3. Sp2016

Based upon the Farid Zakaria you tube video:

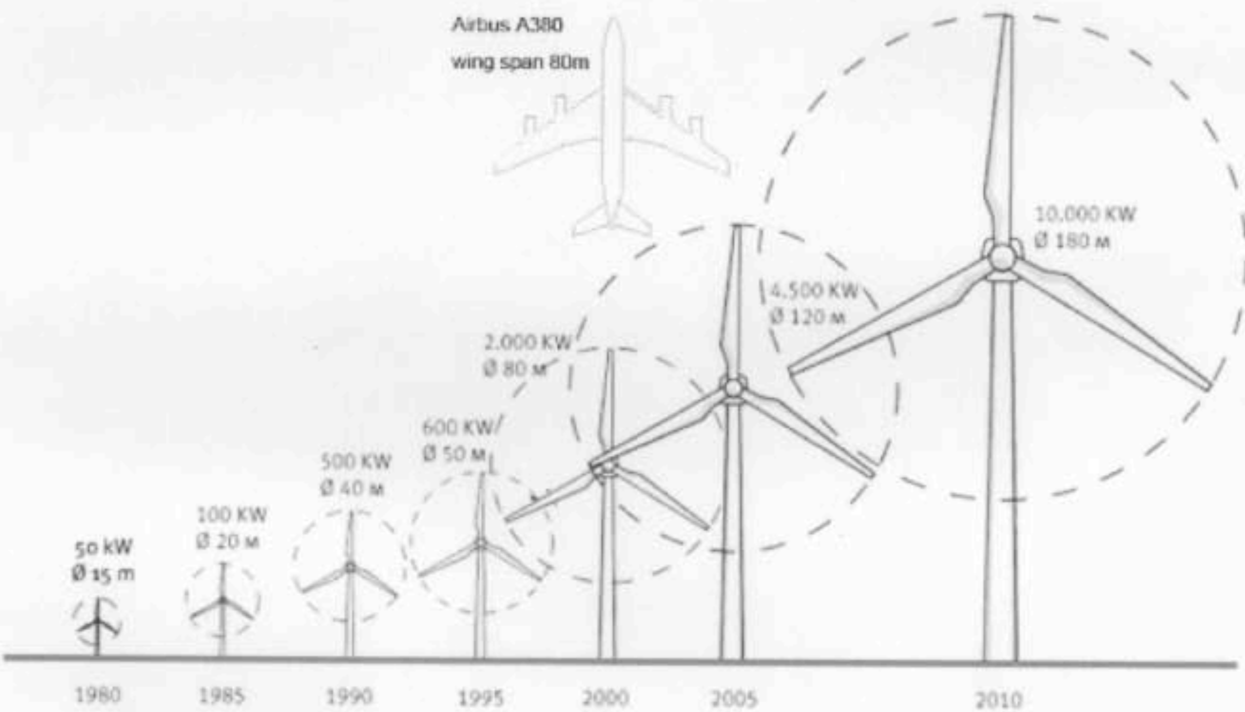
How much electrical energy will Denmark get from wind energy by 2020?

How much electricity in France comes from reused nuclear fuel ?

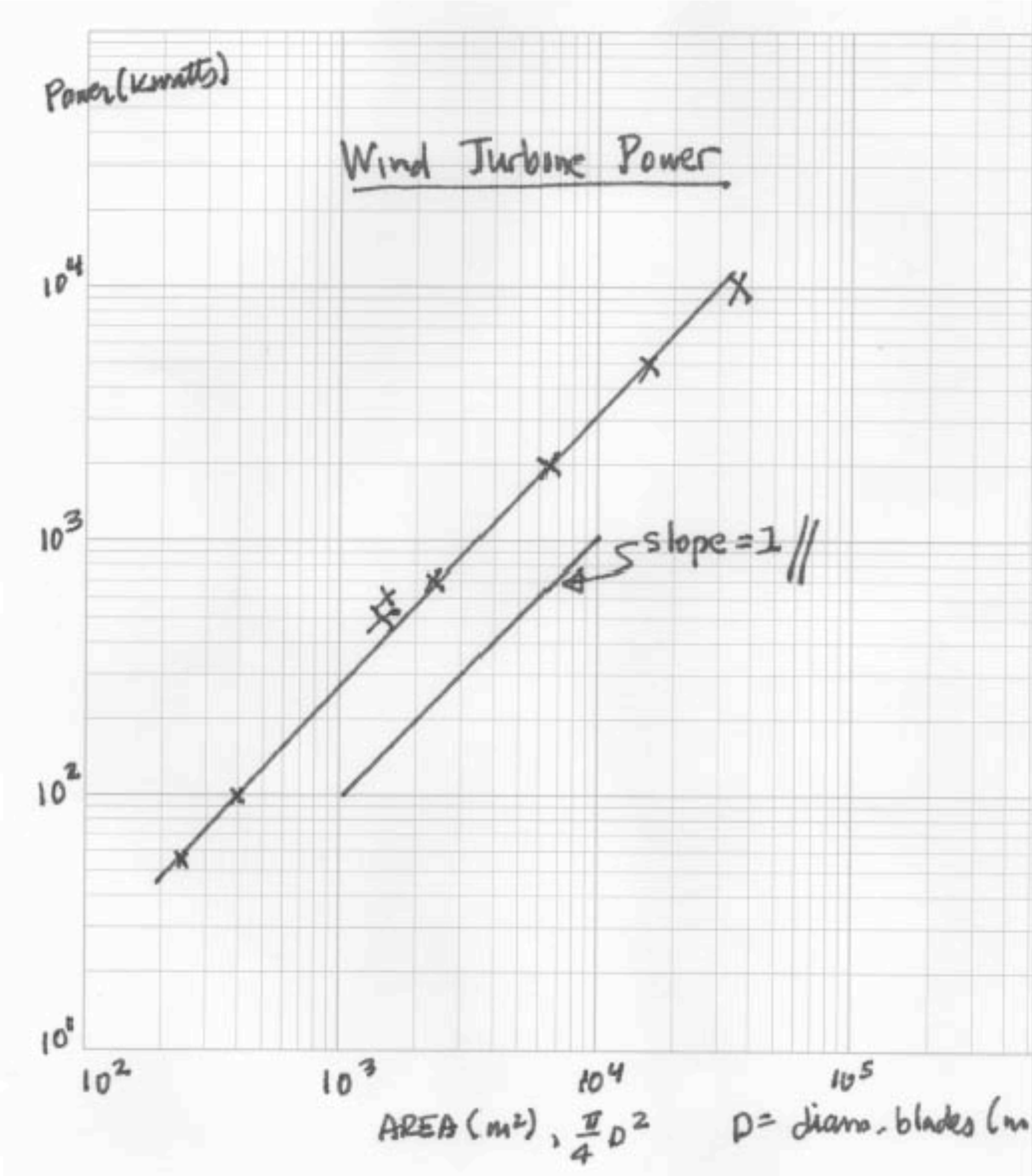
The solar energy capacity in Germany is what fraction of the total solar capacity in the world?

Turbine Sizes

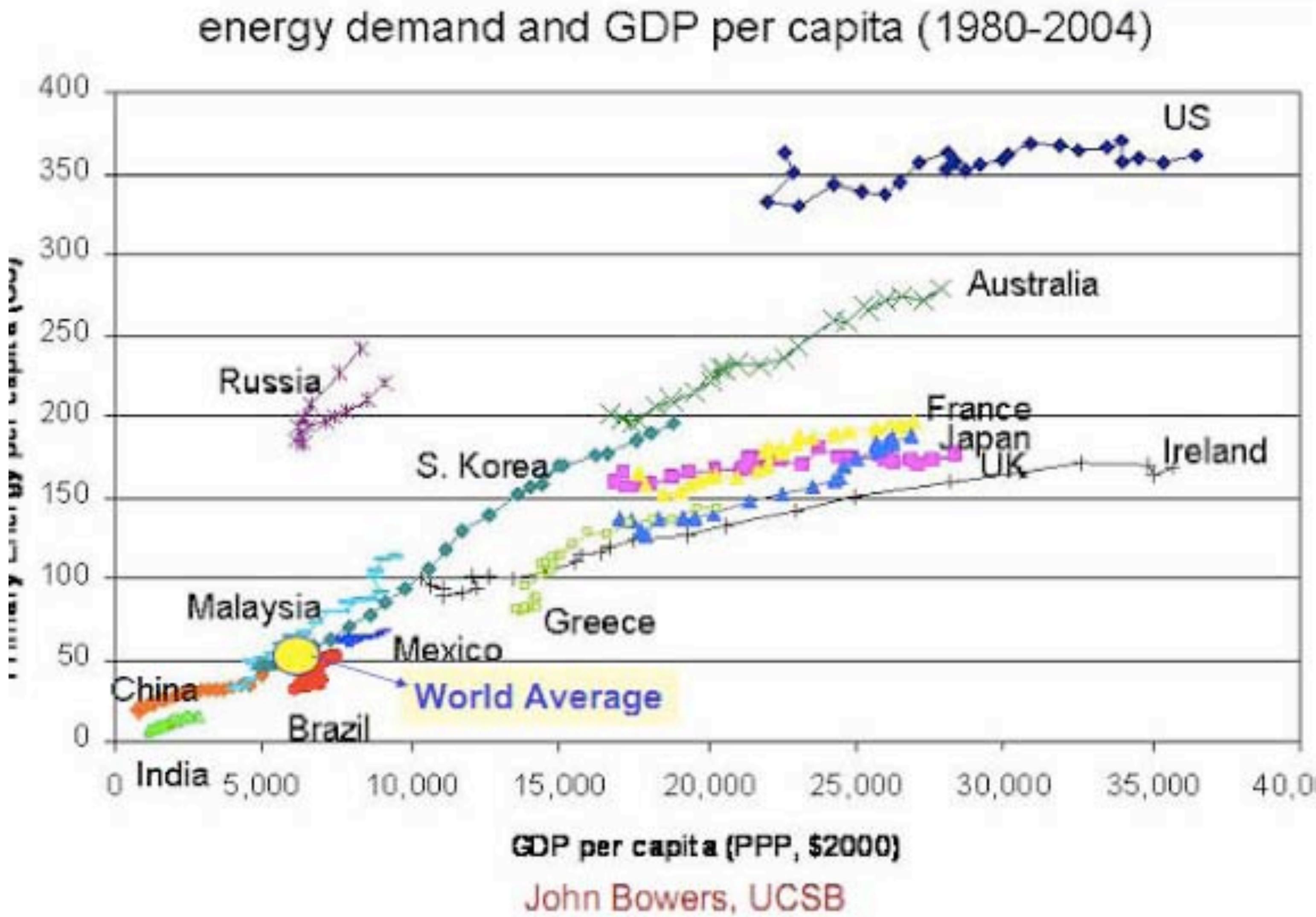
Horizonal axis (HAWT)



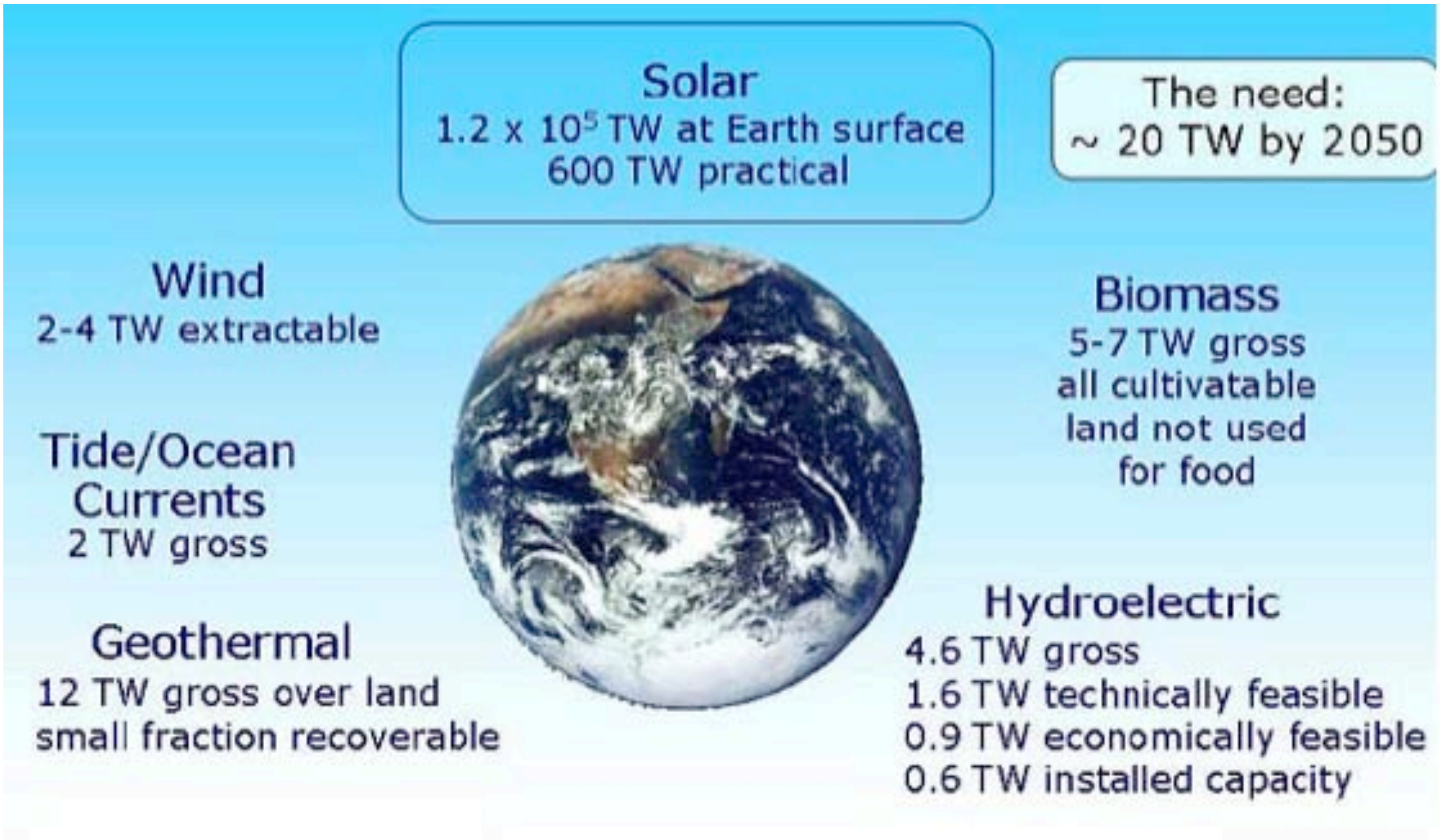
Trend toward bigger turbine sizes



Power (kwatts)
Wind Turbine Power
10^4
10^3
10^2
10^1
slope = 1
10^2
10^3
10^4
10^5
AREA (m²), π/4 D²
D = diam. blades (m

