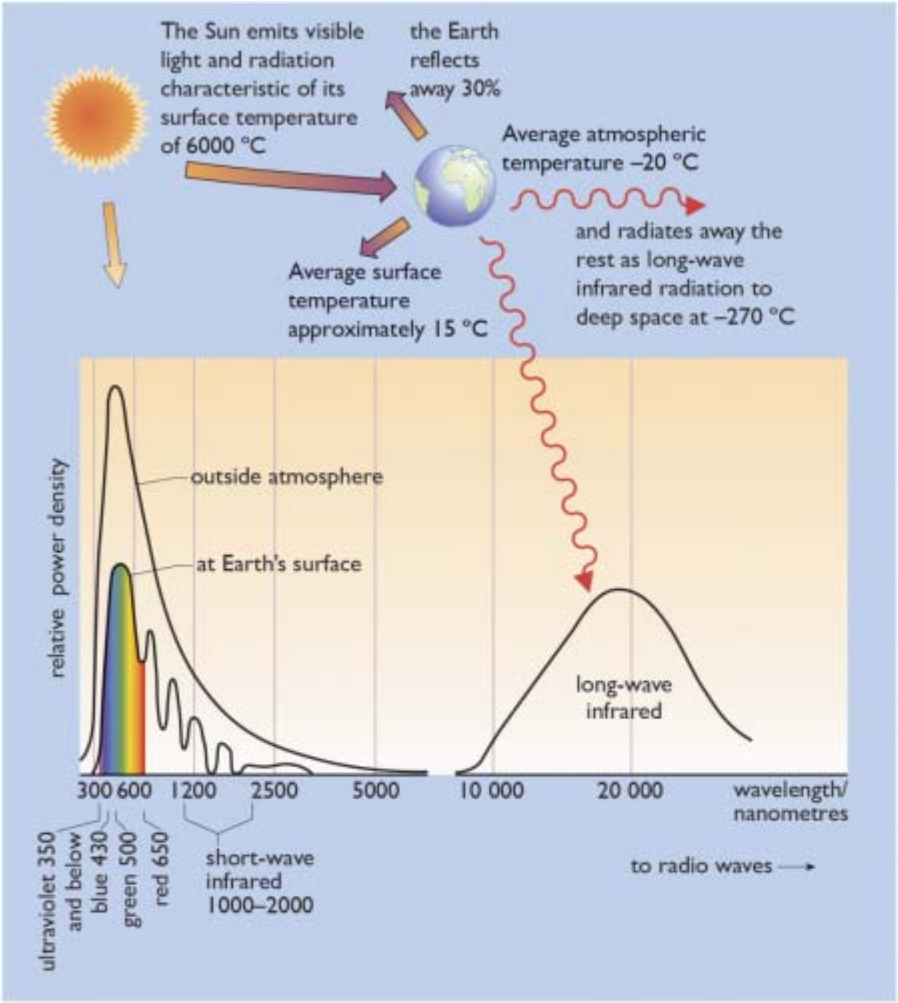
- Generating 12 TW (1998 Global Primary Power) requires 0.1% of Globe = $5x10^{11}$ m^2 (i.e., 5.5% of U.S.A.)

Nate Lewis, Caltech

Solar Source

Energy Content	Magnitude
Solar Radiation on Earth	5,500,000 EJ
Solar Radiation on lower regions on Earth	3,800,000 EJ
Global Coal Resources	200,000 EJ
Global Plant Mass	10,000 EJ
Global Fossil Fuel Production	300,000 EJ
Typical Caribbean Hurricane	40 EJ
Hiroshima Bomb (1945)	0.000084 EJ

