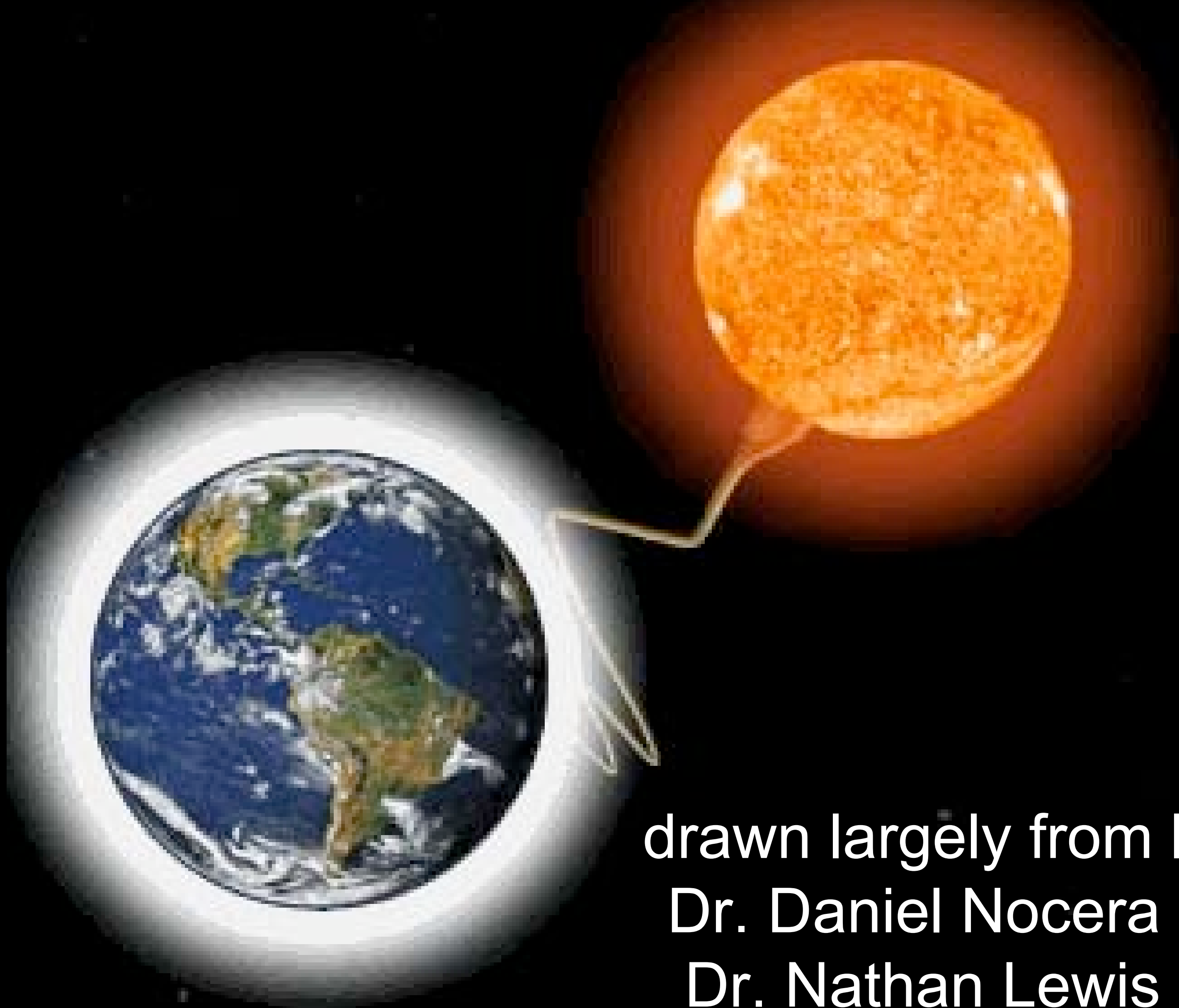
XX. "powering the planet"