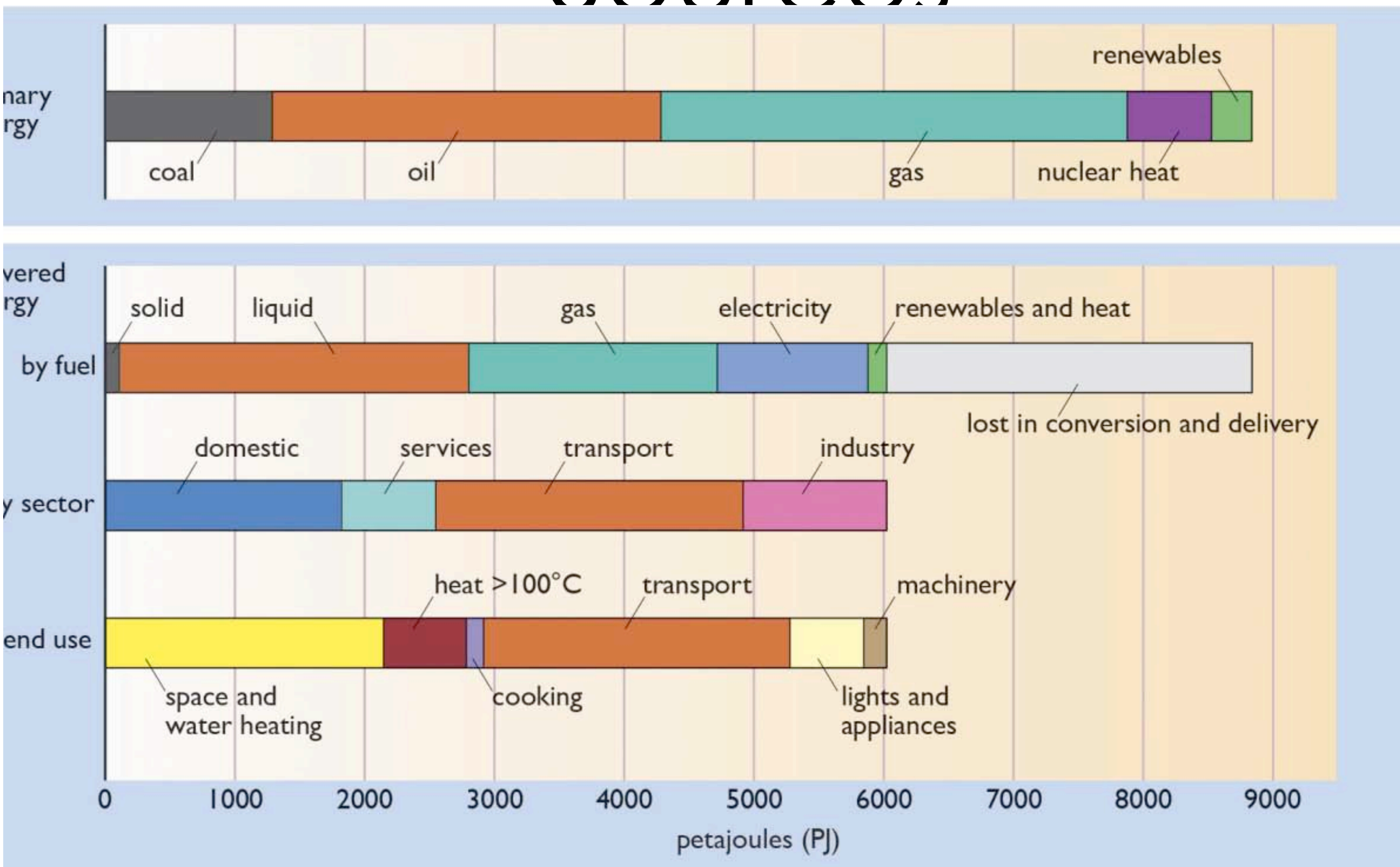

energy demand and GDP per capita (1980-2004)
400
350
300
250
200
150
100
50
0
US
Australia
Russia
France
Japan
Ireland
UK
S. Korea
Malaysia
Greece
Mexico
China
World Average
Brazil
India
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
GDP per capita (PPP, $2000)
John Bowers, UCSB

What is the energy solution?



Nate Lewis, Caltech

Use of Different Energy Sources

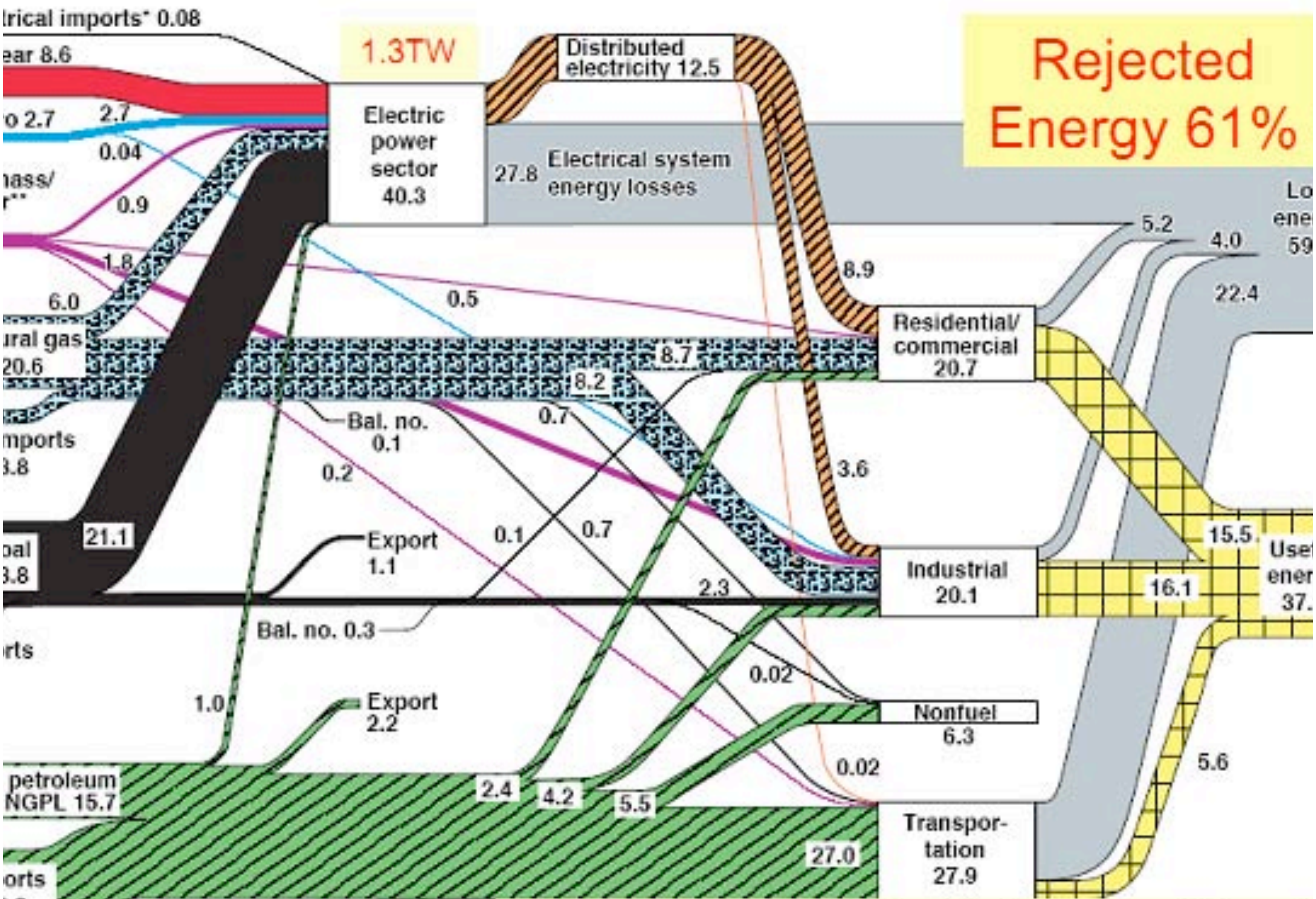


S. Energy Flow Trends – 2002

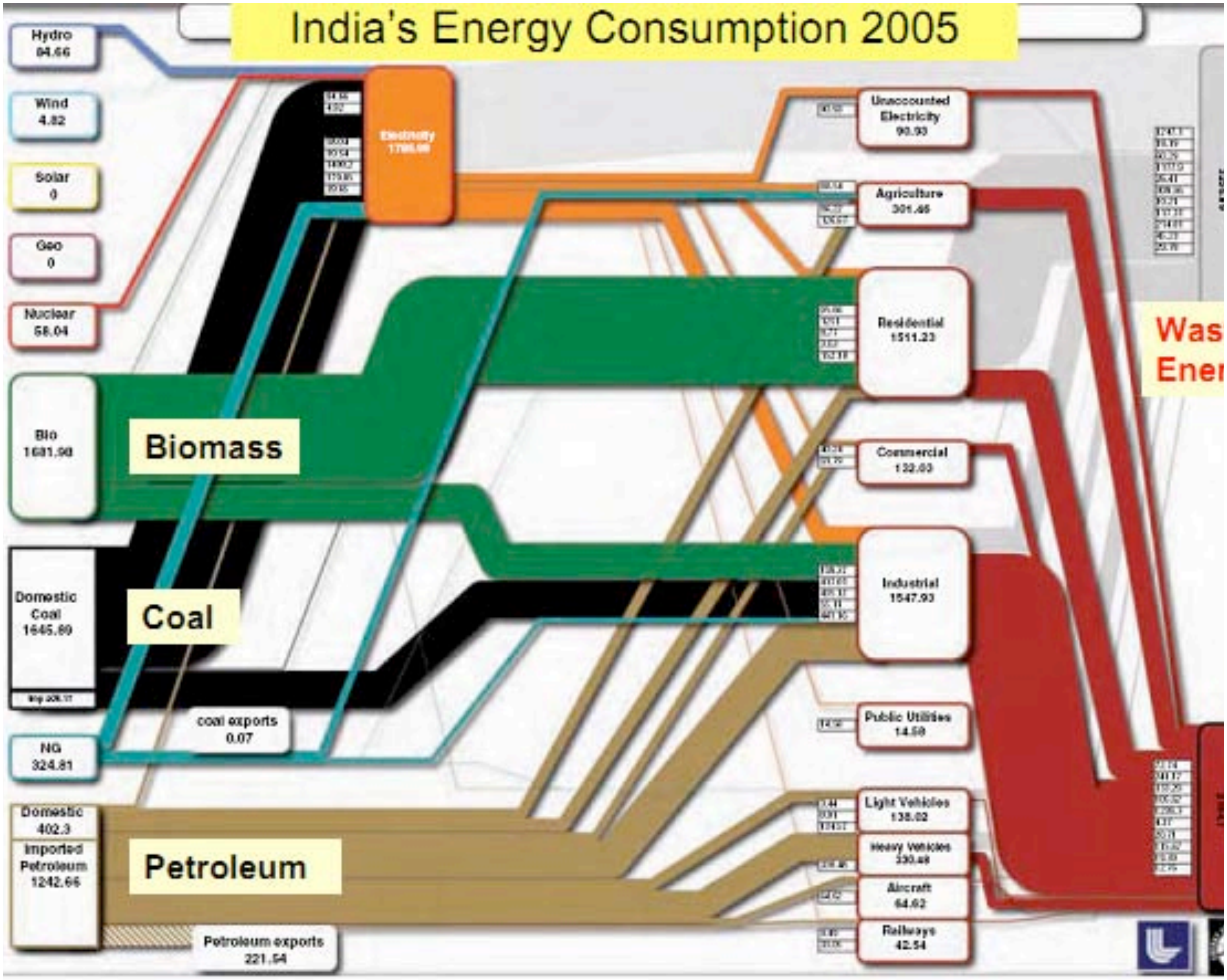
Power ~3.3TW

et Primary Resource Consumption ~103 Exajoules

A. Shakouri 11/2



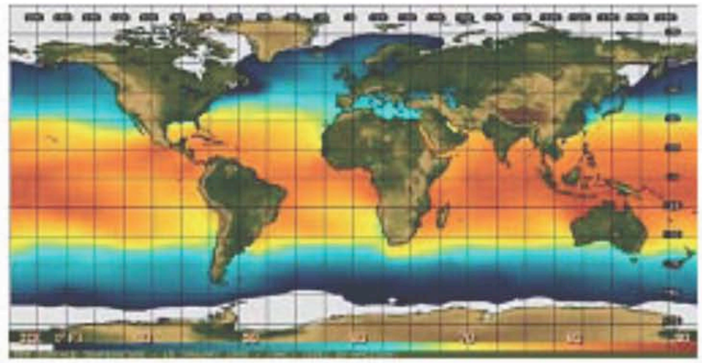
Lawrence Livermore National Lab., http://eed.llnl.gov/f



India's Energy Consumption 2005
Hydro 84.66
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
Was
Ener

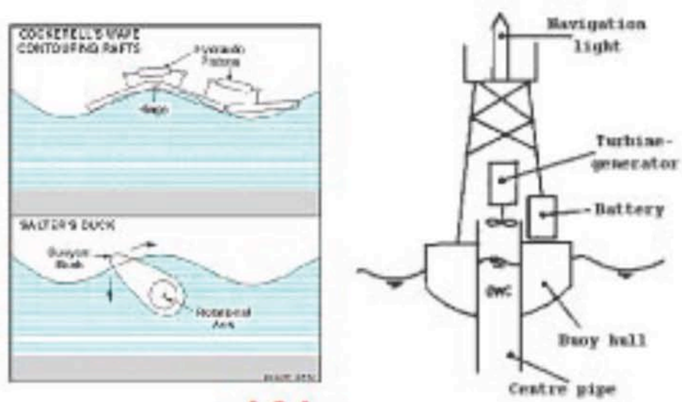
Energy from the Oceans?