Solar Irradiation



World Insolation

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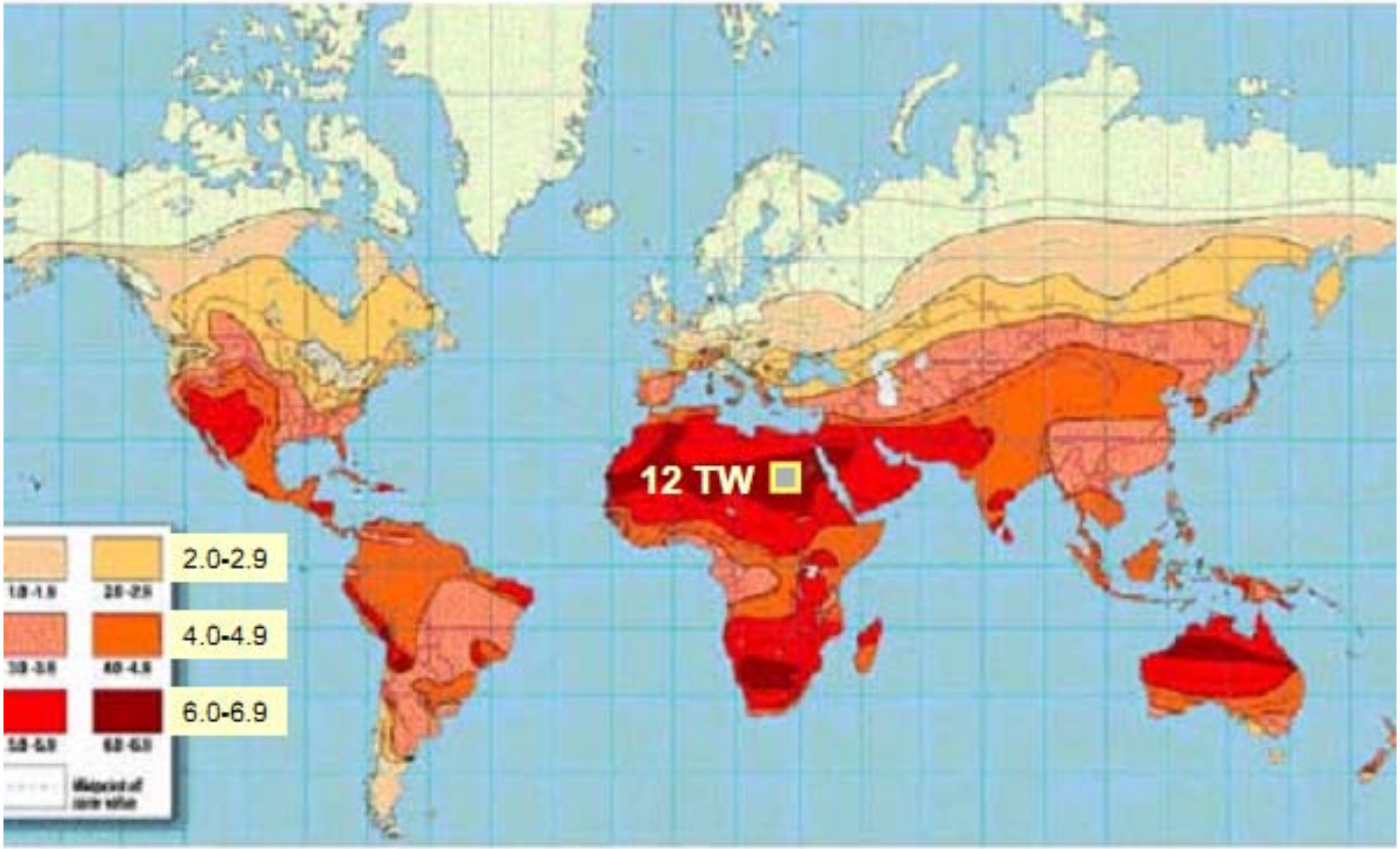
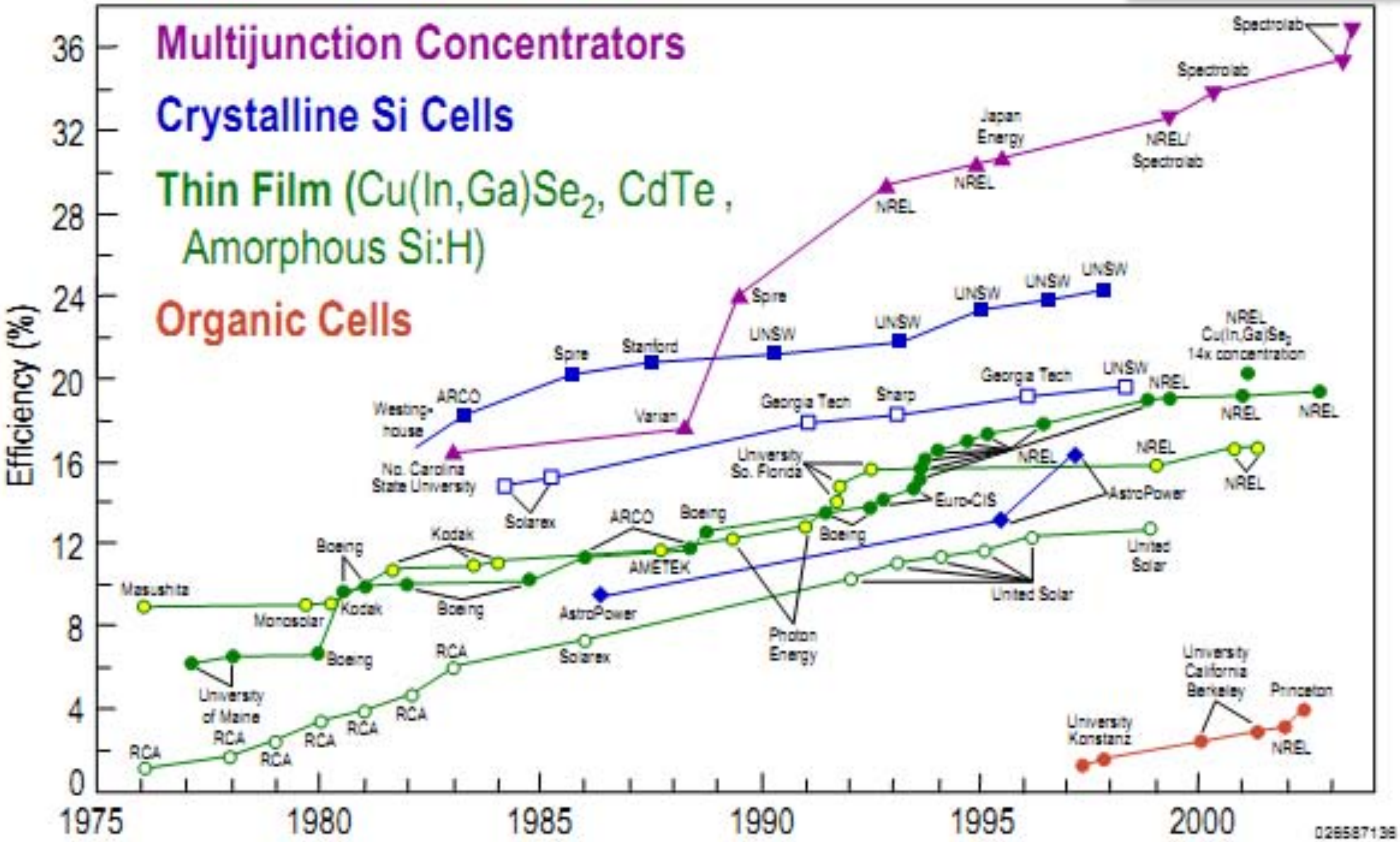
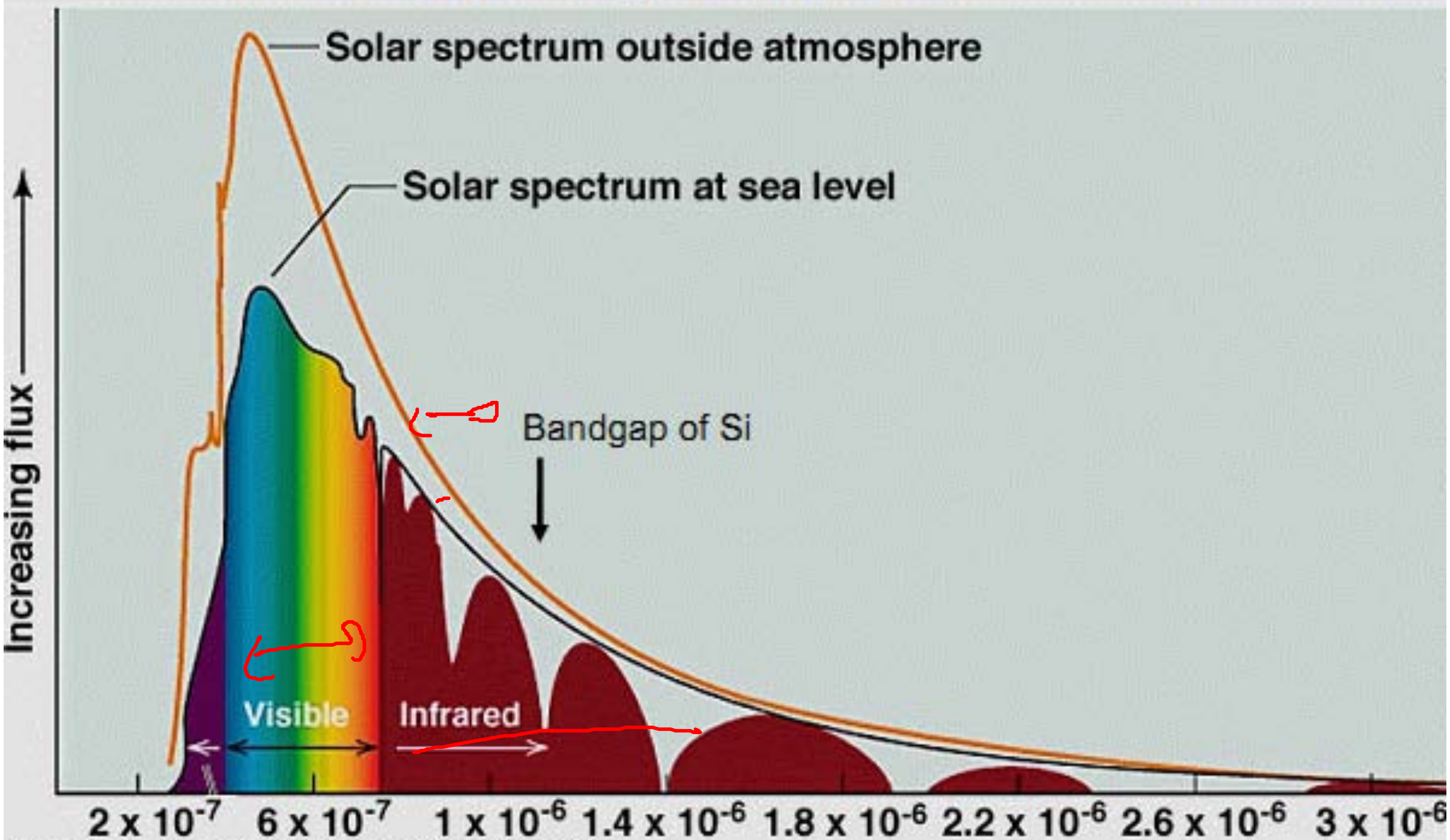


Best Research-Cell Efficiencies



L.L. Kazmerski, National Renewable Energy Laboratory, National Center for Photovoltaics