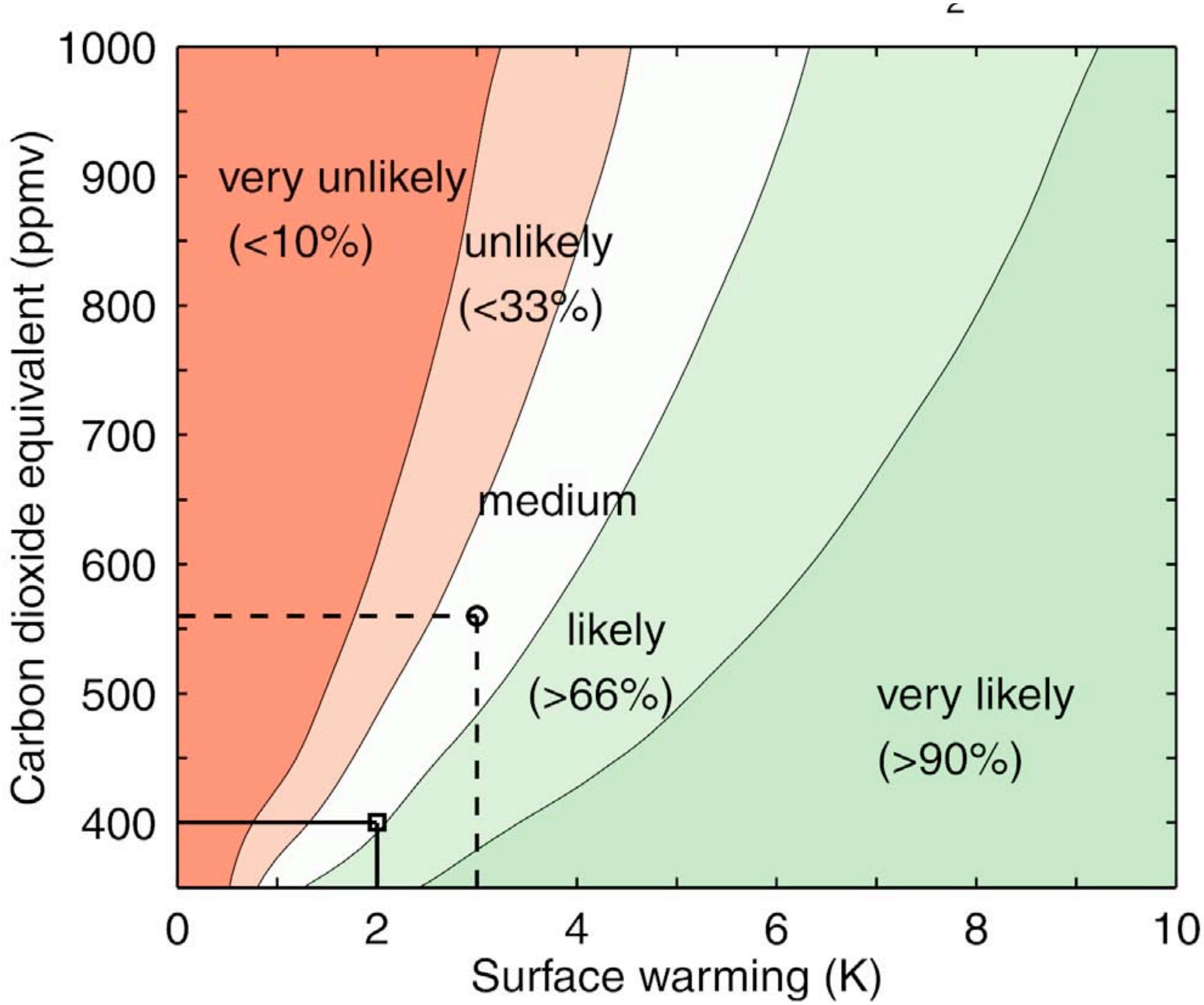


drawn largely from lectures by
Dr. Daniel Nocera (MIT) and
Dr. Nathan Lewis (Caltech)

review

- for the first time, the IPCC has documented widespread impacts from climate change that has *already occurred*
- impacts of climate change are certain to increase in number, range and severity as warming continues
- it may be difficult to agree on a “harm threshold” that must be avoided, but....
- many scientists maintain that impacts for warming $\geq$2 °C (v. pre-industrial) will be unacceptably severe
- this suggests a “prudent” CO_2 concentration cap of <400 ppm (v. 385 ppm now)

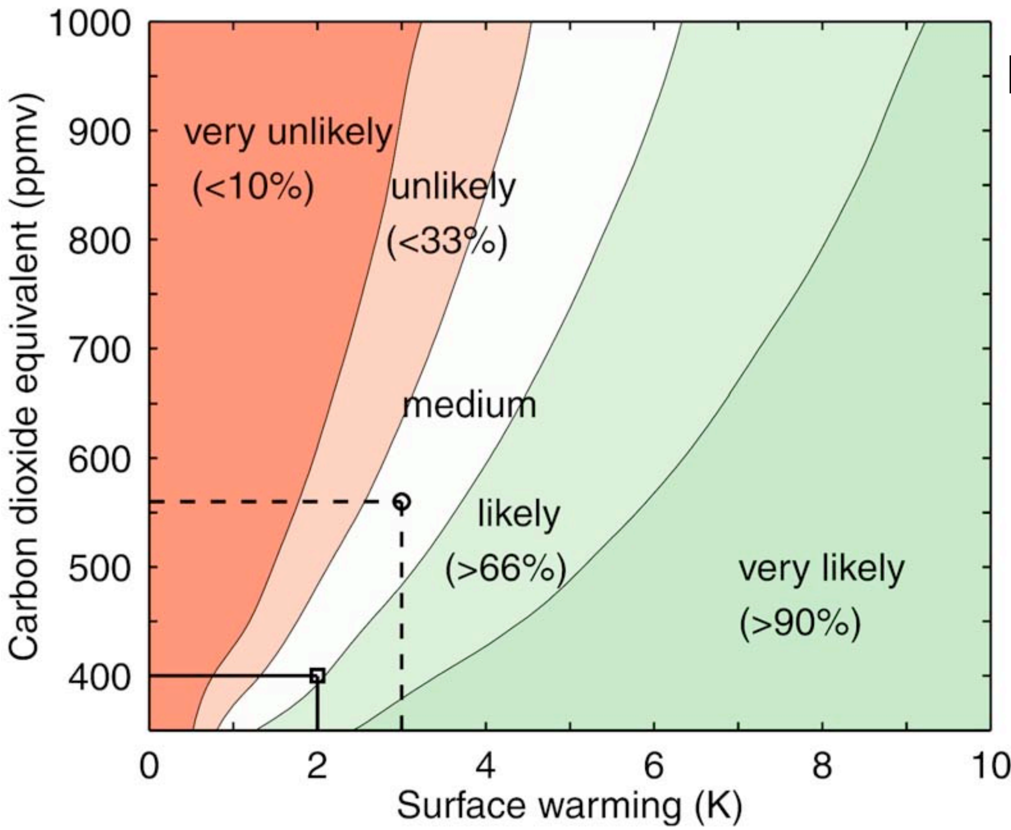
Probability of remaining below a global mean temperature level for a given CO_2 (equivalent) stabilization level, taking into account uncertainty in climate sensitivity and ocean heat uptake. Likelihood terminology from IPCC.



at equilibrium

Knutti et al., 2005

clicker



Probability of remaining below a global mean temperature level for a given CO_2 stabilization level.