Currents



Thermal Differences

Tides



Waves

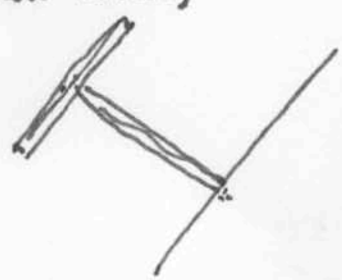
Ken Pedrotti, UCSC

TIDAL POWER

1. TIDAL STREAM GENERATOR
   Kinetic energy

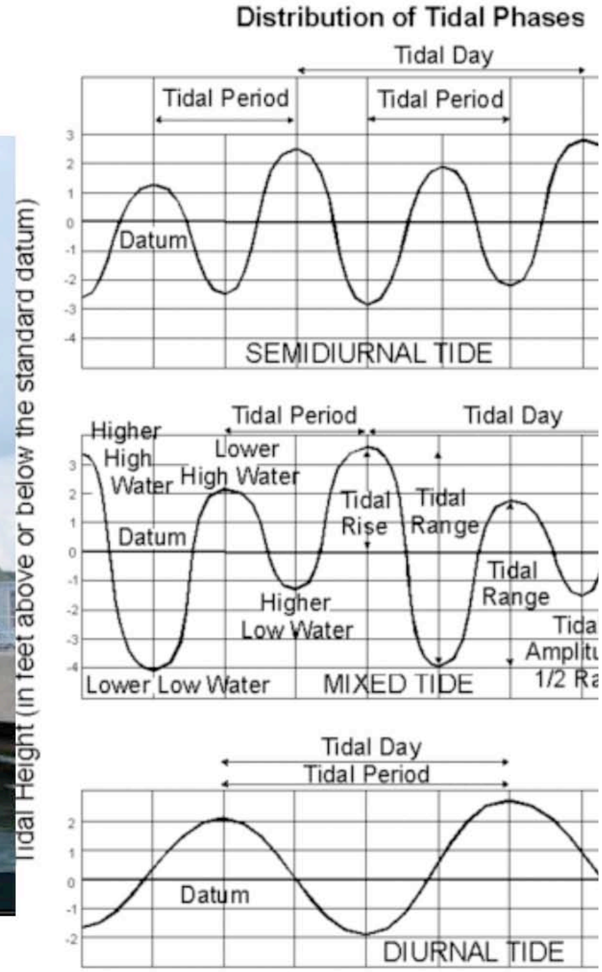
2. TIDAL BARRAGES
   potential energy

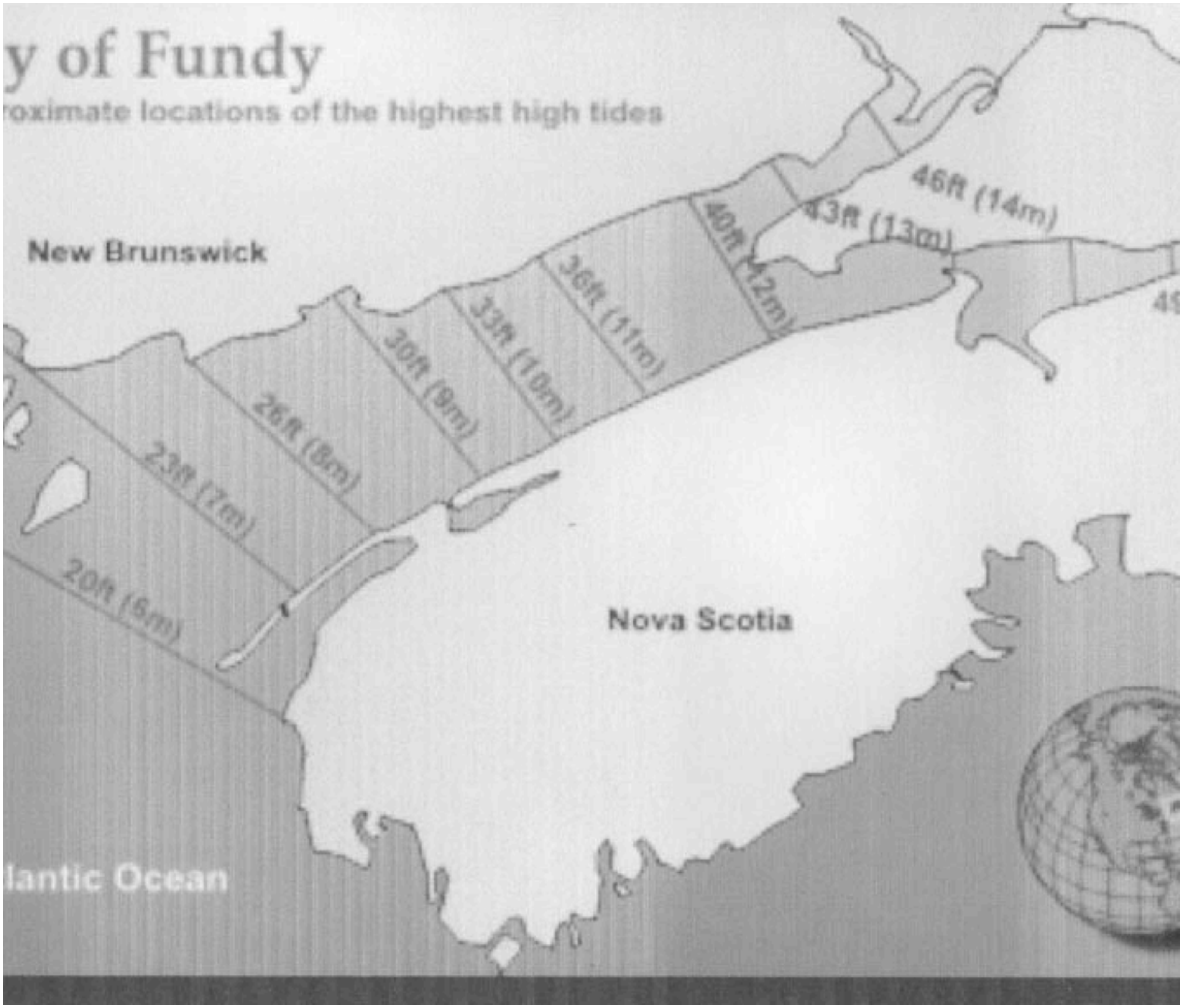
*3. DYNAMIC TIDAL POWER
   (hasn't been tried) 1997



Tidal Power


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

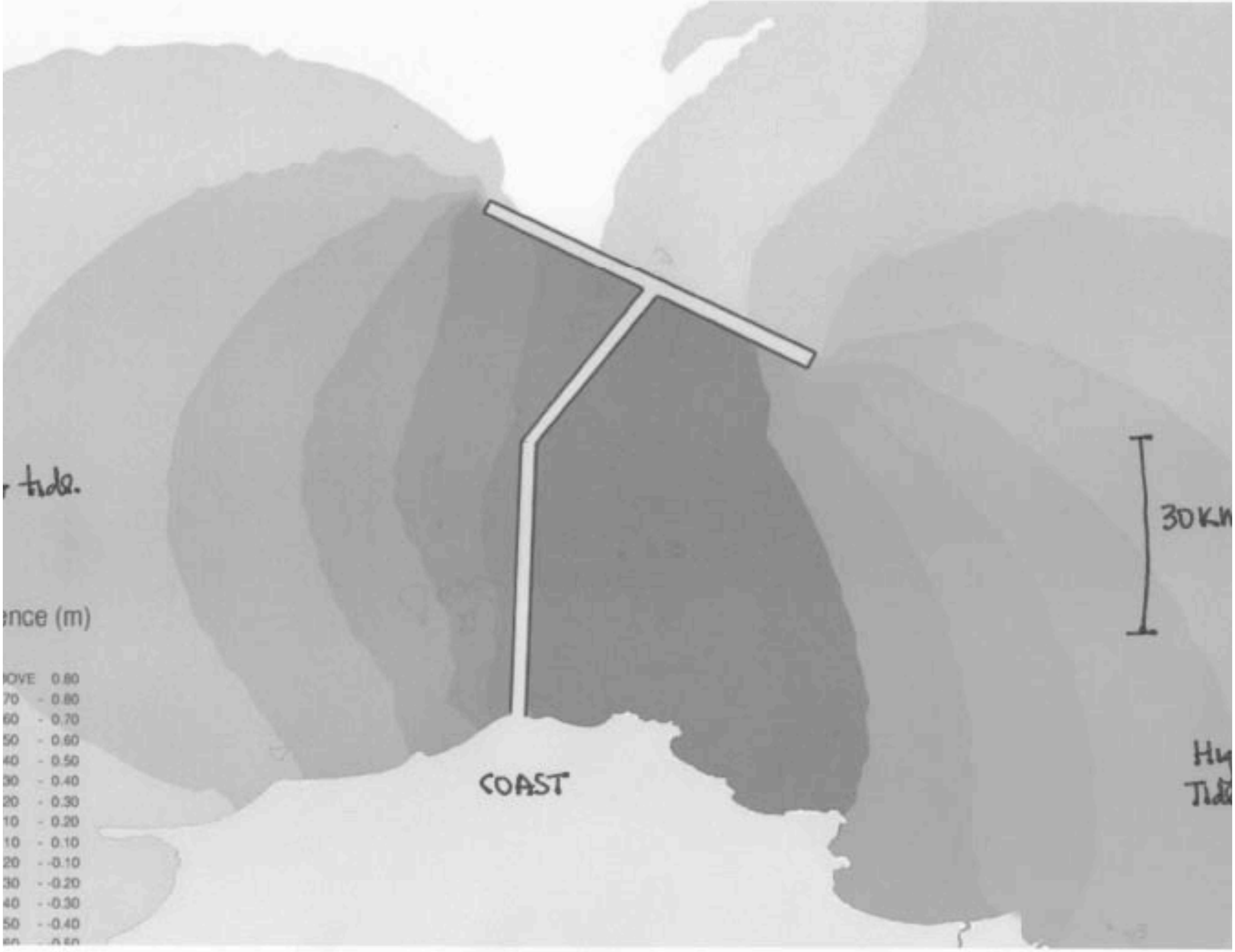

Distribution of Tidal Phases
Tidal Height (in feet above or below the standard datum)
Tidal Day
Tidal Period
Tidal Period
Datum
SEMIDIURNAL TIDE
Tidal Period
Tidal Day
Higher High Water
Lower High Water
Tidal Rise
Tidal Range
Datum
Tidal Range
Higher Low Water
Lower Low Water
MIXED TIDE
Tidal Day
Tidal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


y of Fundy
roximate locations of the highest high tides
New Brunswick
46ft (14m)
43ft (13m)
40ft (12m)
36ft (11m)
33ft (10m)
30ft (9m)
26ft (8m)
23ft (7m)
20ft (6m)
Nova Scotia
lantic Ocean

From Dunlap


Cumberland Basin
Minas Channel
Digby Gut
Petit Passage
Grand Passage
Bay of Fundy
Tidal Potential Map
Image courtesy of the Offshore Energy
Research Associations, www.offshoreenergyresearch.ca