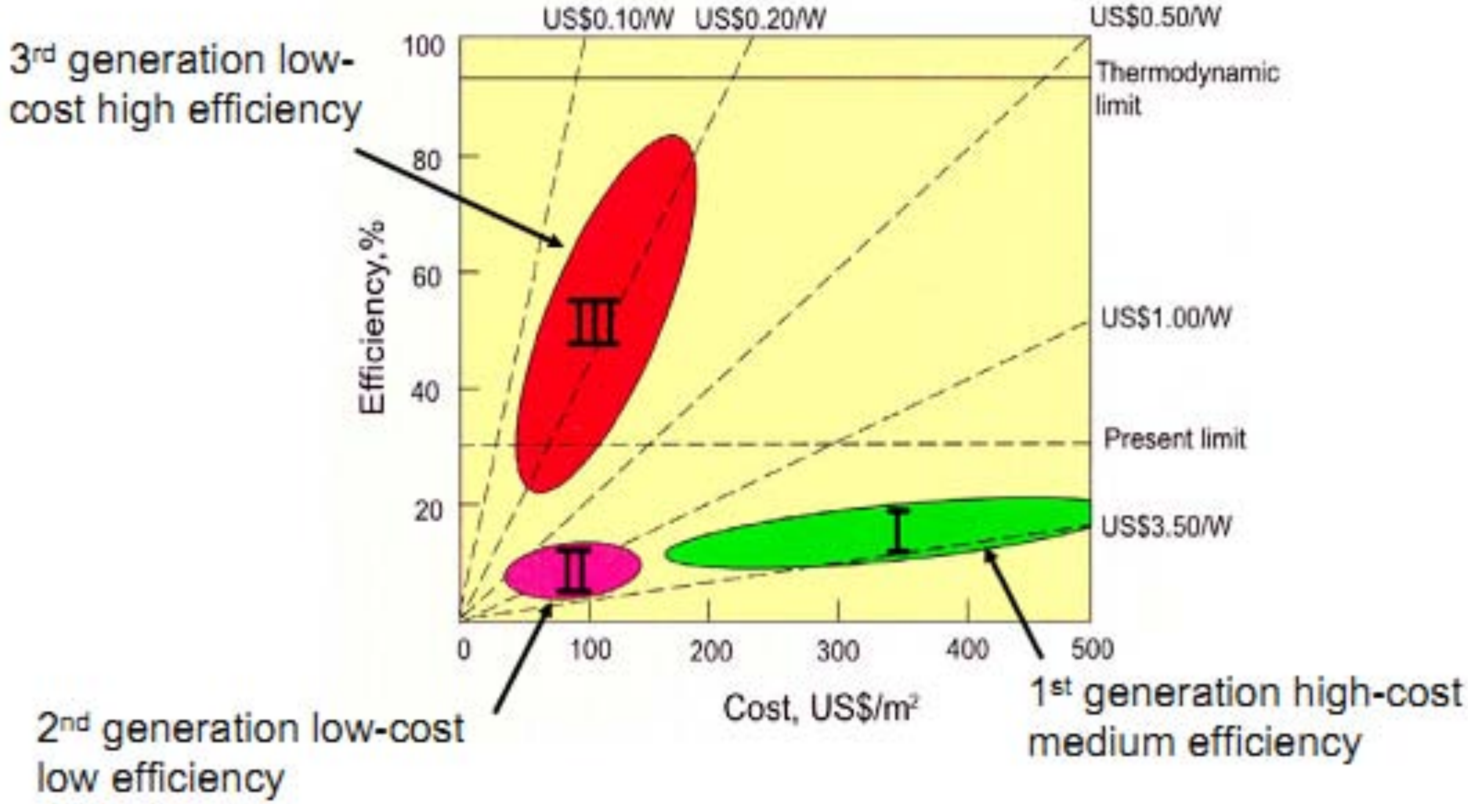
Solar Spectrum

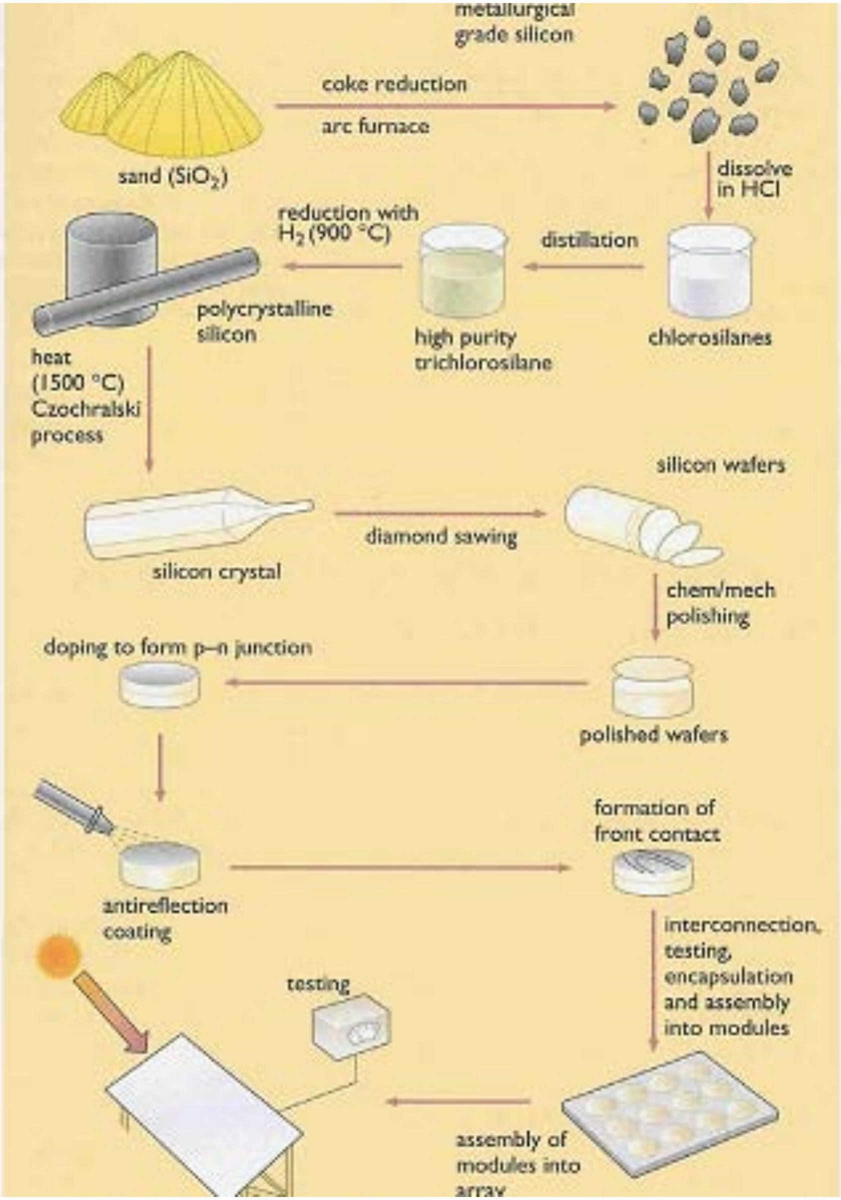


http://csep10.phys.utk.edu/astr162/lect/light/spectrum.html

Cost/Efficiency

Cost/watt and cost/ area are important





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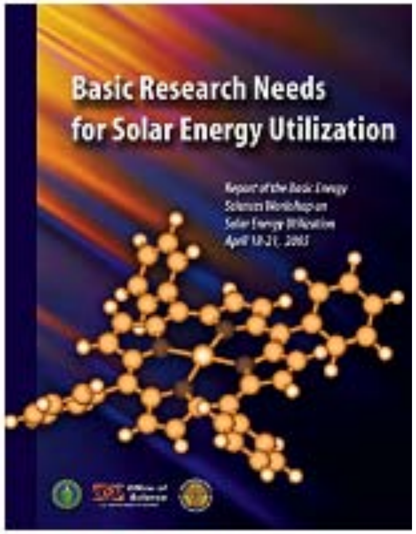
Boyle Renewable Energy Sources

BASIC RESEARCH NEEDS FOR SOLAR ENERGY UTILIZATION

Chair: Nathan S. Lewis, Caltech, George Crabtree, Argonne

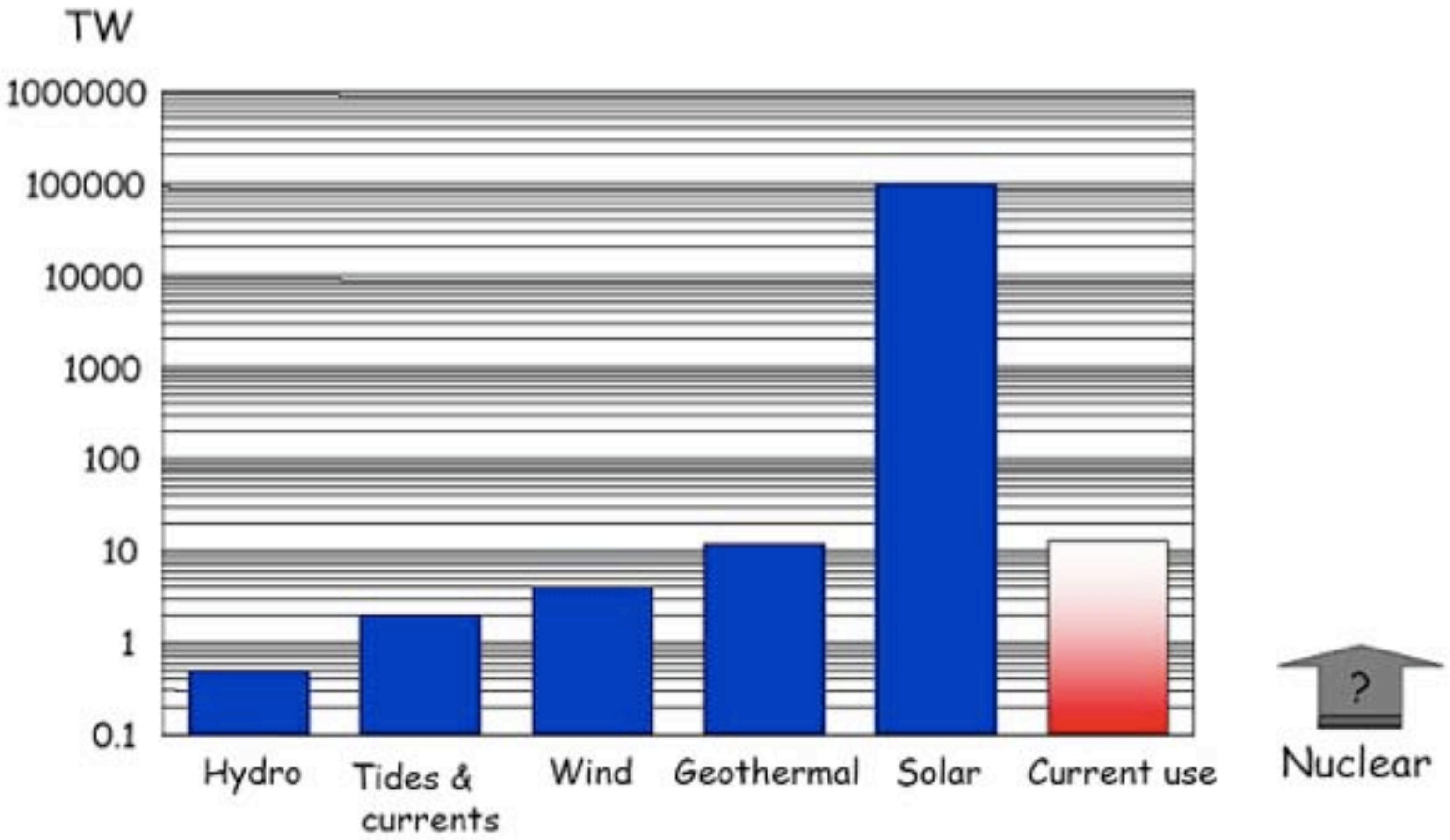
April 2005



PRIORITY RESEARCH DIRECTIONS

- 50% Efficient Solar Cells
- Plastic Photovoltaics
- Nanostructures: Low Cost and High Efficiencies
- Fuels from Water and Sunlight: Efficient Photoelectrolysis
- Leveraging Photosynthesis for Production of Biofuel
- Bio-inspired Smart Matrix for Solar Fuels Production
- Solar-powered Catalysts for Energy-rich Fuels Formation
- Bio-inspired Molecular Assemblies for Integrating Photon-to-fuels Pathways
- Achieving Defect-tolerant and Self-repairing Solar Conversion Systems
- Solar Thermochemical Fuel Production
- New Experimental and Theoretical Tools
- Solar Energy Conversion Materials by Design
- Materials Architectures for Solar Energy: Assembling Complex Structures