I have a high tolerance for pain, but not risk. I can handle 5 °C warming, but no more (my snorkel is only 4 m long, exactly!). What is the allowable CO_2 concentration?

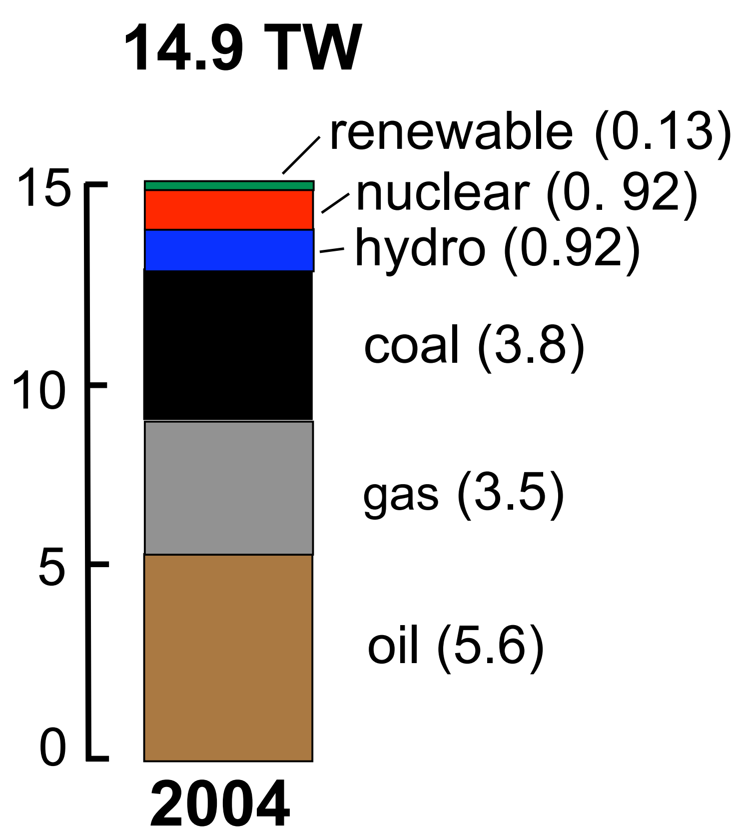
a) <u>500 ppm or less</u>, b) ~600 ppm, c) ~700 ppm, d) ~800 ppm, e)~1000 ppm

today's outline

- where does our energy come from and where does it go?
- how much will we need in the future (and why)?
- where will it come from in the future (and why it matters)?
- energy options and opportunities?

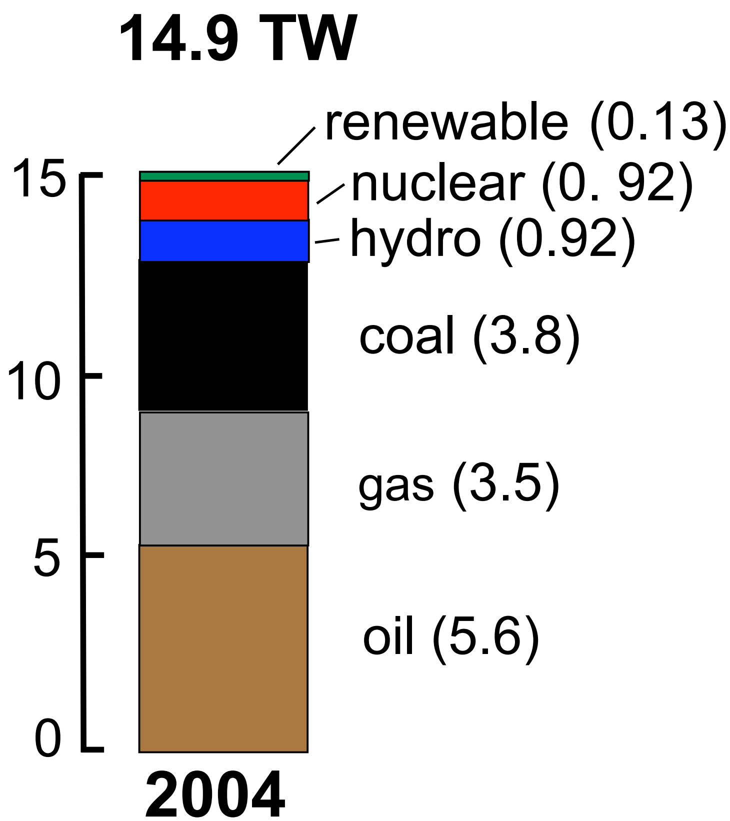
meeting the future energy demand while avoiding unacceptably severe climate change is *the science, engineering and policy challenge of the millennium* global energy use by source (and projected)

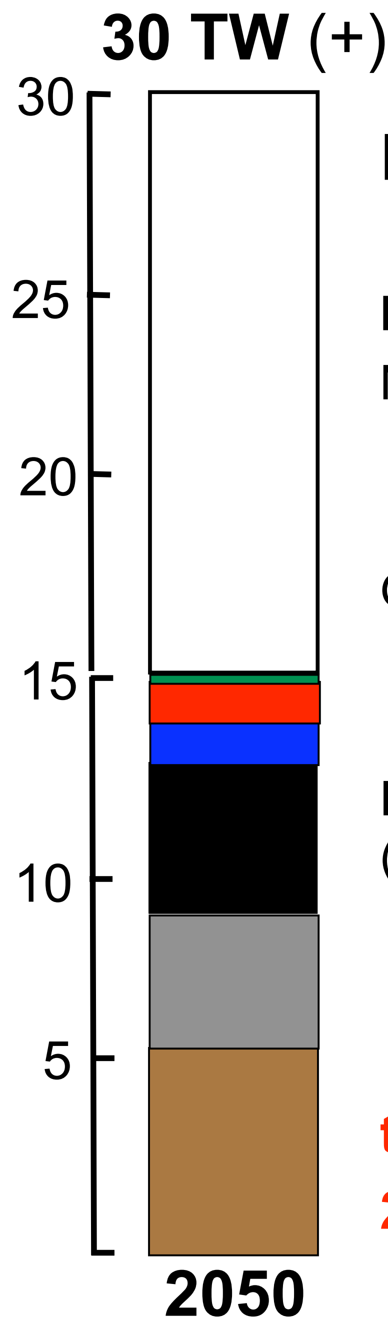
this is simply a global "burn rate" expressed in quadrillions of Watts



global energy use by source (and projected)