DYNAMIC TIDAL POWER



K, China, Korea / tides ~ parallel to coast

frm. K. Hulsbergen, 2010

Biomass Energy Potential

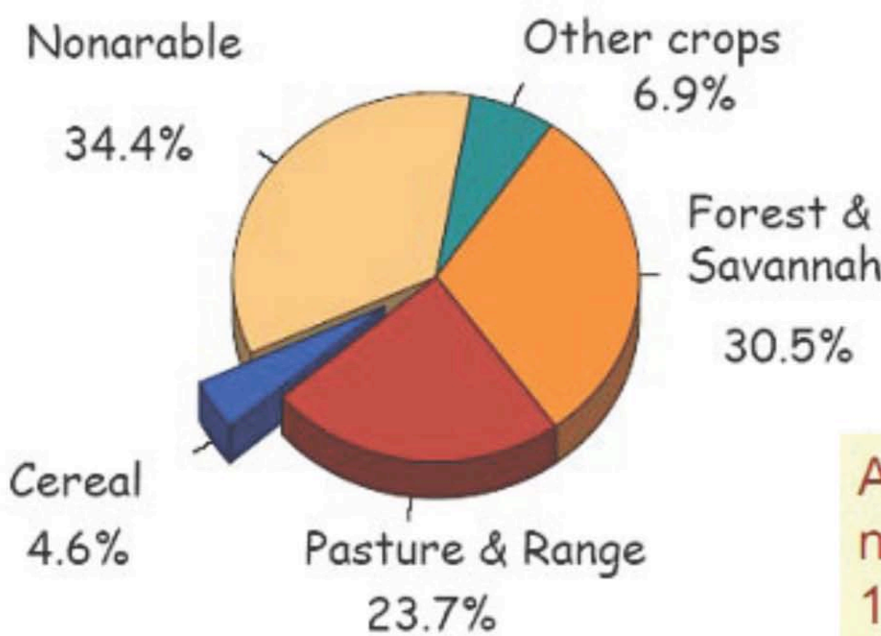
Global: Top Down

- Requires Large Areas Because Inefficient (0.3%)
- 3 TW requires ≈ 600 million hectares = $6x10^{12}$ m^2
- 20 TW requires ≈ $4x10^{13}$ m^2
- Total land area of earth: $1.3x10^{14}$ 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)

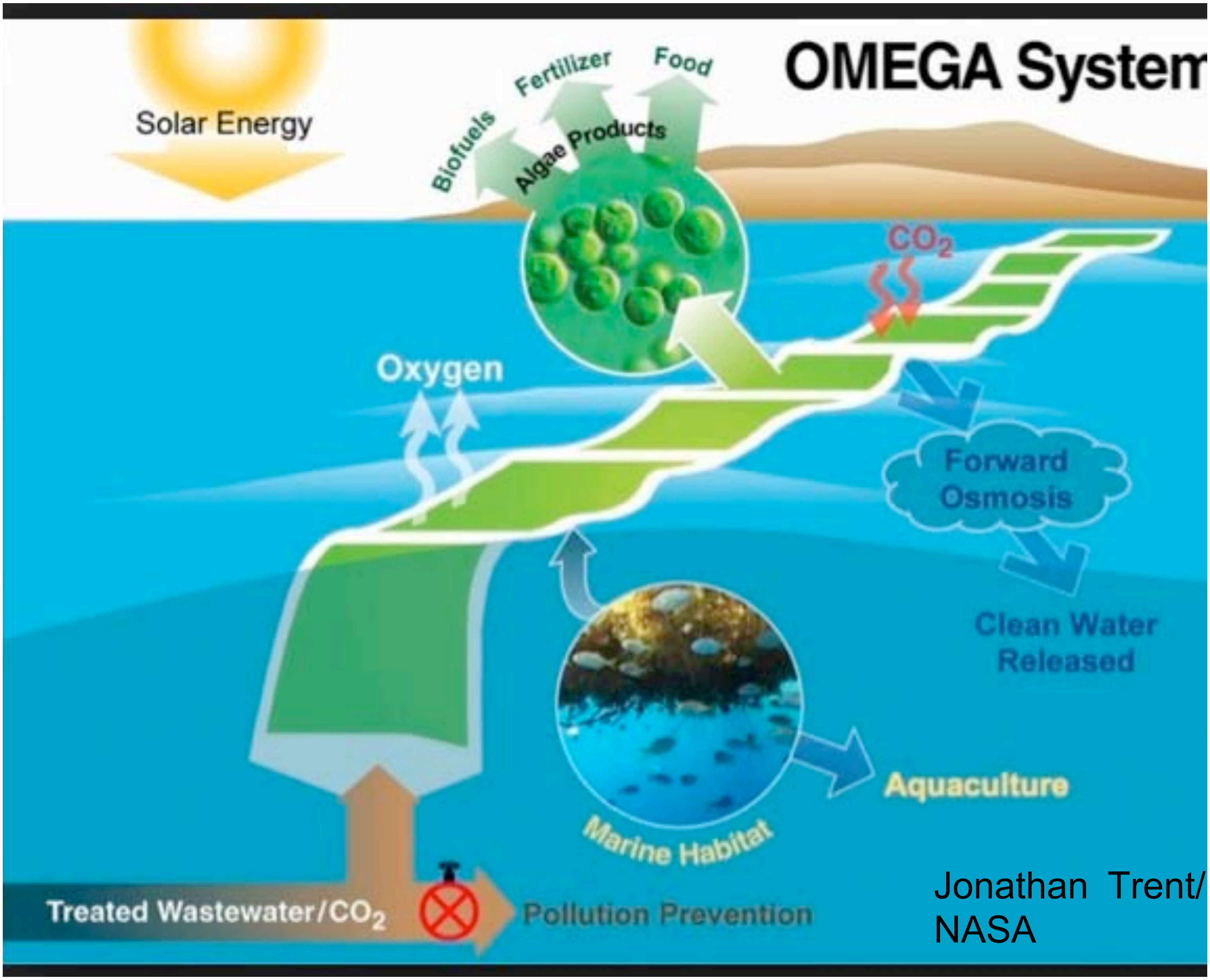
Chris Somerville, UC Berkeley

Biofuels

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, Berkele

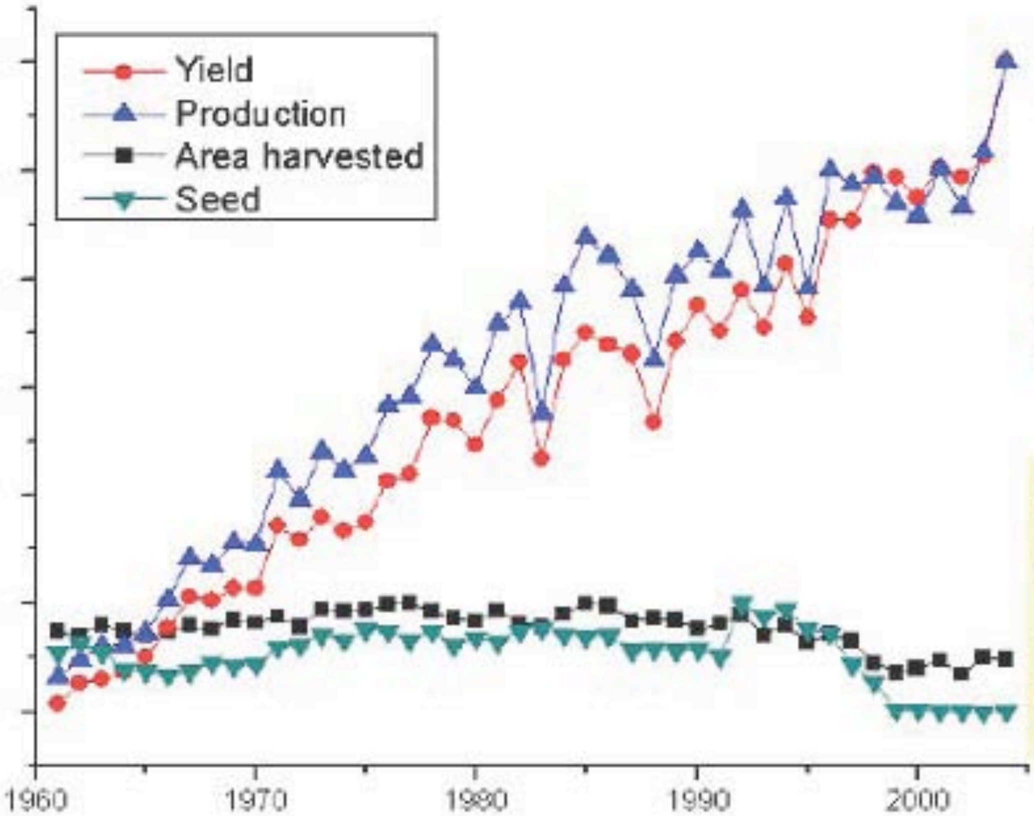


Jonathan Trent/ NASA

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: opulation = 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

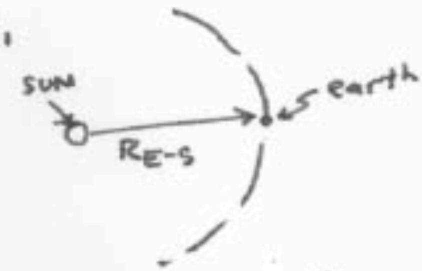
Energy Content	Magnitude
Solar Radiation on Earth	5,500,000 EJ
Solar Radiation on lower regions on Earth	3,800,000 EJ
Global Coal Resources	200,000 EJ
Global Plant Mass	10,000 EJ
Global Fossil Fuel Production	300,000 EJ
Typical Caribbean Hurricane	40 EJ
Hiroshima Bomb (1945)	0.000084 EJ

Energy from the Sun

$P_{TOTAL} = 7.3 \times 10^{26}$ watts (more or less isotropic)

power density at earth from sun,

$$\frac{P_{TOTAL}}{A} = \frac{P_{TOTAL}}{4\pi R_{E-S}^2}$$



$$\therefore \frac{P_{TOTAL}}{A} = \frac{7.3 \times 10^{26} \text{ watts}}{4\pi \times (1.49 \times 10^{11} \text{m})^2}$$

$$= 1367 \text{ watts}/\text{m}^2$$

↑ power density emitted from sun.

$R_{E-S} = 1.49 \times 10^{11}$ m
changes by ~ 3% during year (closer in winter in north)

Power incident on earth

$$P_E = \left(\frac{P_{TOTAL}}{A}\right) \pi r_e^2$$

$r_e = 6.371 \times 10^6$ m (rad of earth)
looks like a "disk"

$$= 1367 \frac{\text{watts}}{\text{m}^2} \pi (6.371 \times 10^6 \text{m})^2$$

$$P_E = 1.73 \times 10^{17} \text{ watts}$$

only 50% gets to earth surface
(rest reflected or absorbed by atmosphere)

Energy from the Sun (2)

the power density that actually gets to earth surface is the INSOLATION:

$$\frac{P_{SURF}}{A} \cong \frac{\frac{1}{2} P_E}{4\pi r_e^2} = 168\ W/m^2$$

$$= 53.2\ \frac{BTU}{ft^2 \cdot hr}$$

average over the entire surface ~~over a day~~

∴ average energy from sun / day / unit area

$$E_{AVG} = 168\ \frac{W}{m^2} \times 8.64 \times 10^4\ \frac{sec}{day}$$

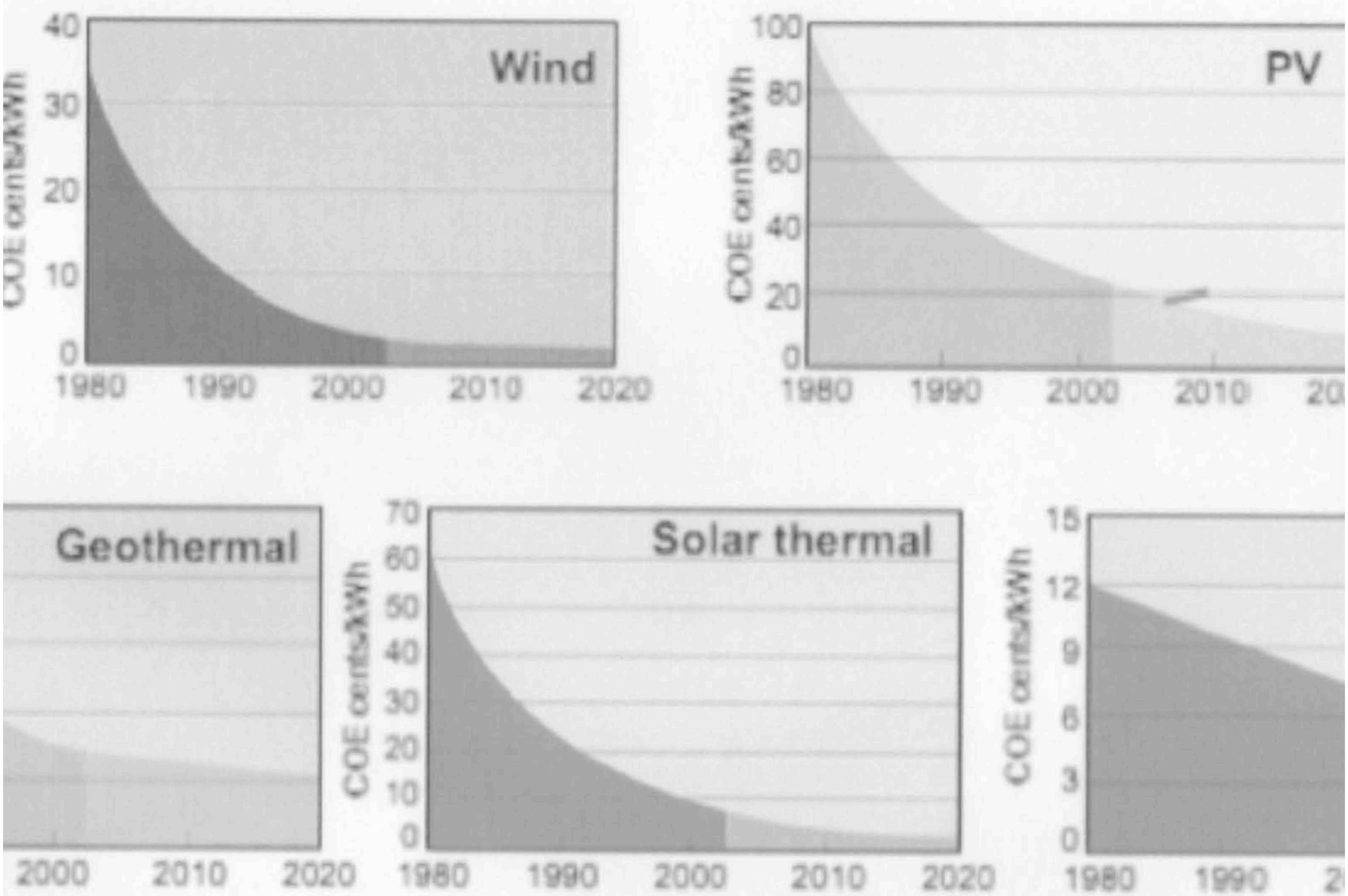
$$= 14.5\ MJ/m^2$$

$$= 1277\ BTU/ft^2$$

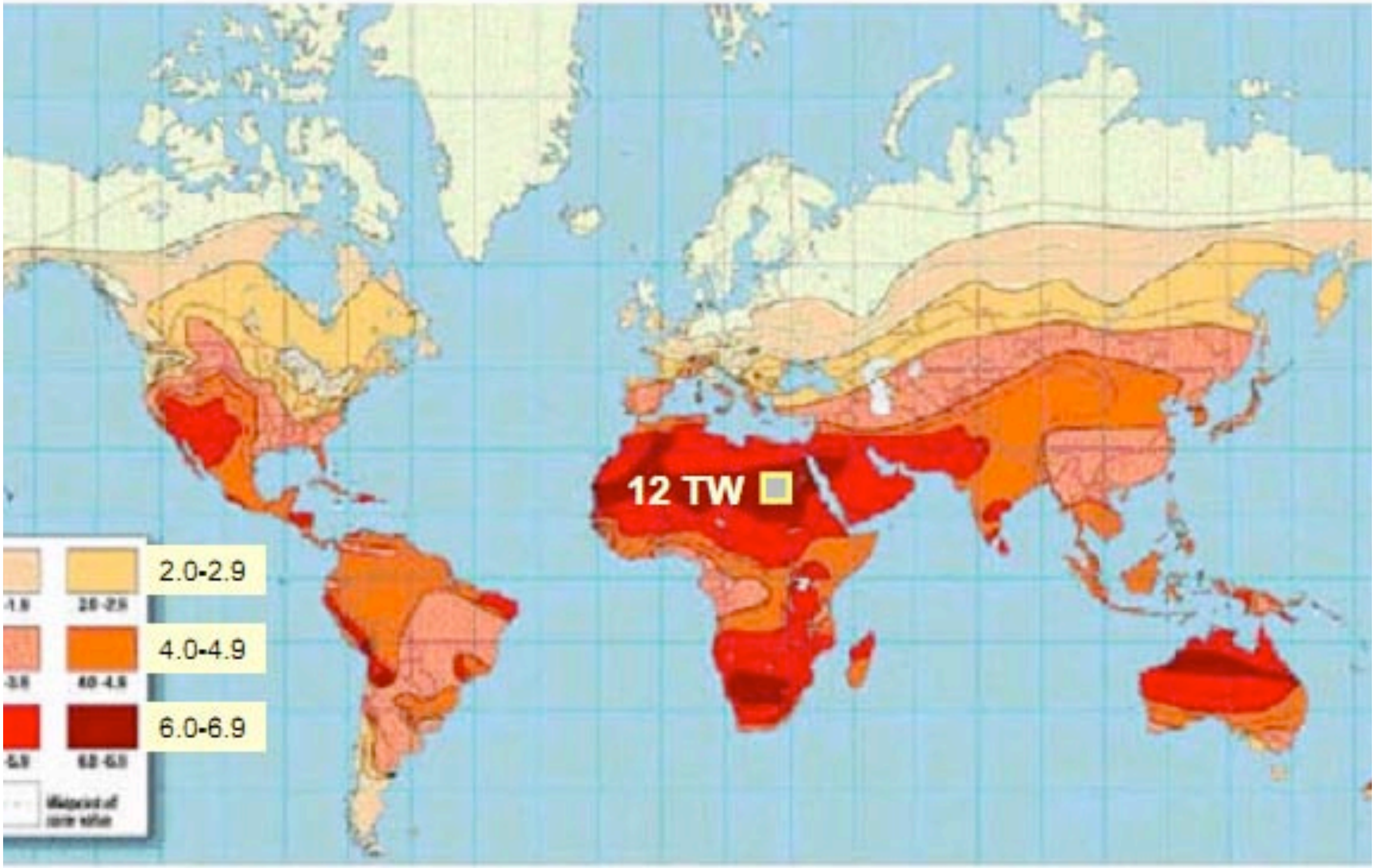
---

of course this depends upon any particular location, time of day, the day of the year and the latitude.