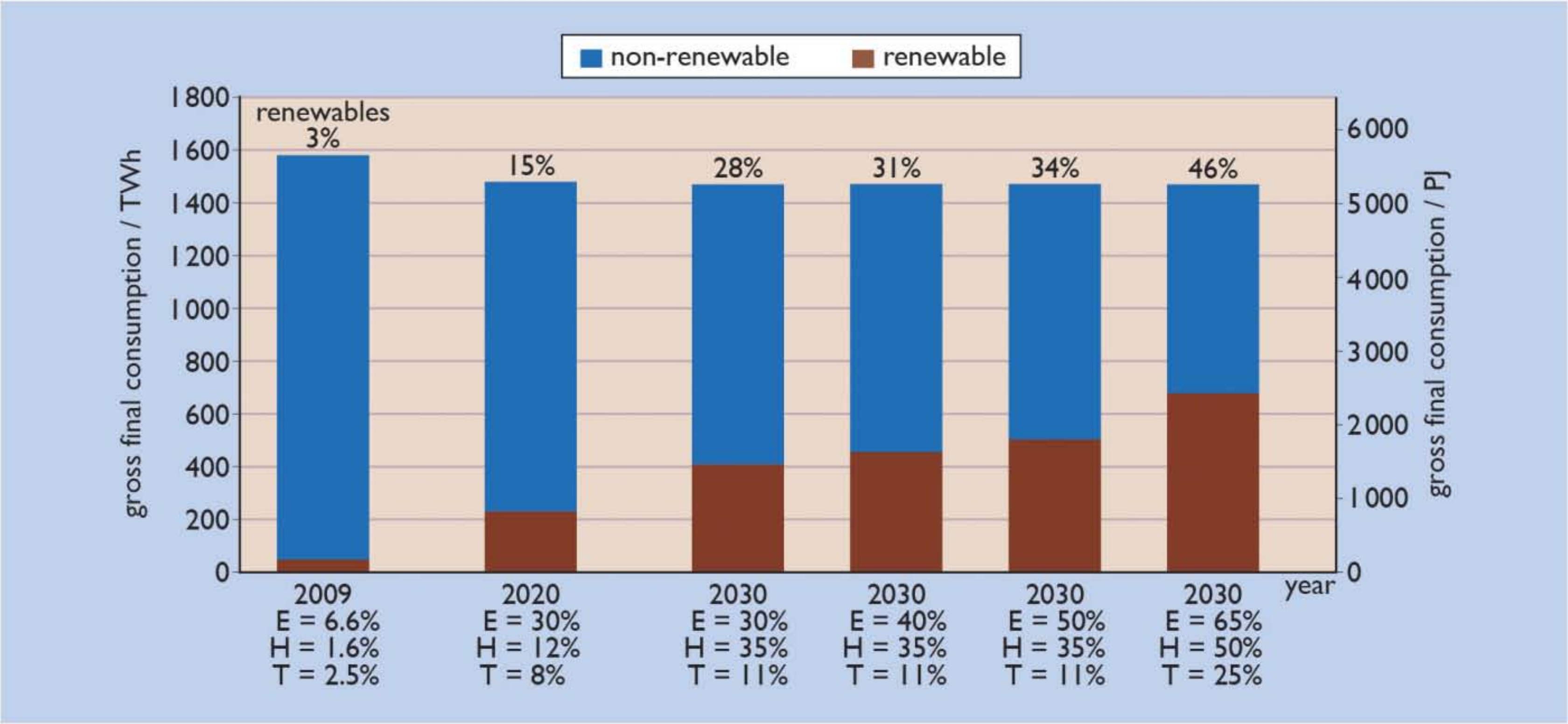
Potential of Carbon Free Energy Sources



From: Basic Research Needs for Solar Energy Utilization, DOE 2005

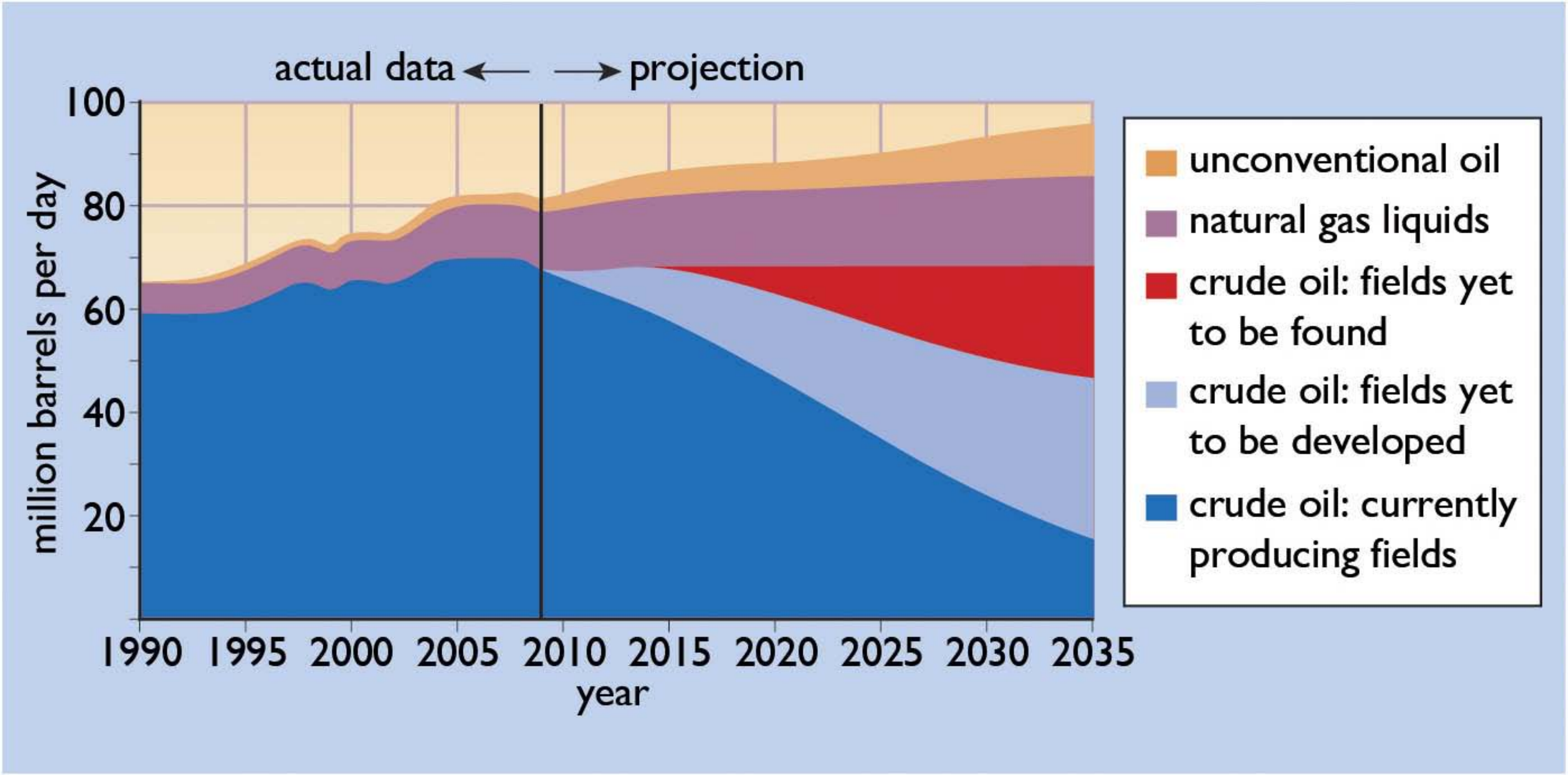
Chris Somerville, UC Berkeley