< 1% renewable
~ 13 % carbon-free





$E = N \times (GDP/N) \times (E/GDP)$

E = world energy consumption (TW)

N is population

N growth = +0.9%/yr

i.e. from 6 to 9.4 billion

GDP/N is *per capita* GDP

GDP/N growth = +1.4%/yr

i.e. from $7500 to $15000

E/GDP is *energy intensity*
(energy consumed per unit of GDP)

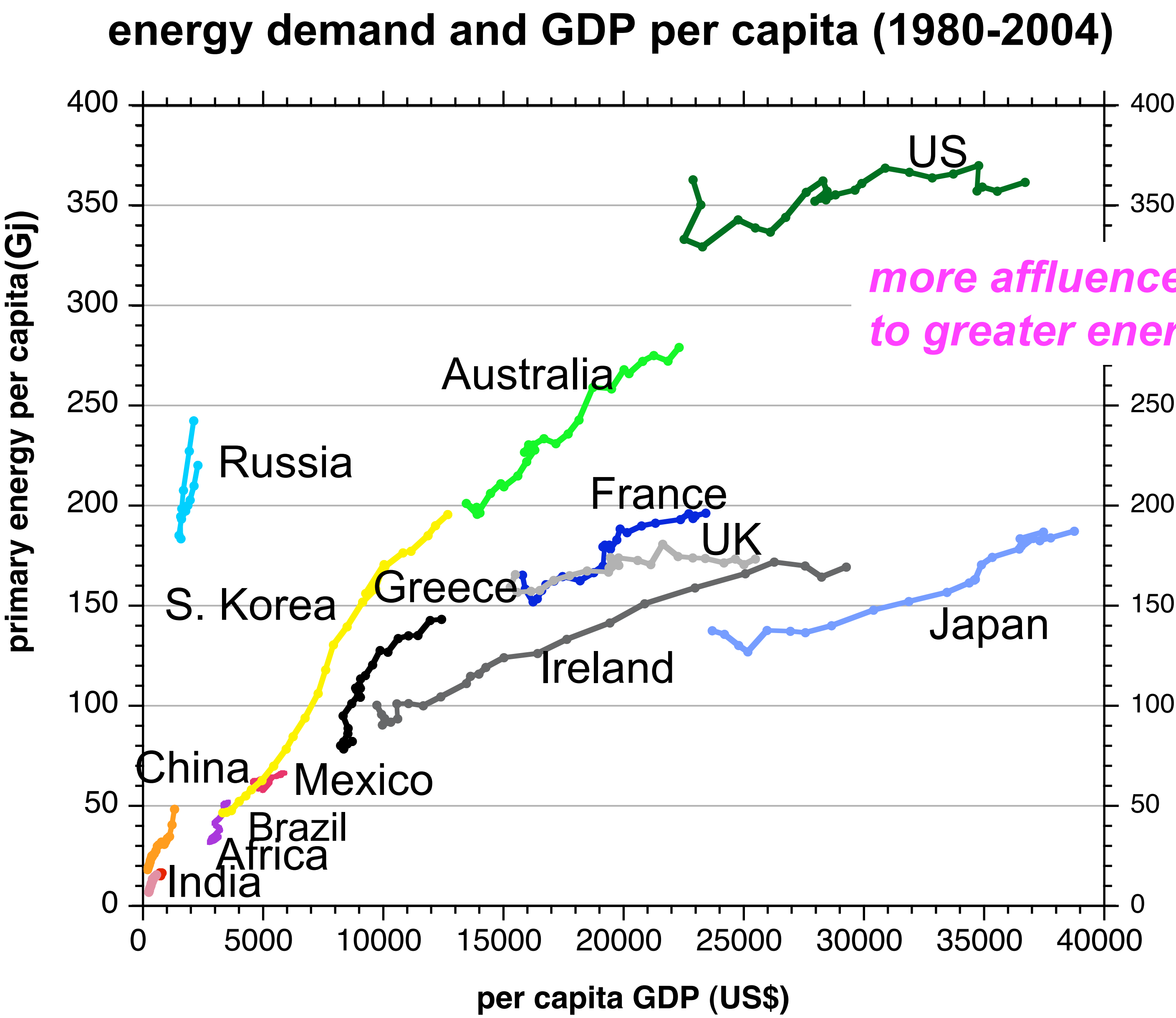
0.294 W/($/yr) > 0.20 W/($/yr)

E/GDP decrease = -0.8 %/yr

therefore E will grow at:

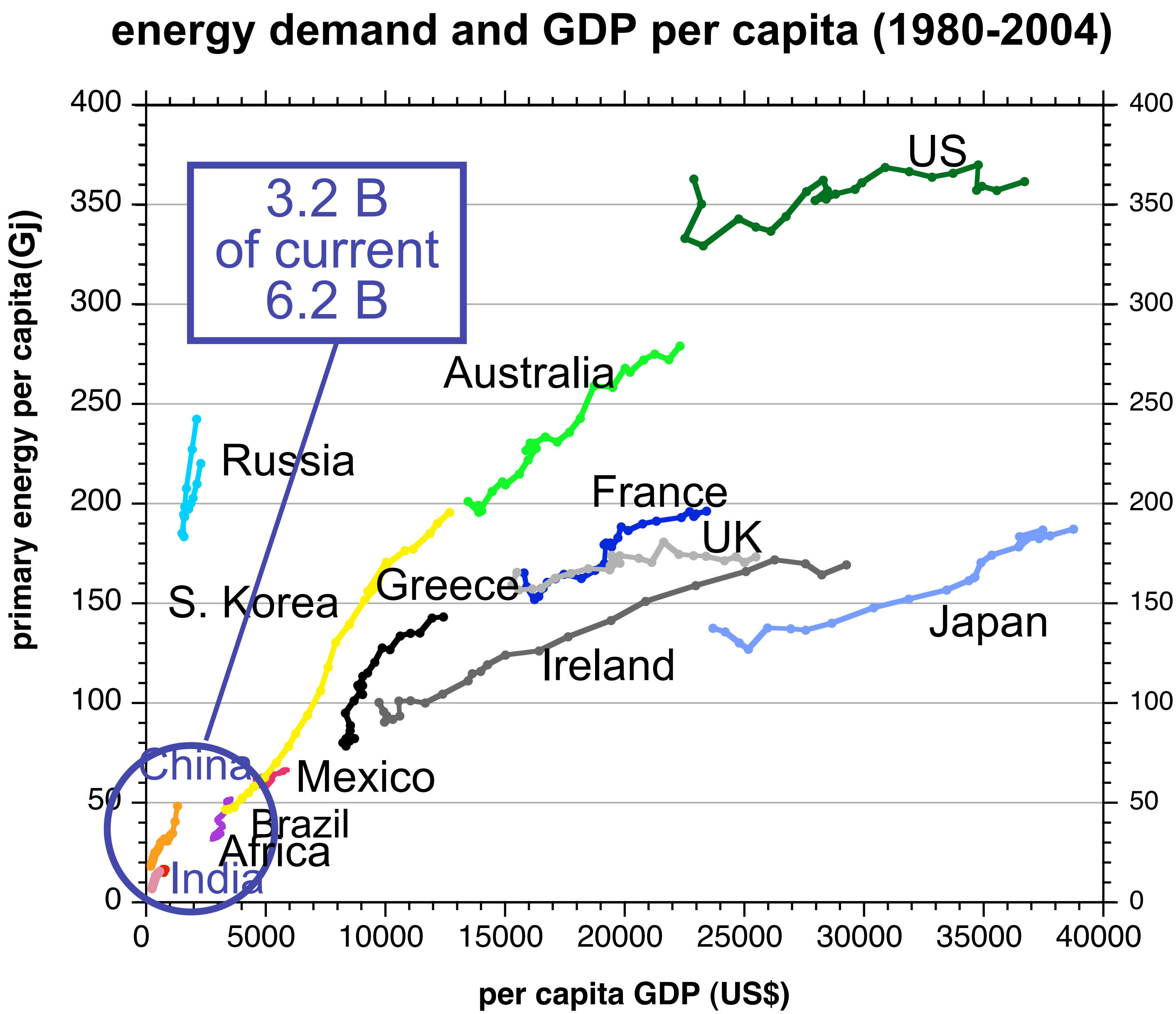
2.3%/yr - 0.8%/yr = 1.5%/yr

energy use per person in different countries

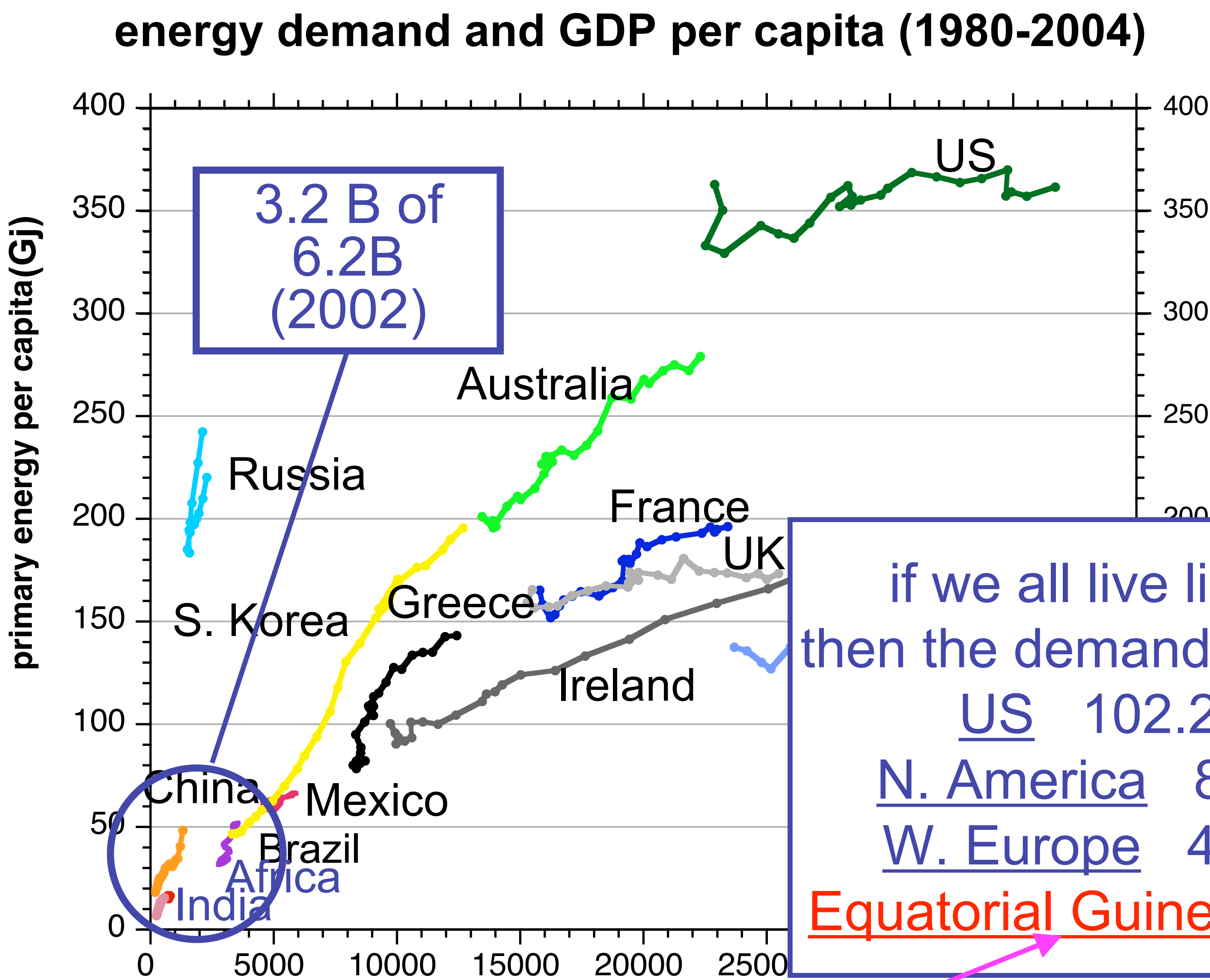


more affluence equates to greater energy use

energy use per person in different countries



energy use per person in different countries



3.2 B of
6.2B
(2002)

if we all live like ___
then the demand in 2050 is:

US 102.2 TW

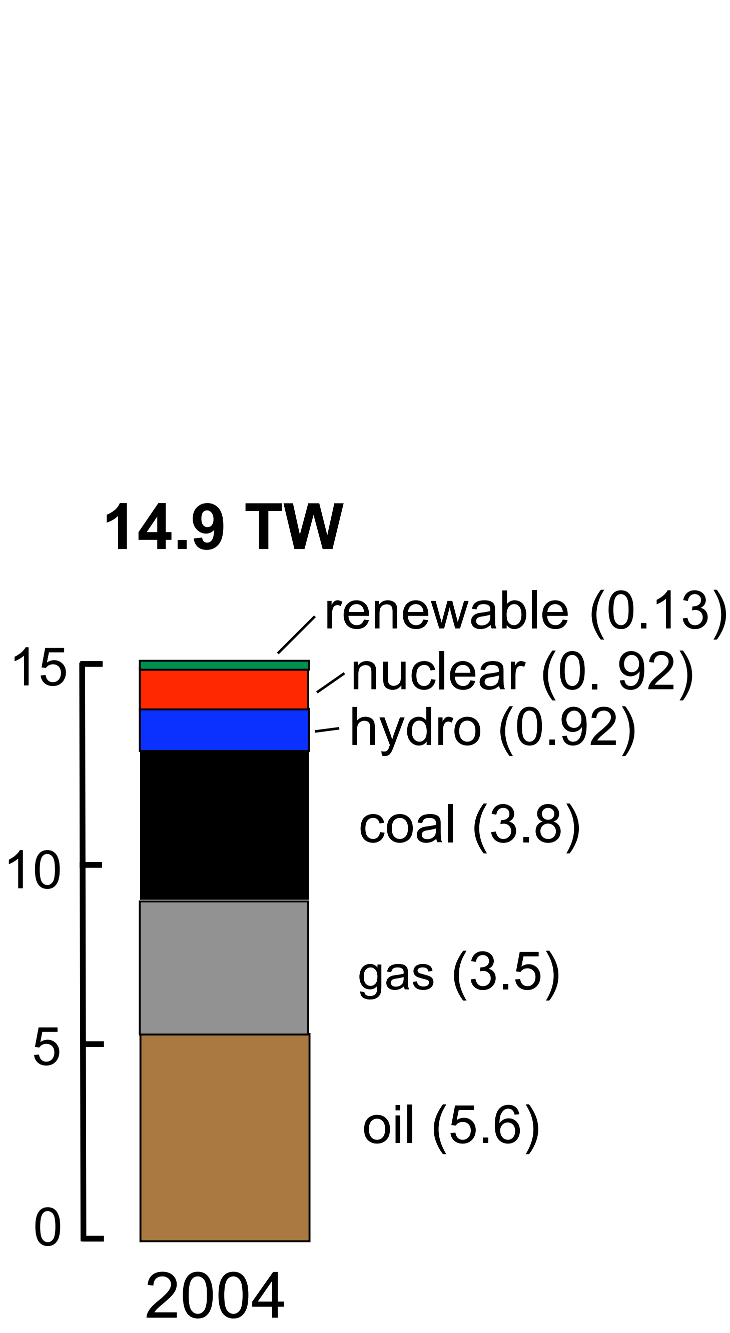
N. America 84.1 TW

W. Europe 45.4 TW

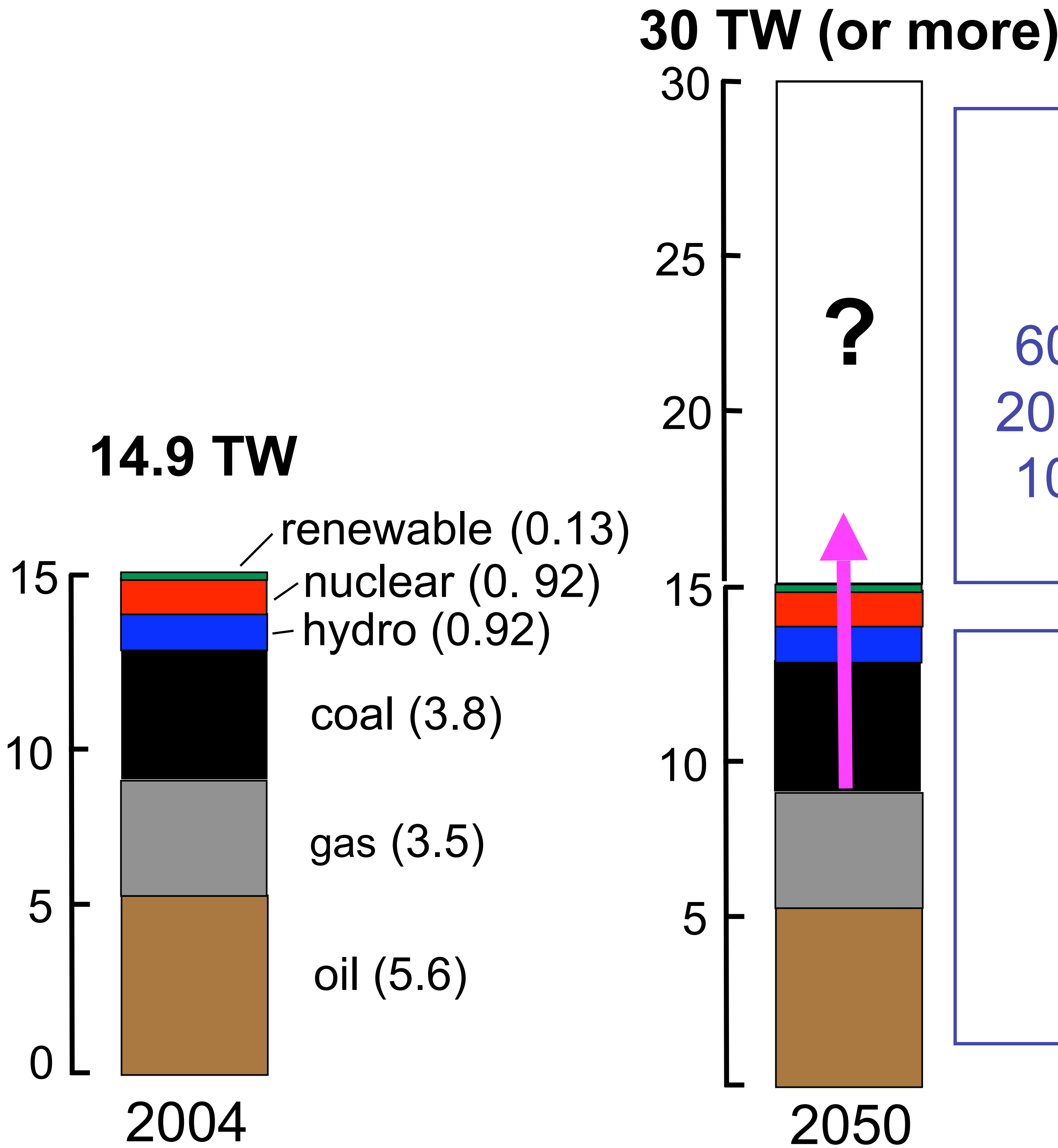
Equatorial Guinea 30.4 TW

thus need to push hard on energy intensity!

how to fill demand?