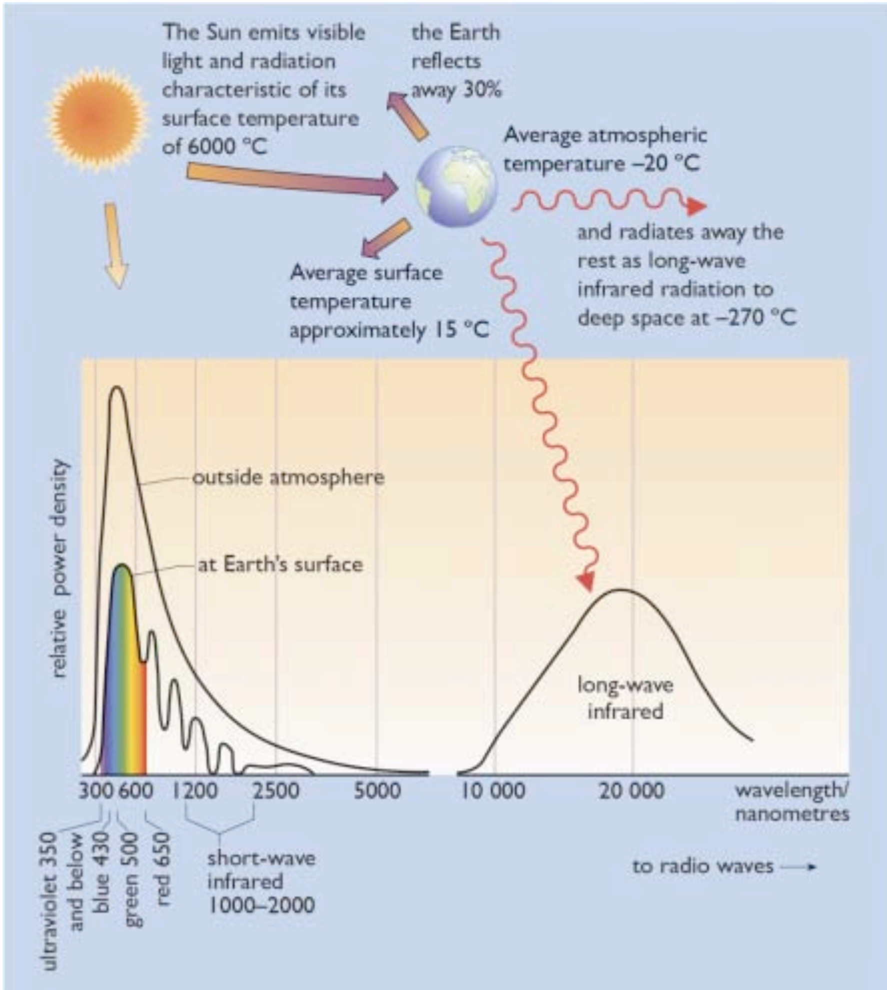
elized cents/kWh in constant $2000



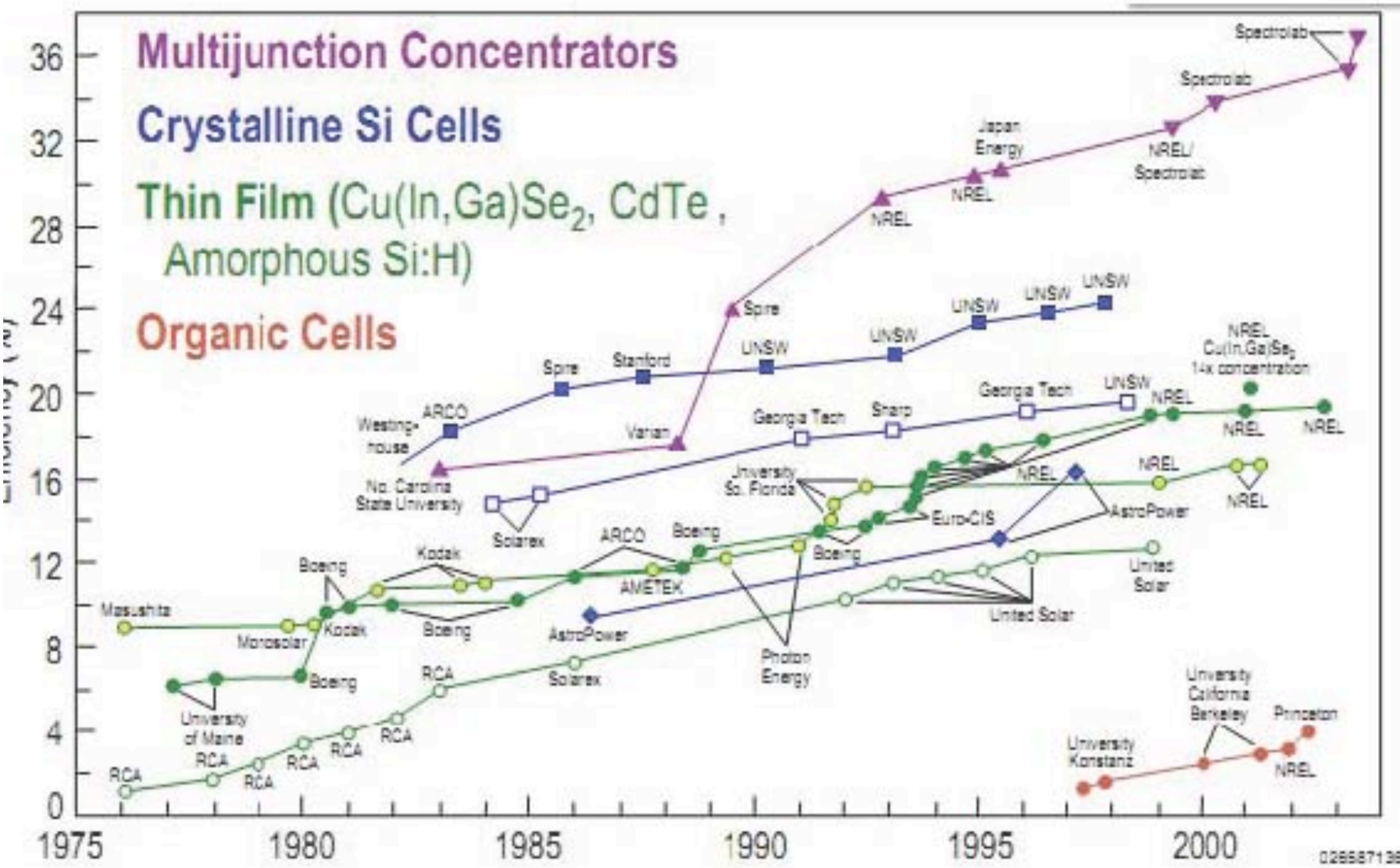
World Insolation

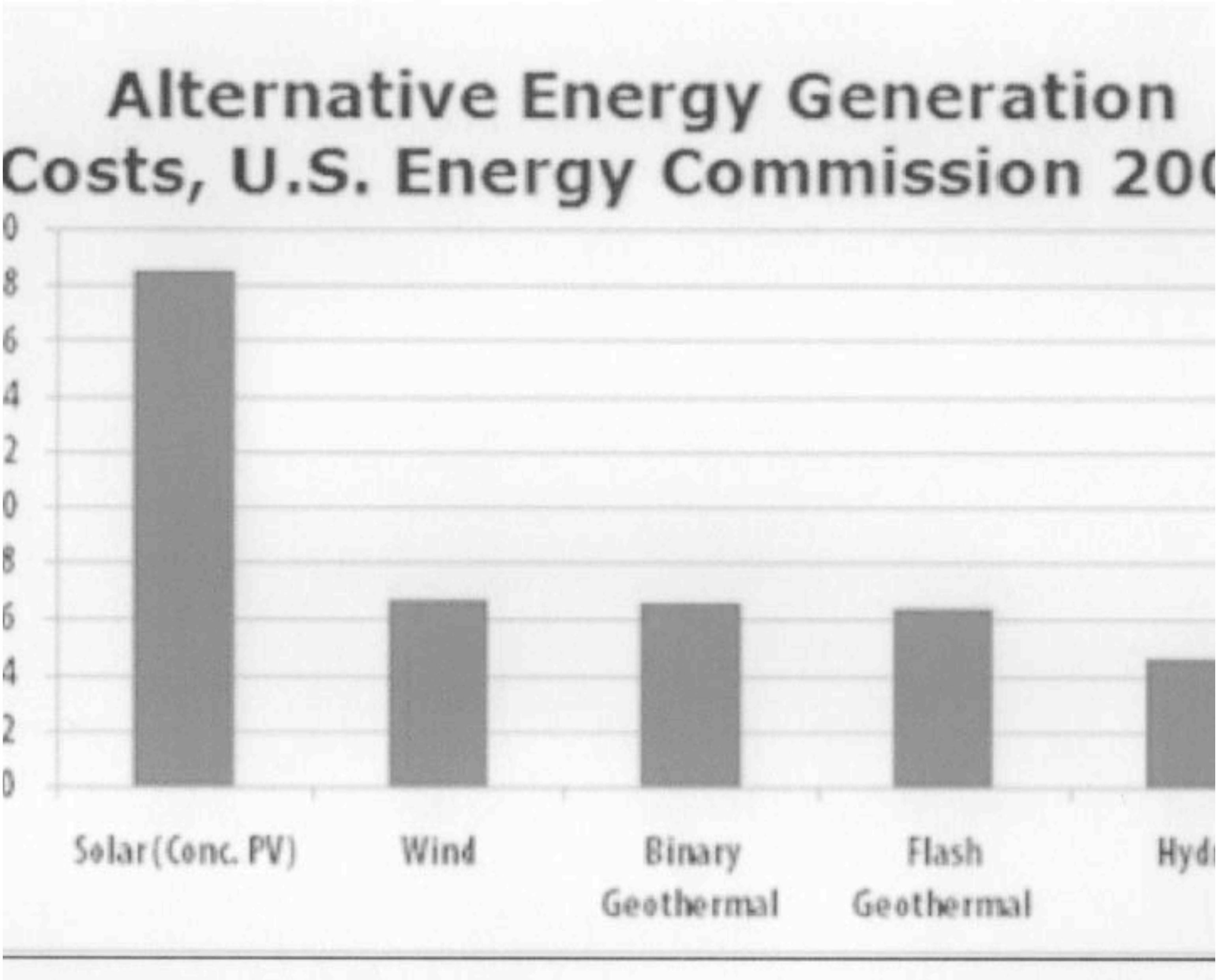


Solar Irradiatior



Best Research-Cell Efficiencies



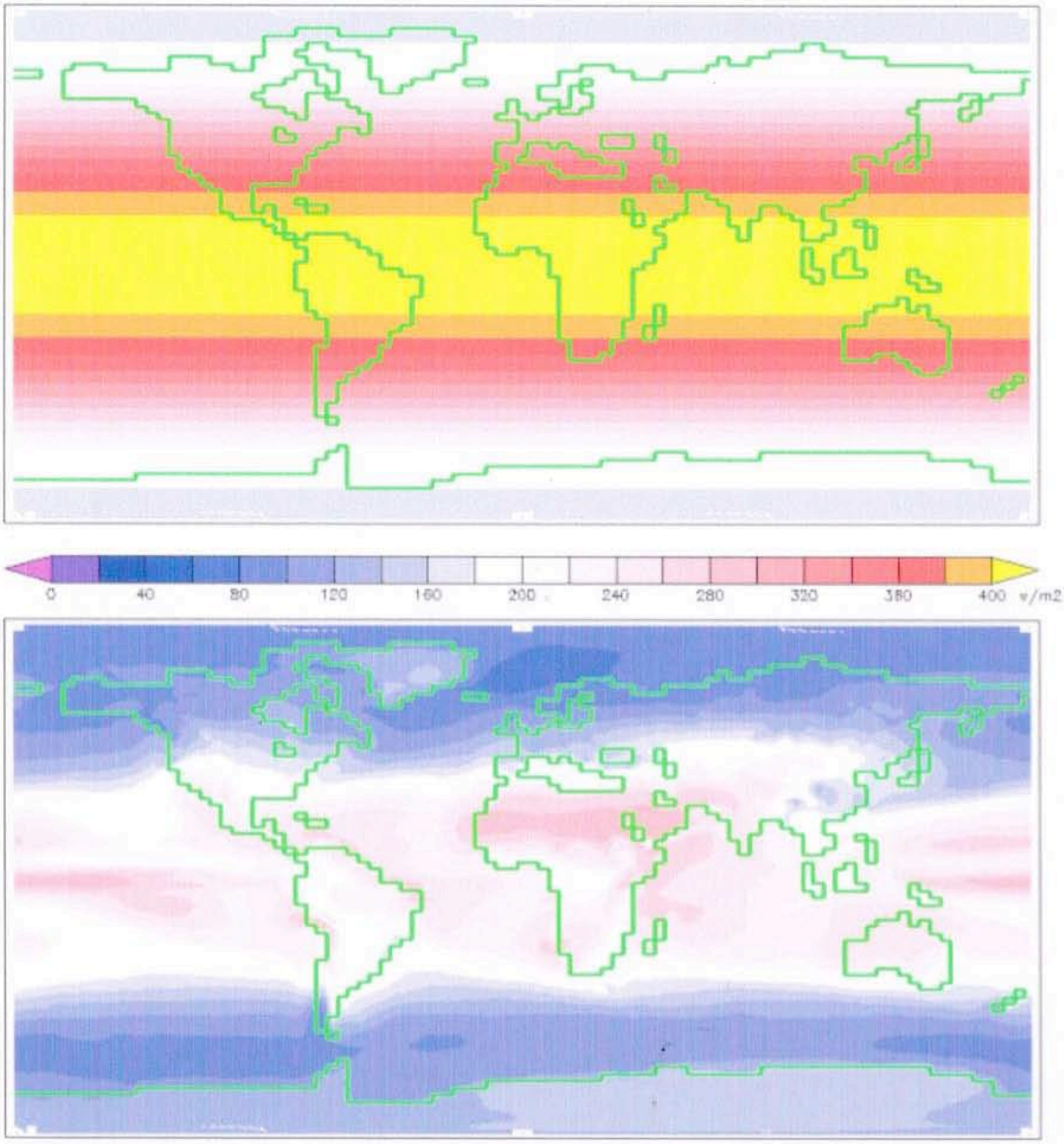

Alternative Energy Generation
Costs, U.S. Energy Commission 20
Solar (Conc. PV)
Wind
Binary Geothermal
Flash Geothermal

interested readers

aas.berkeley.edu/pdf/newsletter/2012Spring.p

nomic discuss of comparative costs of electri
eration that includes subsidies, etc.

Solar Irradiance (in Watts/m^2



Top of atmosph

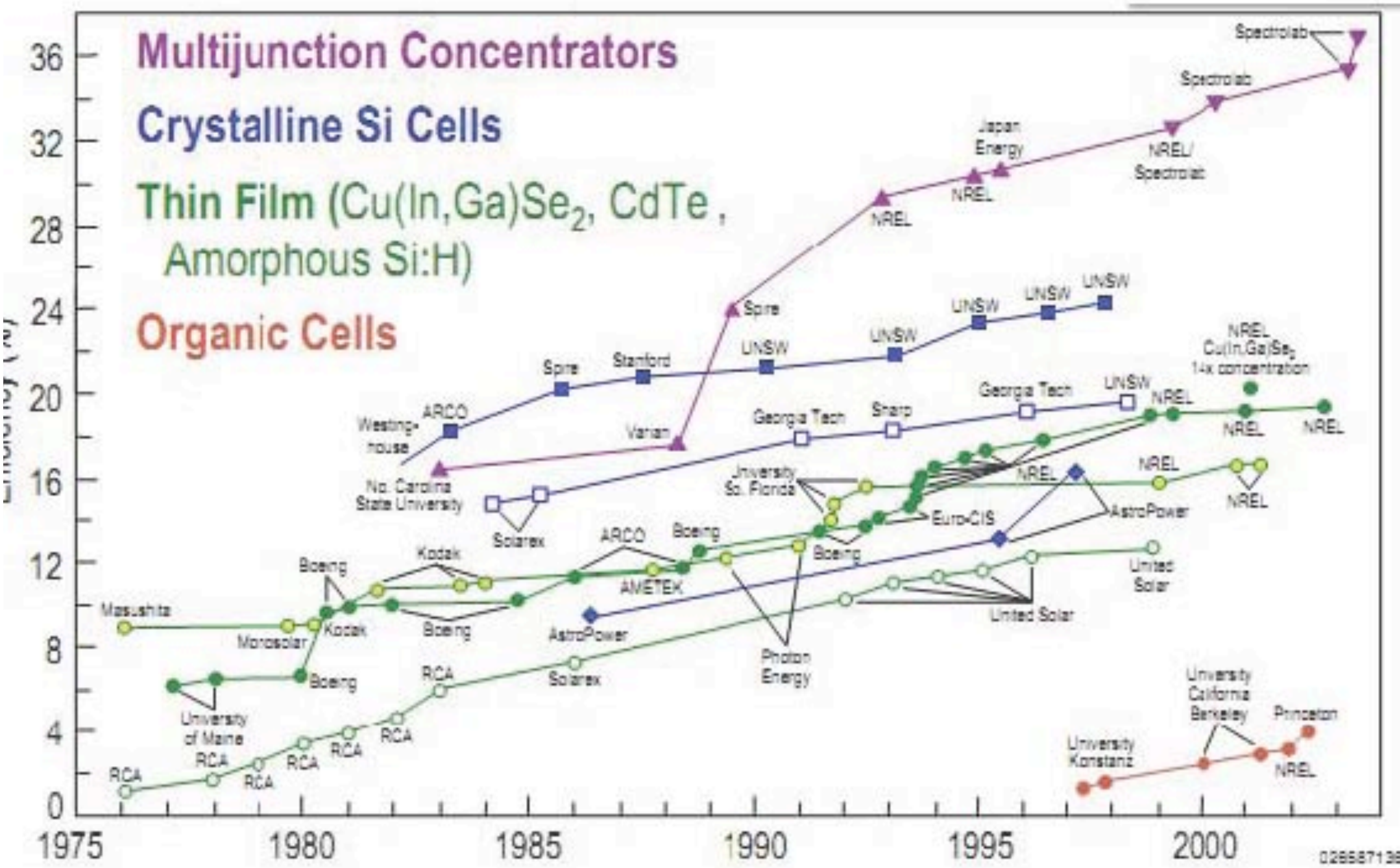
Earth's surface

Several Ways of Capturing the Energy from the Sun

Two Ways for Producing Heat and Electricity

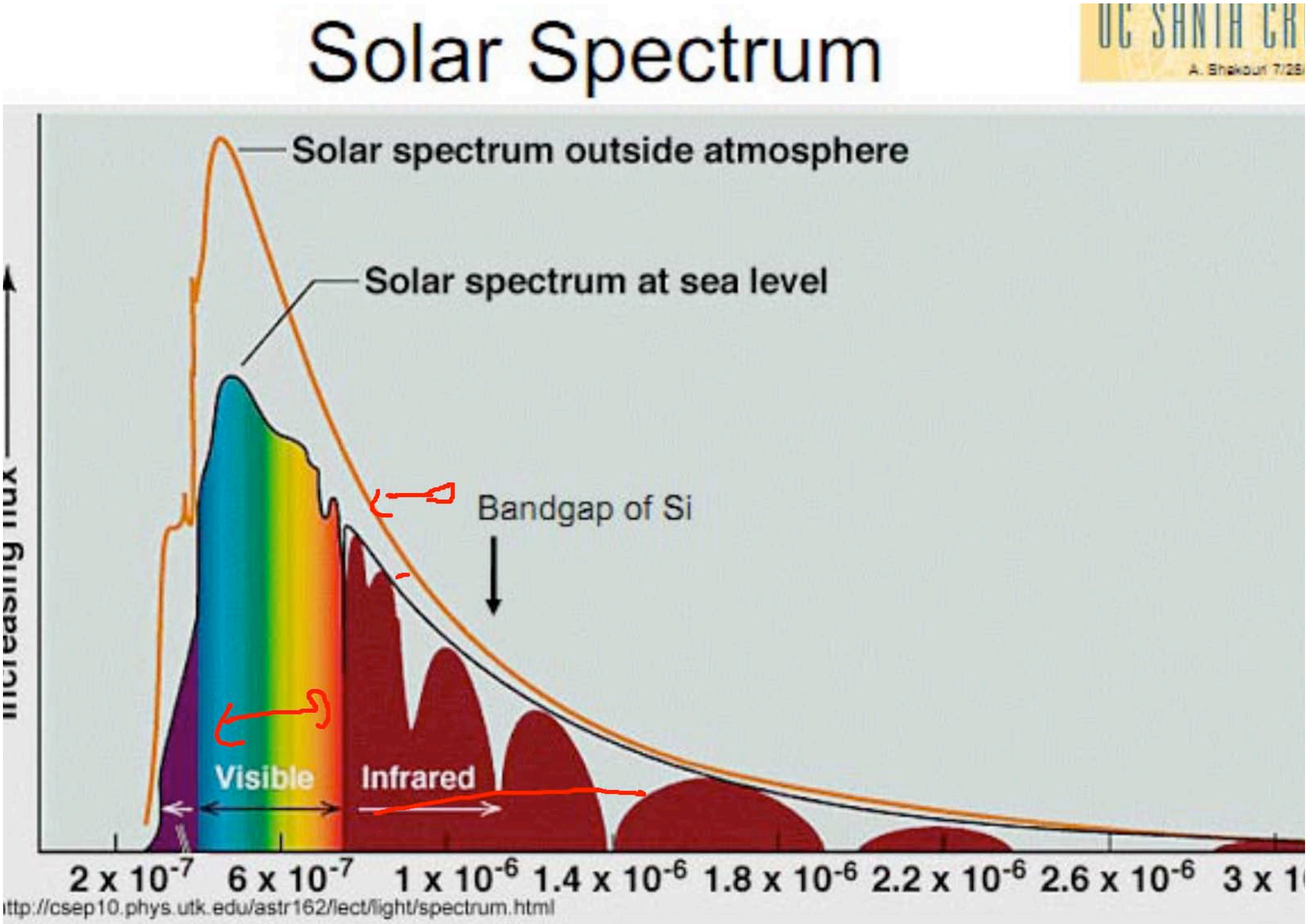
We will discuss them in more detail later.