Potential Contributions of Renewables in the UK



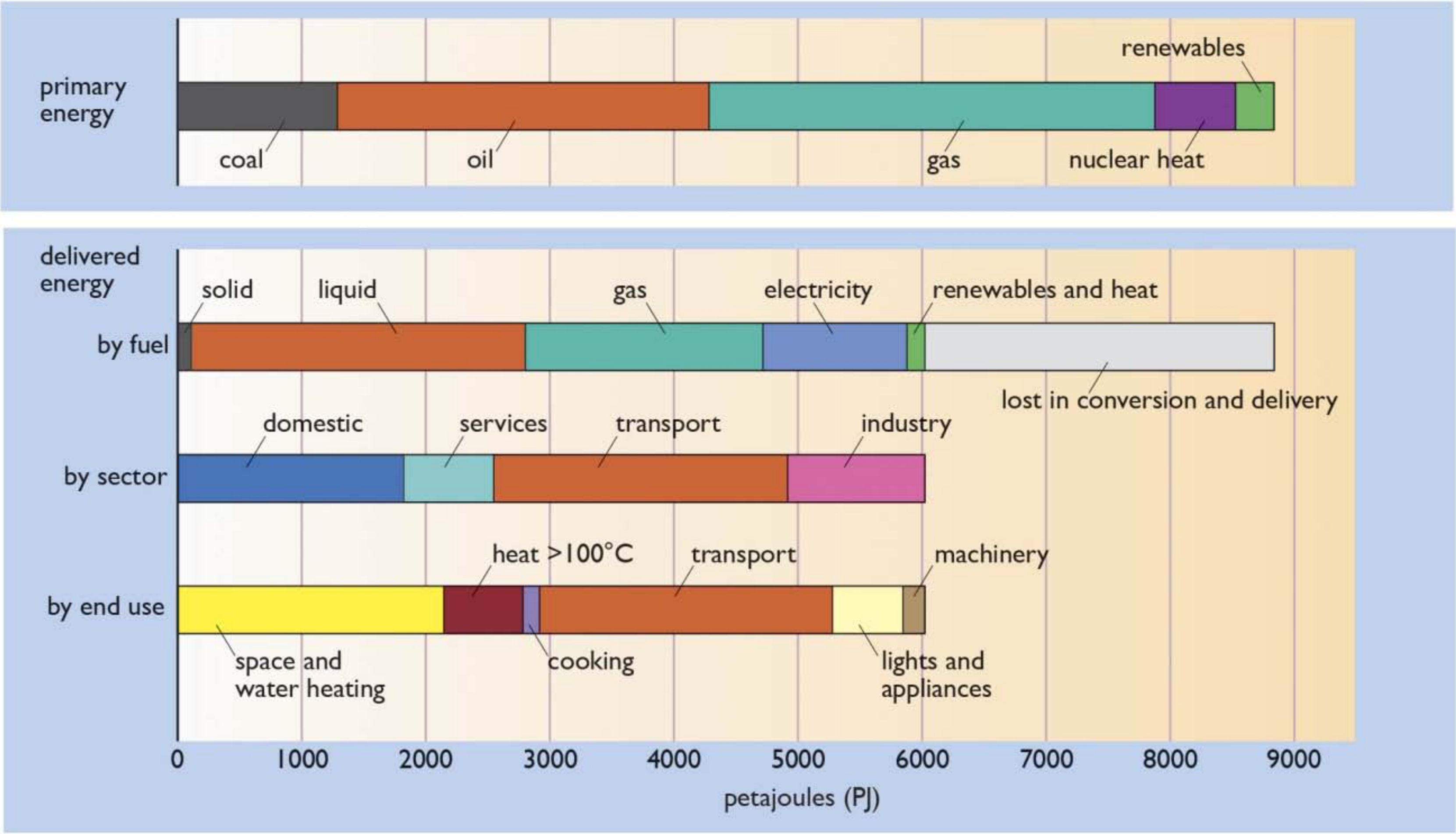
Committee on Climate Change (2011) The Renewable Energy Review, Committee on Climate Change

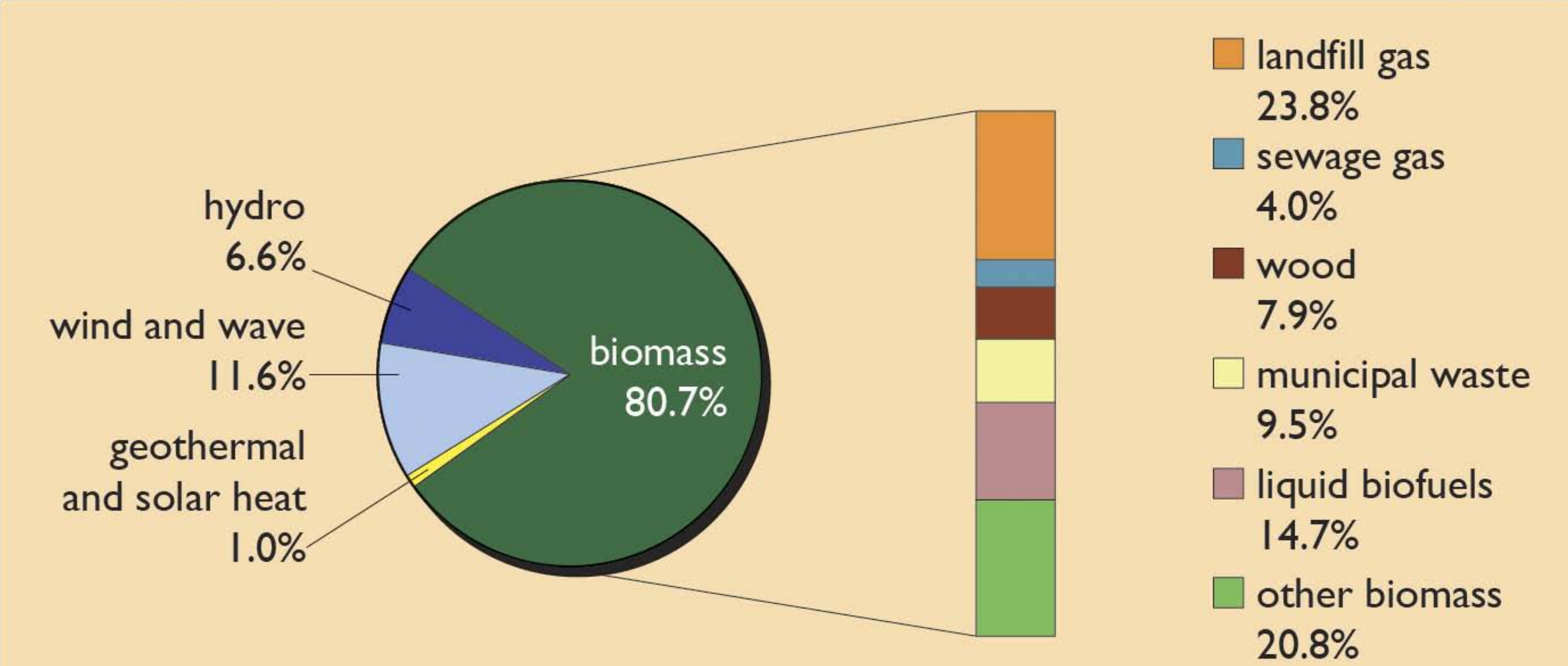
E = electricity, H = heat, T = transport



IEA World Energy Outlook Report (2010), International Energy Agency

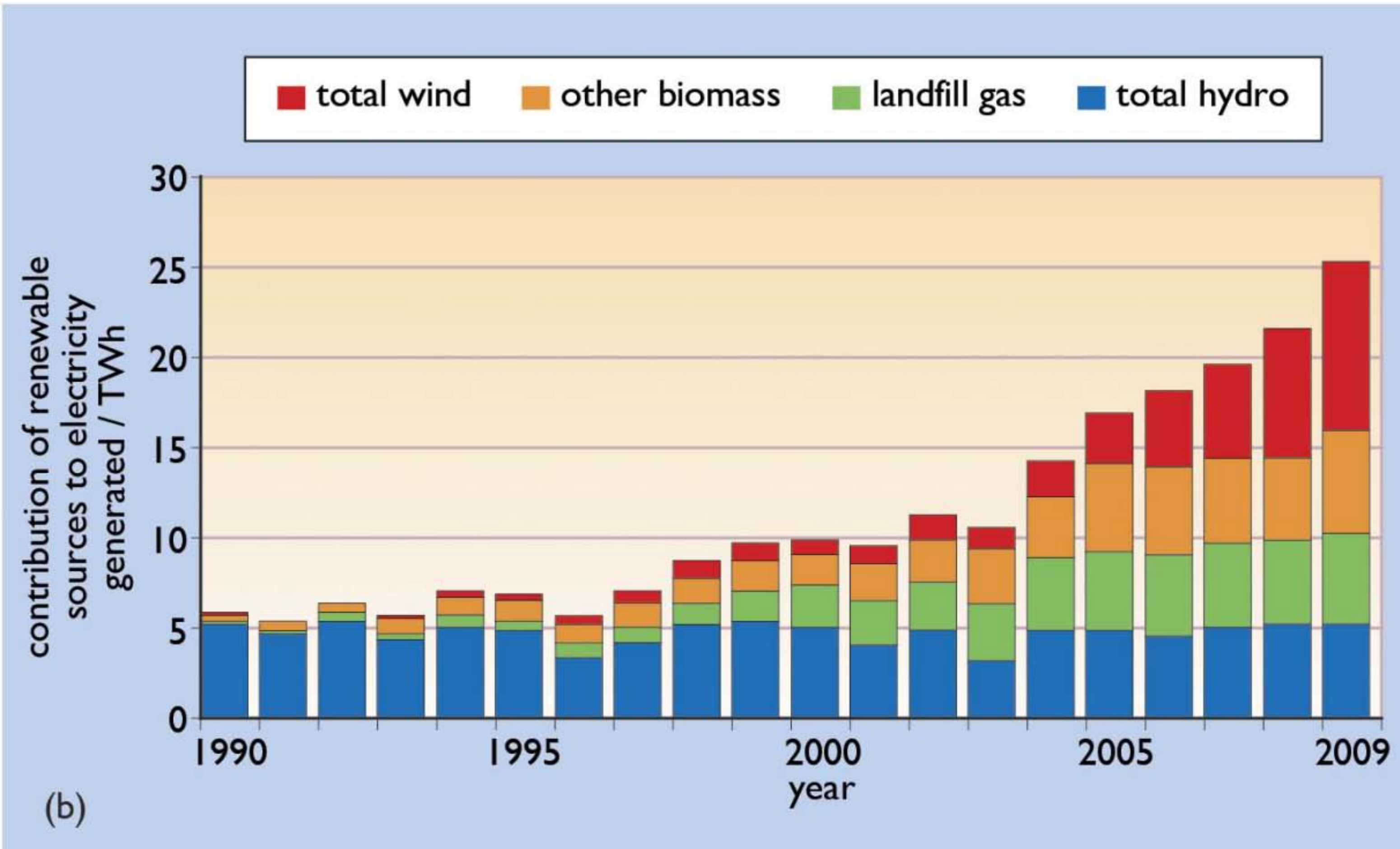
Use of Different Energy Sources





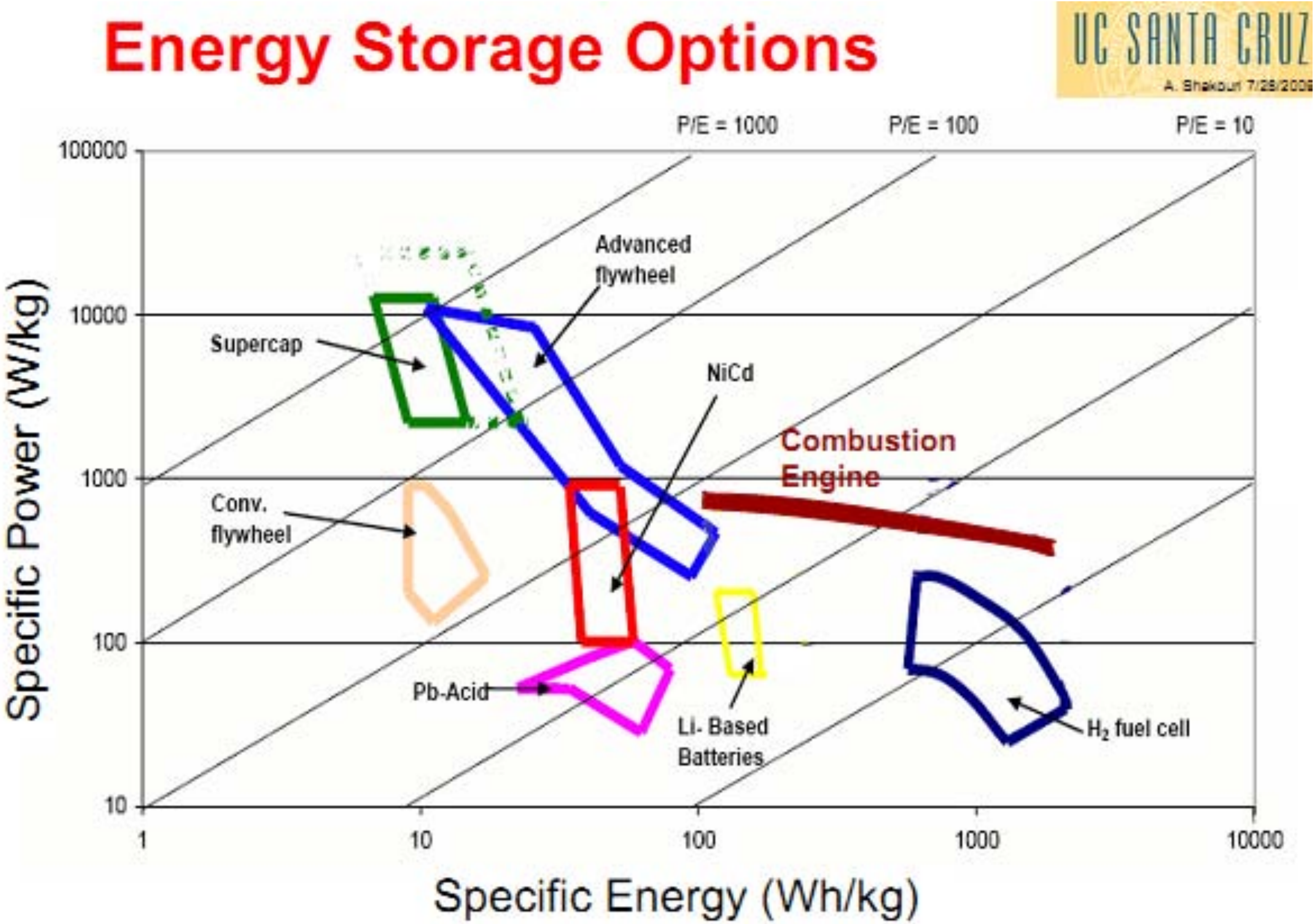
(a) Total contribution: 288 PJ or 3.3% of UK primary energy consumption

Figure 1.6b



total wind
other biomass
landfill gas
total hydro
contribution of renewable sources to electricity generated / TWh
30
25
20
15
10
5
0
1990
1995
2000
2005
2009
year
(b)