Best Research-Cell Efficiencies



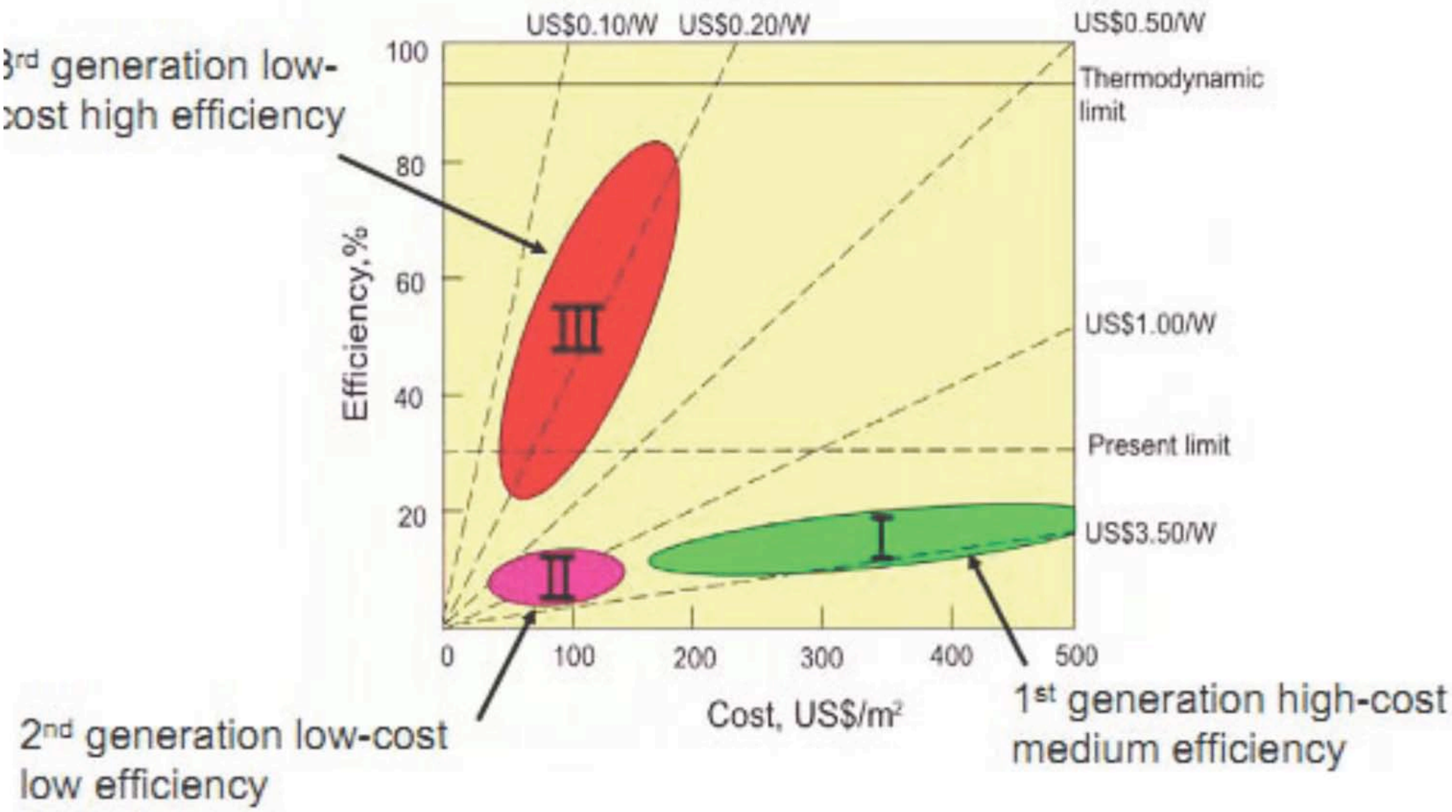
L. Kazmerski, National Renewable Energy Laboratory, National Center for Photovoltaics