Energy Storage Options

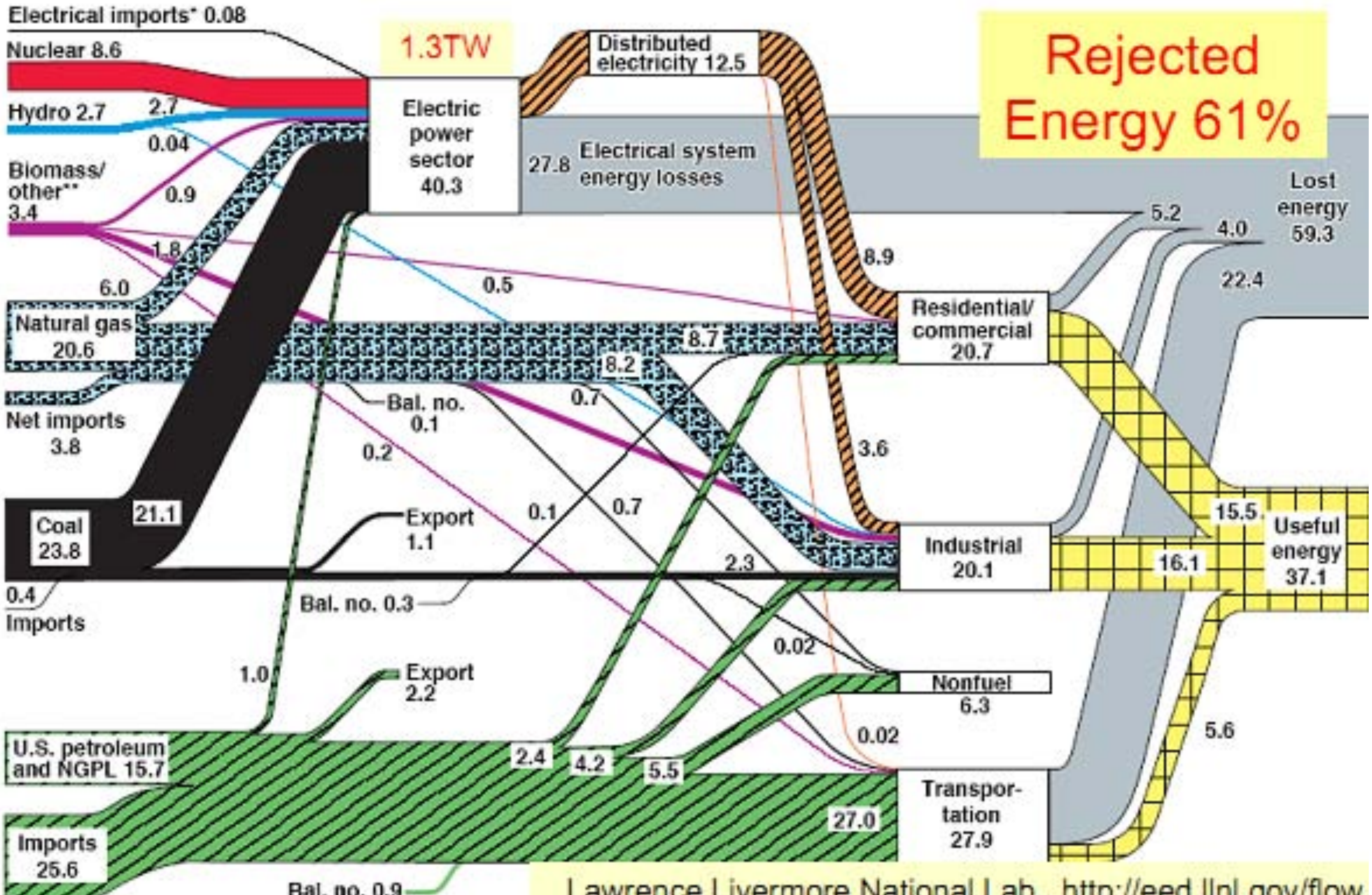


U.S. Energy Flow Trends – 2002

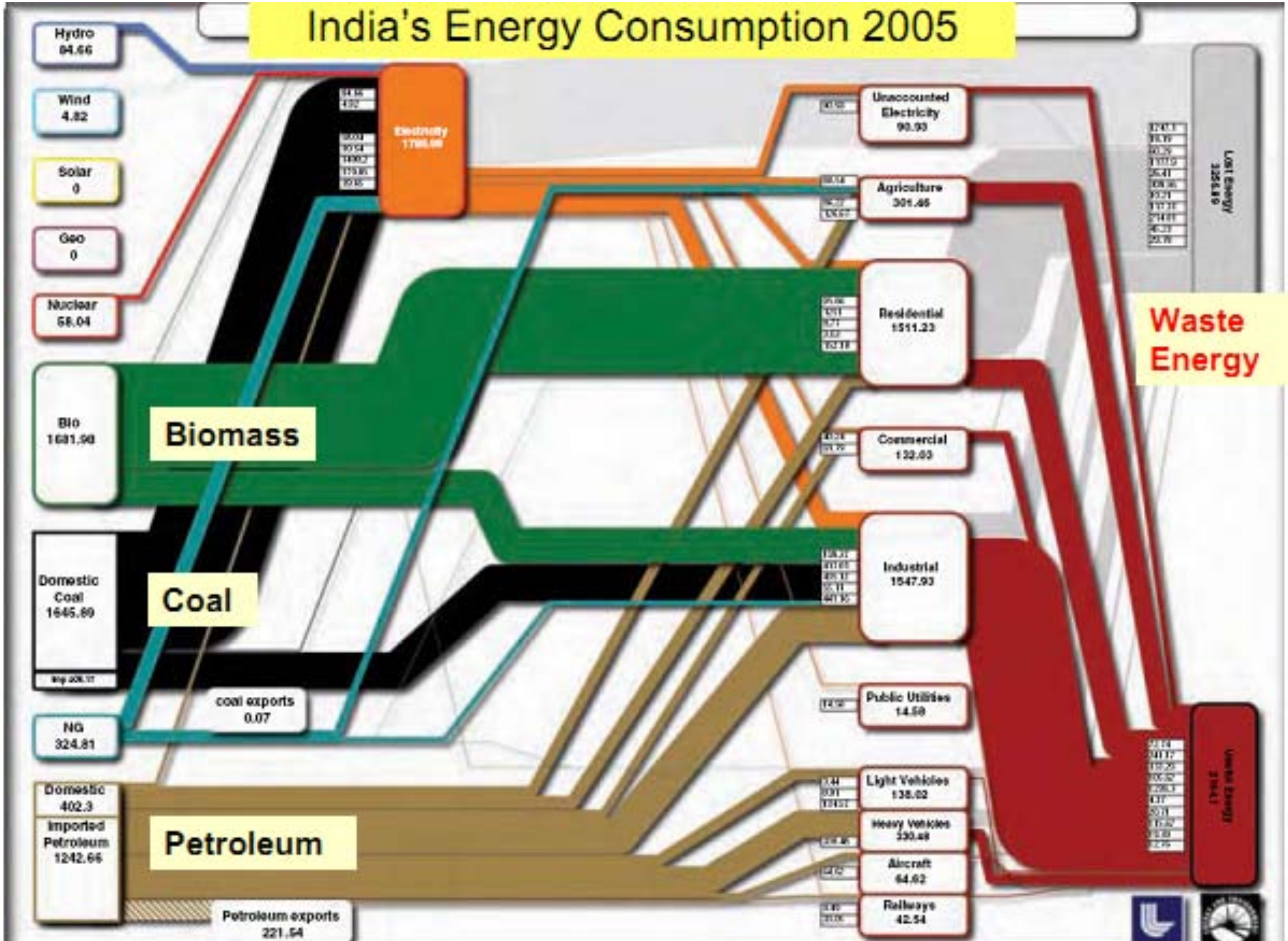
Net Primary Resource Consumption ~103 Exajoules

Power ~3.3TW

A. Shakouri 11/25/2008

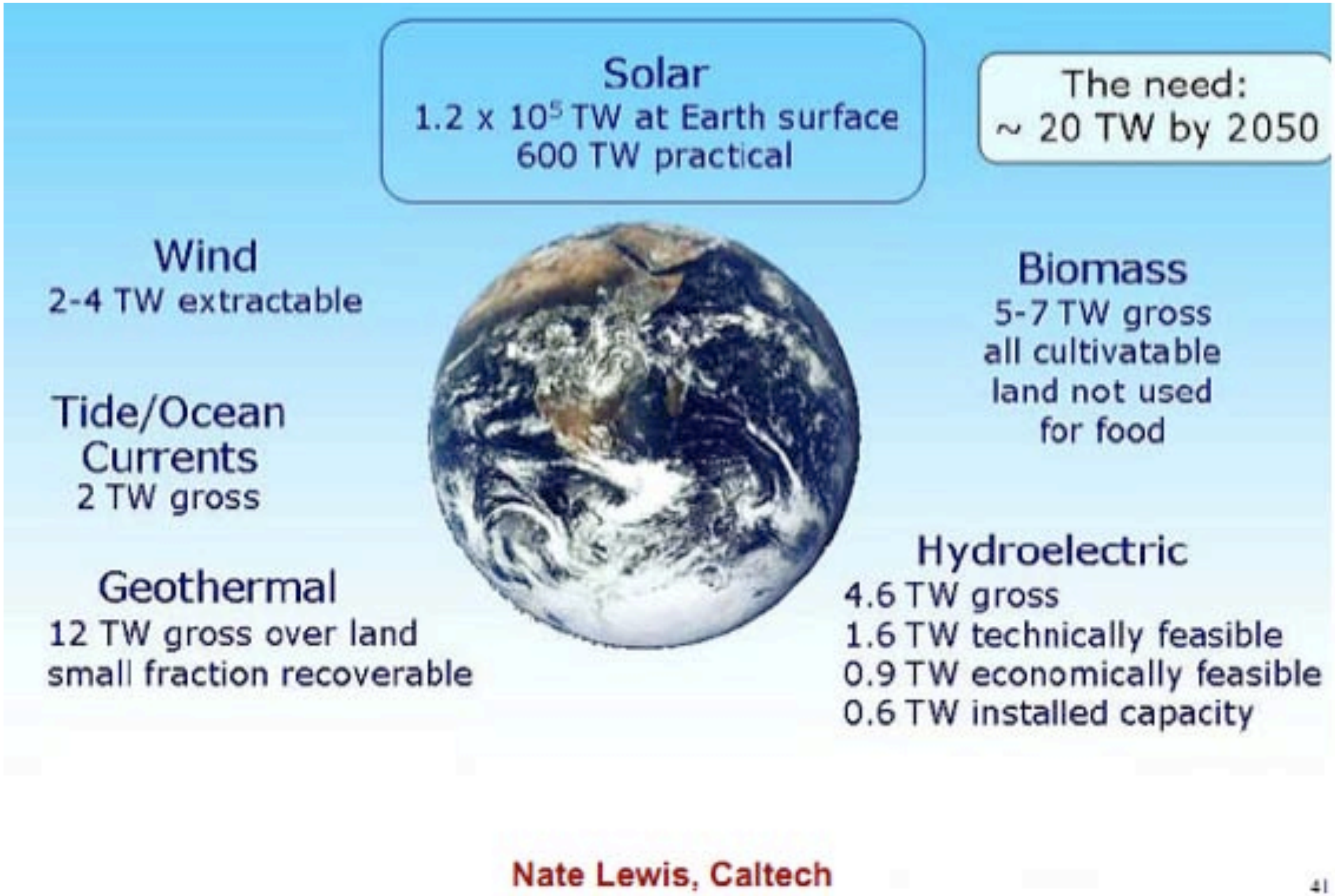


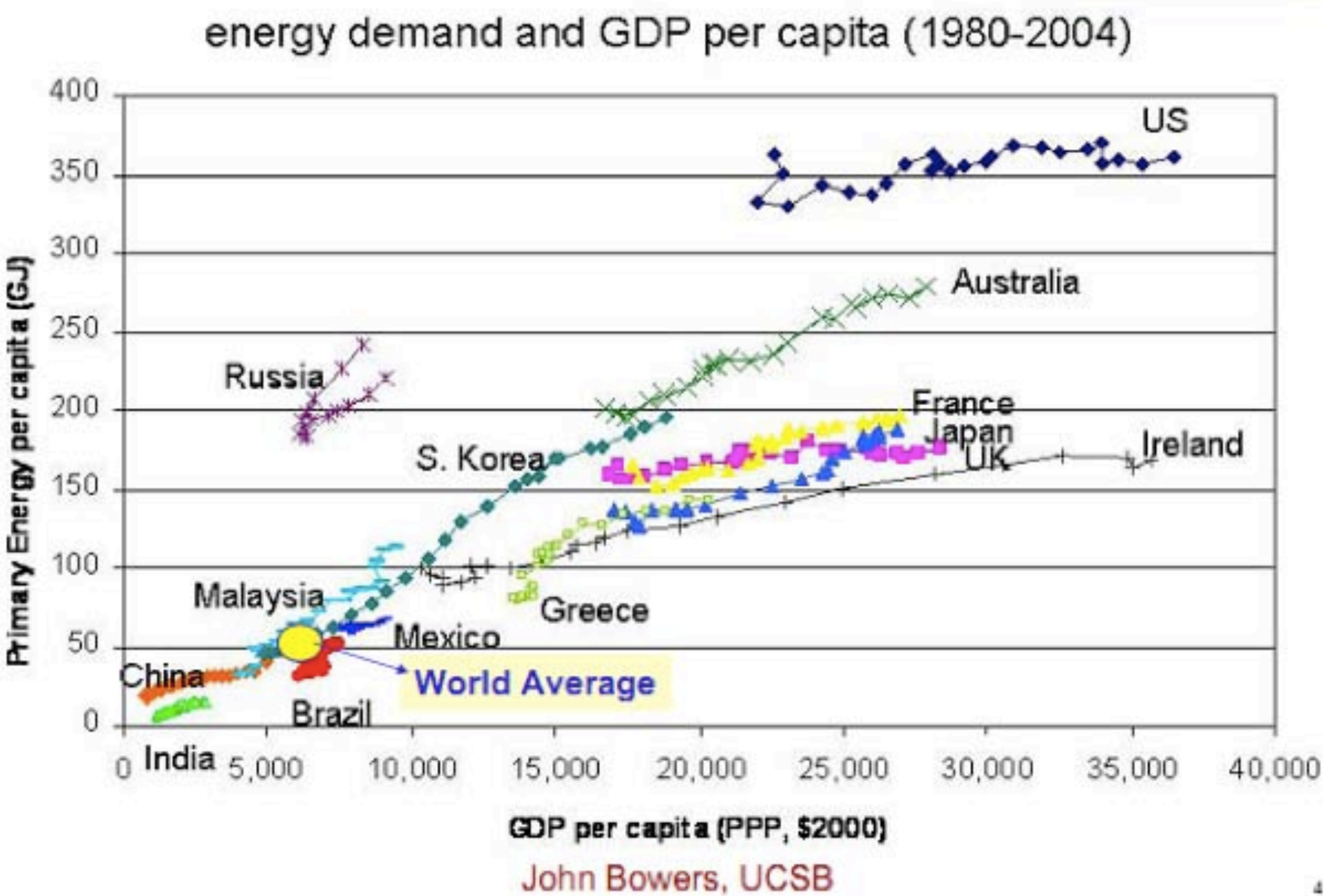
Lawrence Livermore National Lab., http://eed.llnl.gov/flow



India's Energy Consumption 2005
Hydro
94.66
Wind
4.82
Solar
0
Geo
0
Nuclear
58.04
Bio
1681.98
Biomass
Domestic
Coal
1645.89
Coal
coal exports
0.07
NG
324.81
Domestic
402.3
Imported
Petroleum
1242.66
Petroleum
Petroleum exports
221.54
Unaccounted
Electricity
90.93
Agriculture
301.46
Residential
1511.23
Commercial
132.03
Industrial
1547.93
Public Utilities
14.59
Light Vehicles
138.02
Heavy Vehicles
330.48
Aircraft
64.62
Railways
42.54
Waste
Energy

What is the energy solution?




energy demand and GDP per capita (1980-2004)
Primary Energy per capita (GJ)
GDP per capita (PPP, $2000)
0
50
100
150
200
250
300
350
400
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
US
Australia
Russia
France
Japan
Ireland
UK
S. Korea
Malaysia
Greece
Mexico
China
World Average
Brazil
India
John Bowers, UCSB

A FRAMEWORK FOR PRO-ENVIRONMENTAL BEHAVIOURS
Defra January 2008

The headline behaviour goals

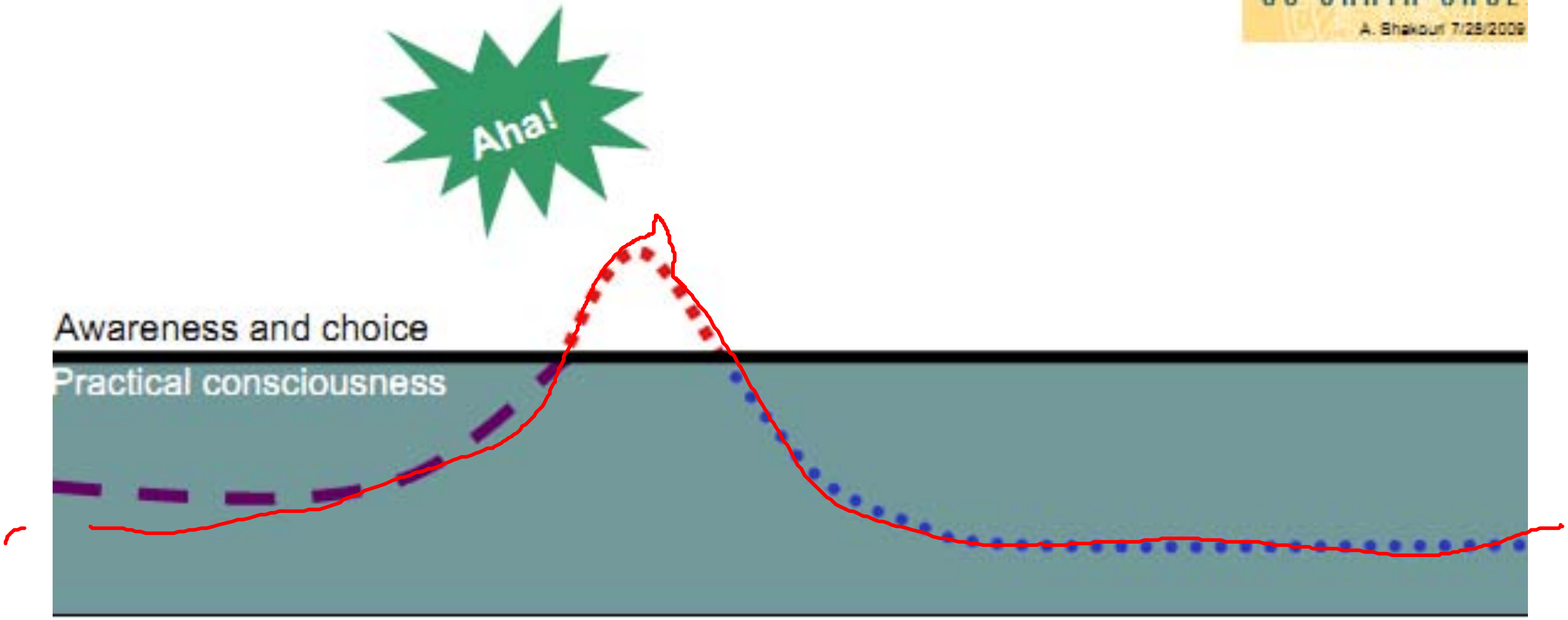
-**Install** insulation -Better energy management -Install microgeneration

-**Increase** recycling -**Waste less** (food)-**More responsible** water usage

-Use more efficient vehicles -Use car less for short trips -**Avoid unnecessary** flights (short haul)-**Buy** energy efficient products

-**Eat** more food that is locally in season -**Adopt lower impact** diet

Elizabeth Shove, Prof. of Sociology, Lancaster University, UK
(Guest Lecture Renewable Energy Class, UC Santa Cruz, Spring 2009)
http://www.soe.ucsc.edu/classes/ee080j/Spring09/



Informs a lot of discussion about how to engender sustainability
Considers habits in isolation
Often implausible in terms of daily routines e.g. comfort, cleanliness

Elizabeth Shove, Spring 2009
http://www.soe.ucsc.edu/classes/ee080j/Spring09/

choice, change, belief, attitude, information, behaviour

But what if we see consumption as consequence of ordinary practice?

What is required in order to be a ‘normal’ member of society?

How does this change, and with what consequence for sustainability?

Elizabeth Shove, Spring 2009

http://www.soe.ucsc.edu/classes/ee080j/Spring09/

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A. Shakouri 7/28

Comfort and indoor environments

it is becoming normal to expect 22 degrees C inside, all year round, all over the world and whatever the weather outside (Standardizing Comfort => Prof. Fanger DTU)

Cleanliness and showering

it is becoming normal to shower once or twice a day (in the UK, the amount of water used for showering is expected to increase five fold between 1991-2021)

Laundering

From once a week to once a day or more, but with lower temperatures than ever before

Similar trends – naturalisation of need

but possibly different dynamics

and different implications for the future

Comfort, cleanliness and convenience By Elizabeth Shove, 2003

Routine/ordinary consumption

Practice, convention, routine, dynamics of sociotechnical systems, structuring of options, standardisation, globalisation

Where the real challenges lie

Individual belief, attitude, behaviour, information, persuasion

Where most effort has focused

Reflexive/conspicuous consumption

Elizabeth Shove, Spring 2009

http://www.soe.ucsc.edu/classes/ee080j/Spring09/

Can Renewables Save the World?

- Fossil fuels have excellent energy characteristics.
- Wind/ geothermal are among the cheapest of renewables. There is potential for significant growth but they can not solve our energy problem.
- Solar energy has the potential to provide all our energy needs.
  - Currently expensive; it is intermittent.
- Currently no clear options for large scale energy storage
- Biomass has the potential to provide part of transportation energy needs
  - Cellulosic biofuels and algaes are interesting but they have not demonstrated large scale/long term potential. One has to consider the full ecosystem impact (water, food, etc.).

Can Renewables Save the World?

- If our goal is to have a planet where everybody has a level of life similar to developed countries, energy need is enormous and it is not clear if we can do this by working on the supply side alone.
- Energy efficiency is important but it is not enough.
- We need to consider changes in lifestyle, city planning and social structure (transportation, lodging, grid).