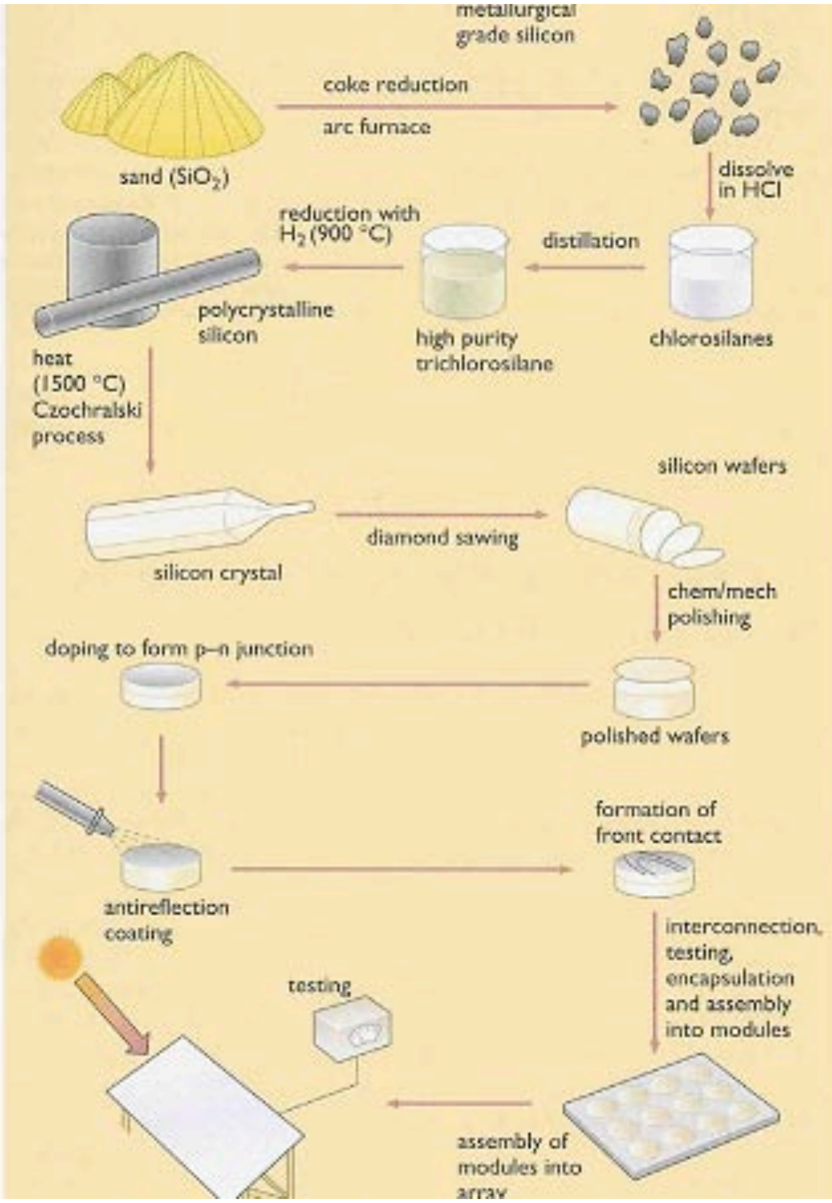
Solar Spectrum



Cost/Efficiency

Cost/watt and cos
area are importar





UC SANTA CRUZ

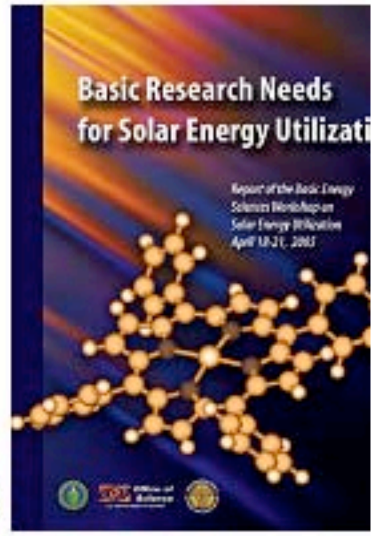
A. Shakouri 7/28/2009

Boyle
Renewable
Energy Sources

BASIC RESEARCH NEEDS FOR SOLAR ENERGY UTILIZATION

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

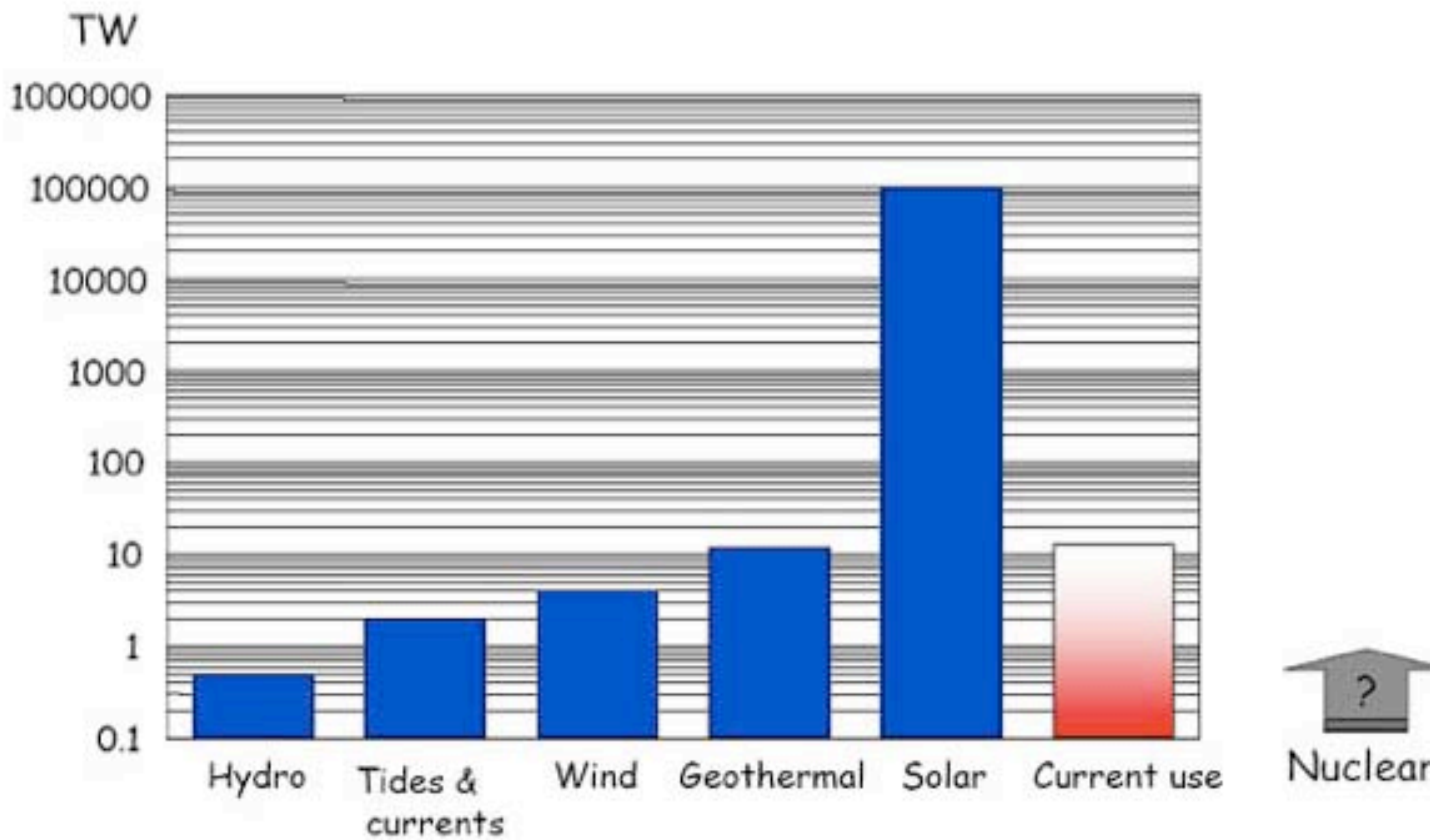
April 2005



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

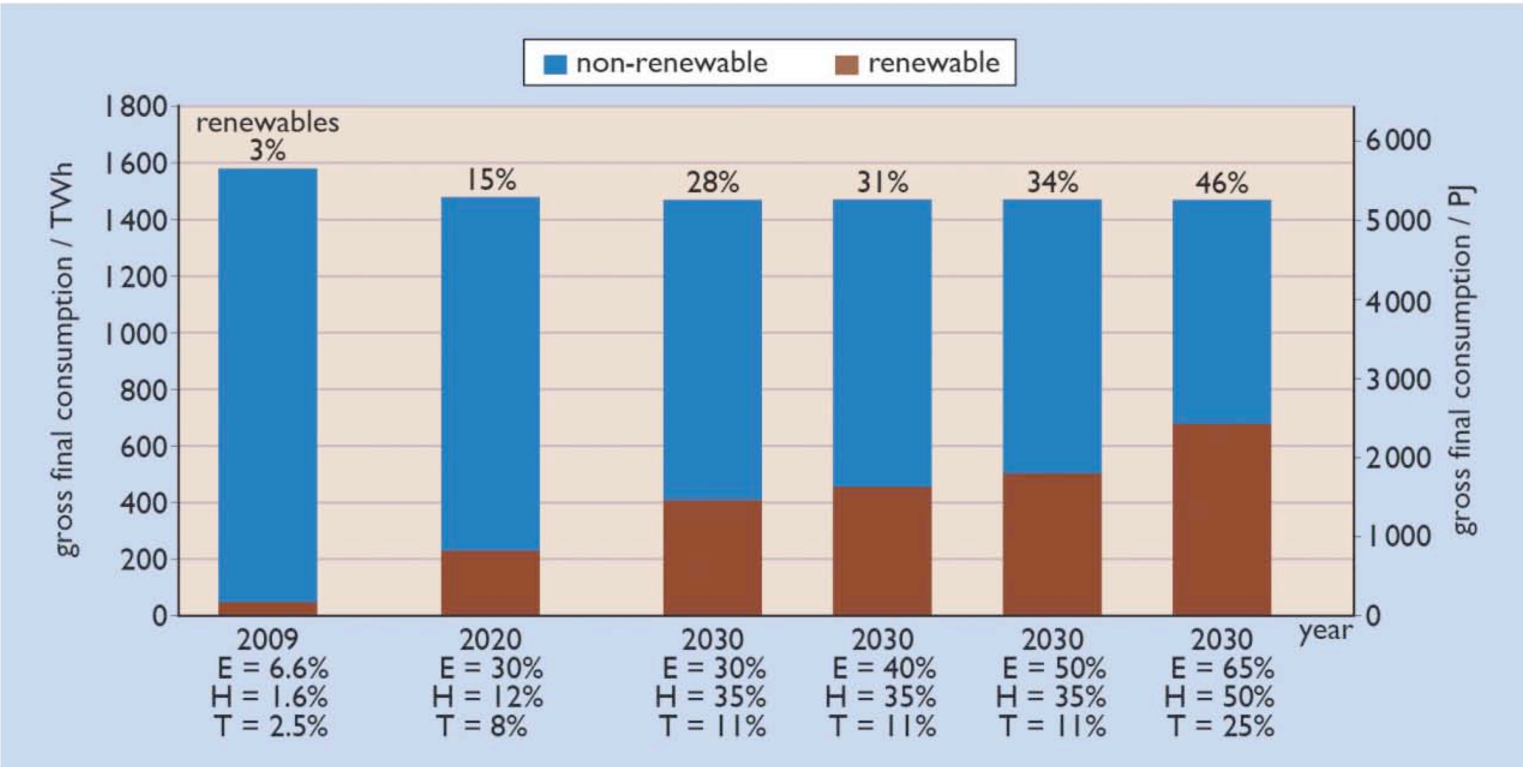
Potential of Carbon Free Energy Sources



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

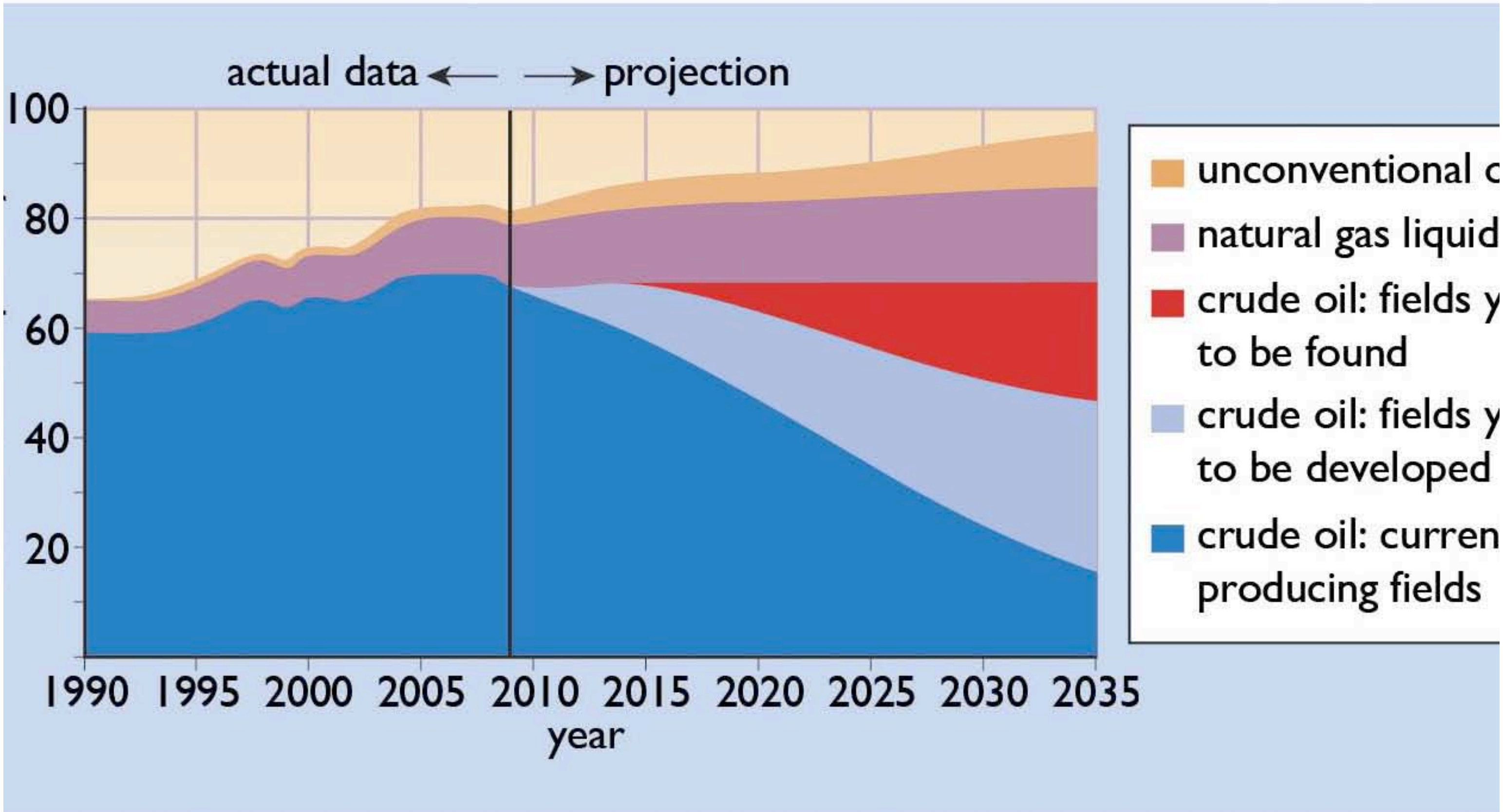
Chris Somerville, UC Berkeley

Potential Contributions of Renewable in the UK

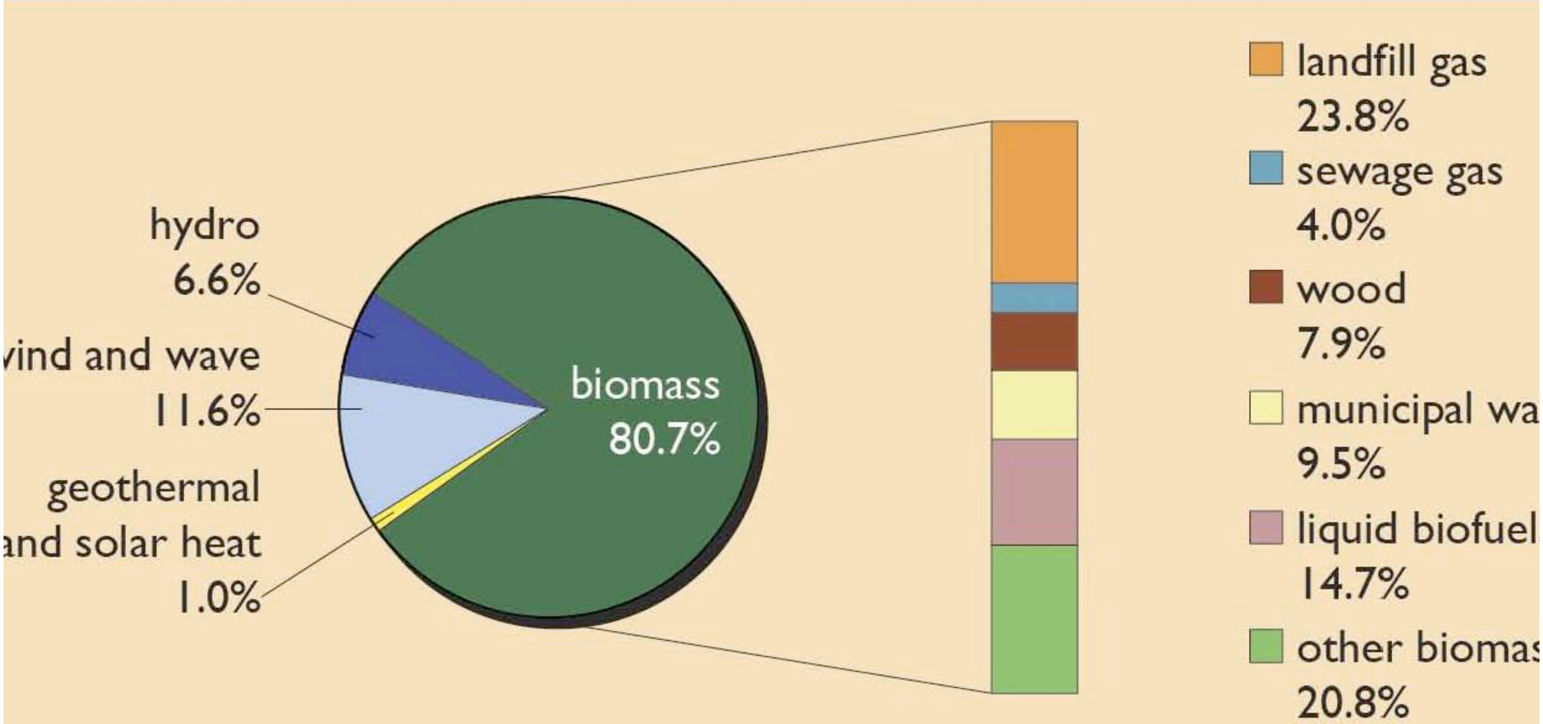


ttee on Climate Change (2011) *The Renewable Energy Review*, Committee on Climate Change

E = electricity, H = heat, T = transport

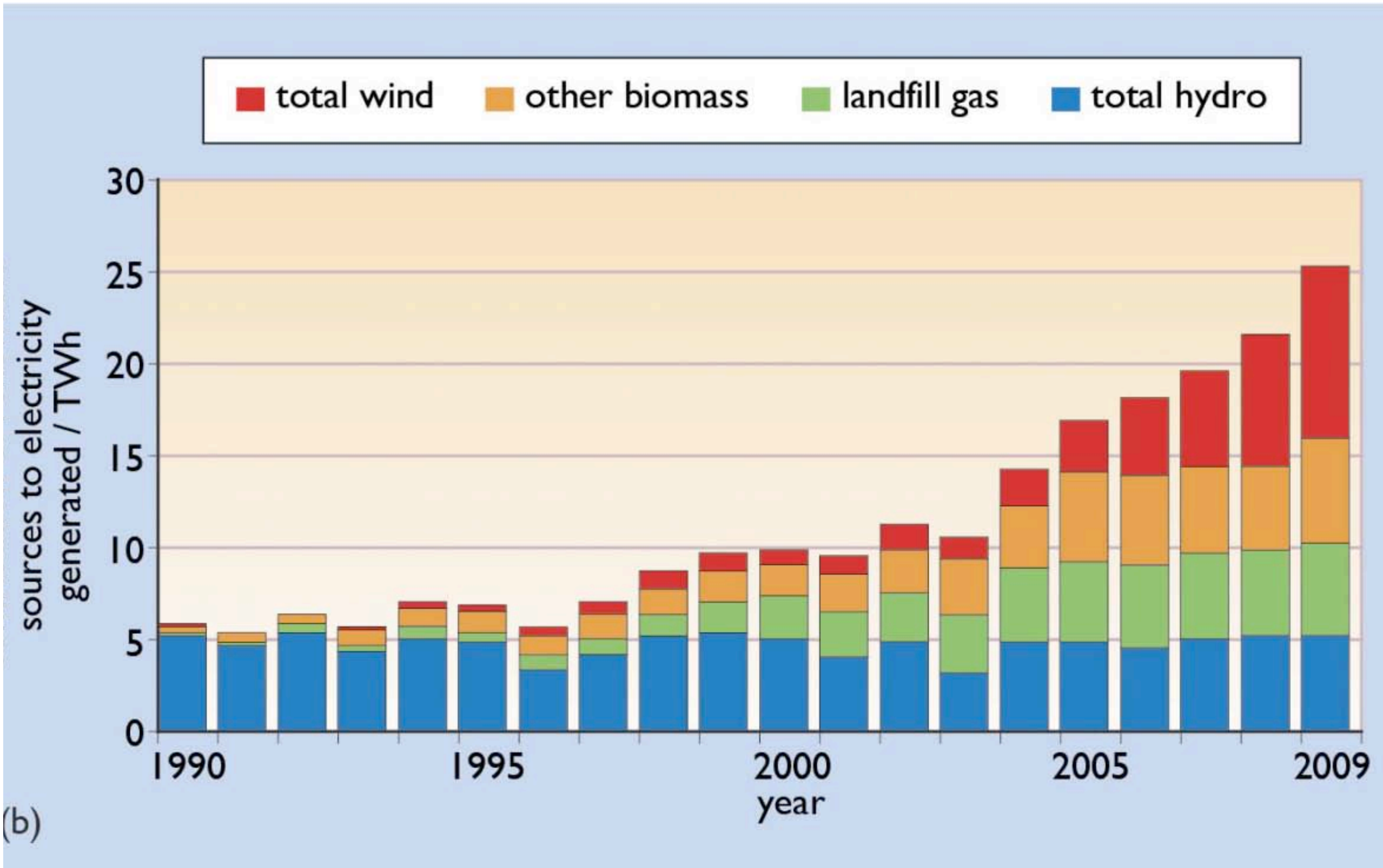


World Energy Outlook Report (2010), International Energy Agency



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

Figure 1.6b


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

Energy Storage Options

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