how to fill demand?



why worry?

we have:

60 -160 yrs worth ***oil****

200 - 400 yrs ***nat. gas****

1000 - 2000 yrs ***coal****

*at 1998 consumption rates

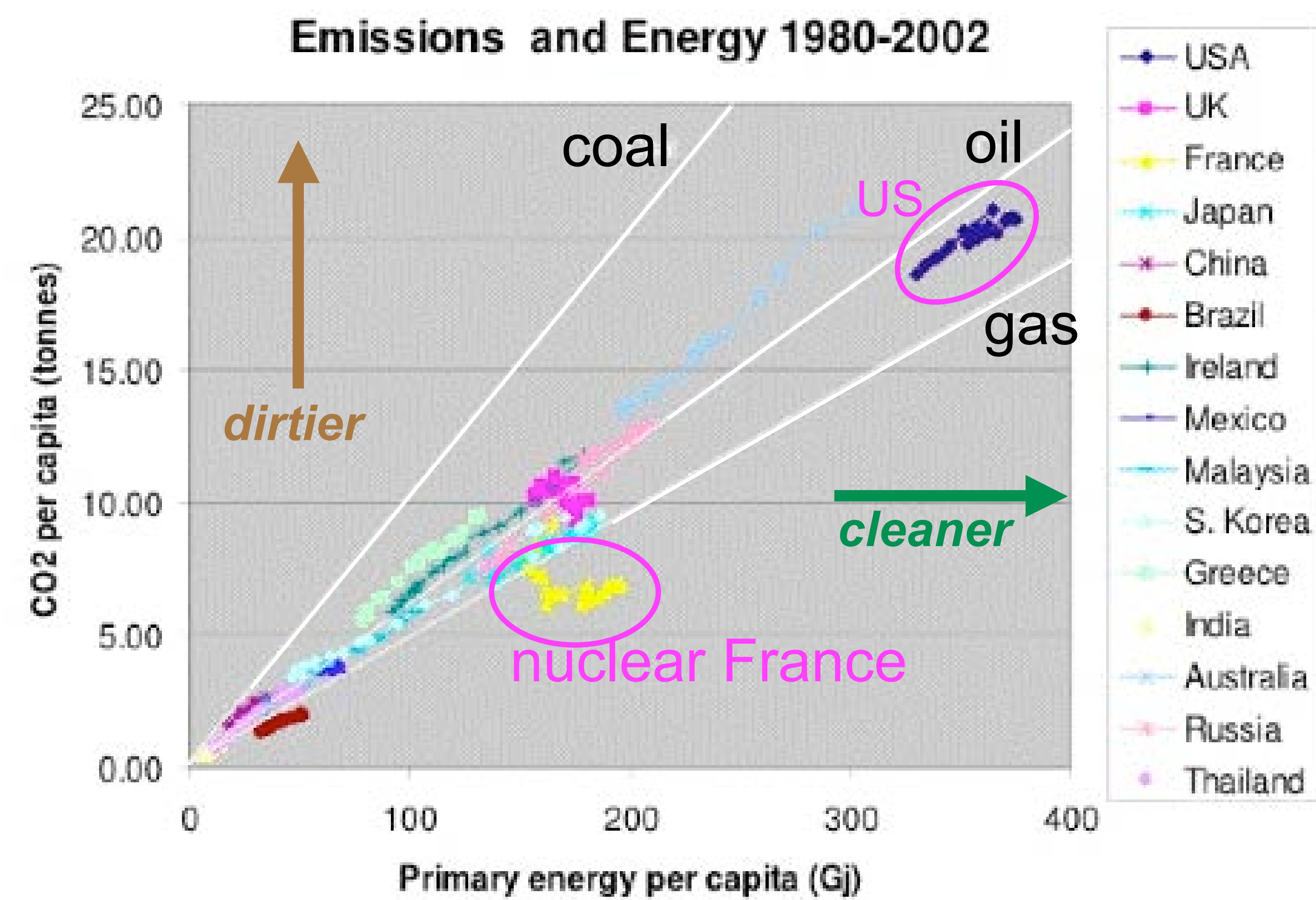
because:

cost

energy security

environment

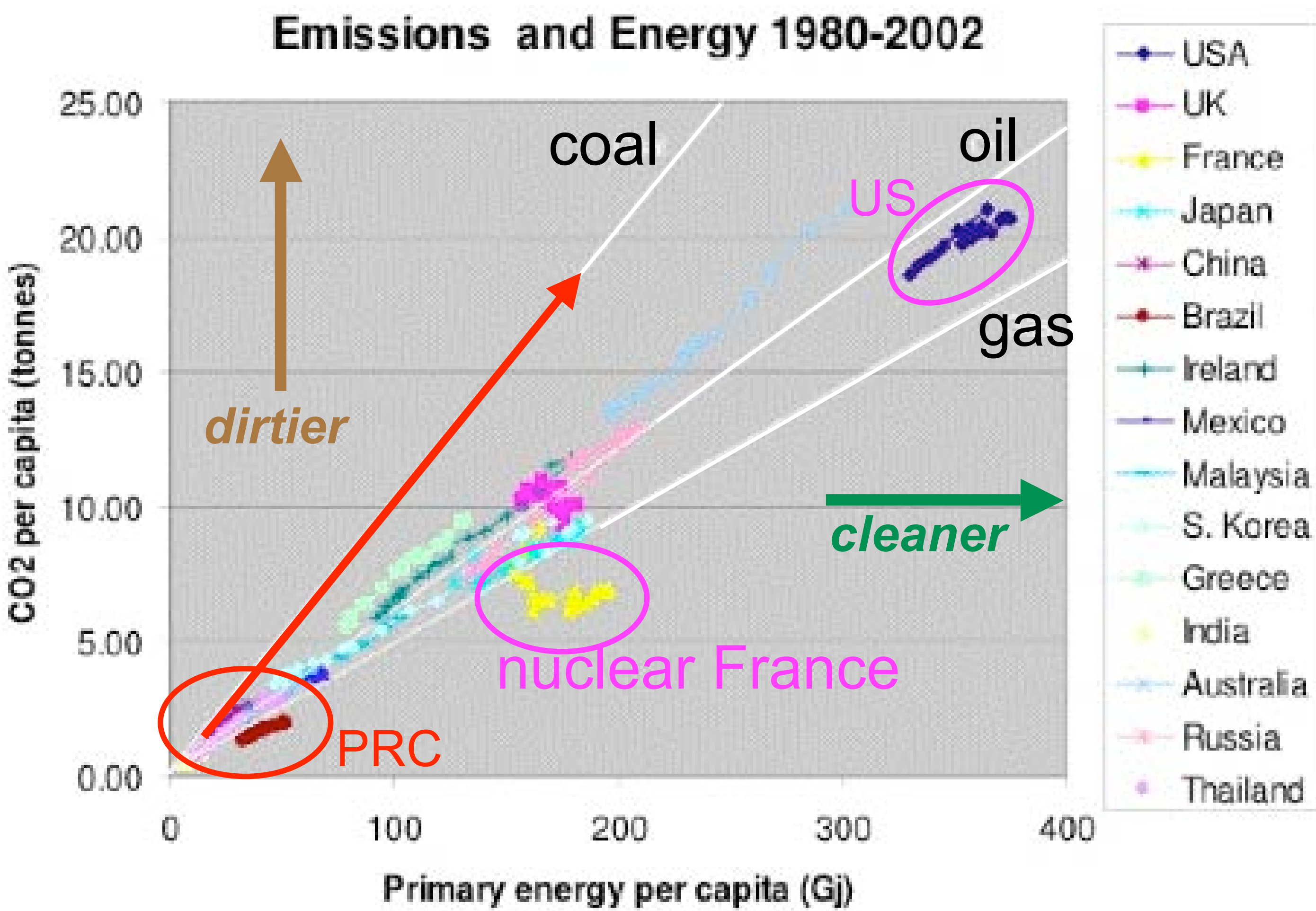
emissions from various fossil fuels & nations



some fossil fuels and economies produce more CO_2 per unit of energy than others (i.e. they have a higher *carbon intensity*)

(white lines are trajectories if economies are run entirely on the specified fuel)

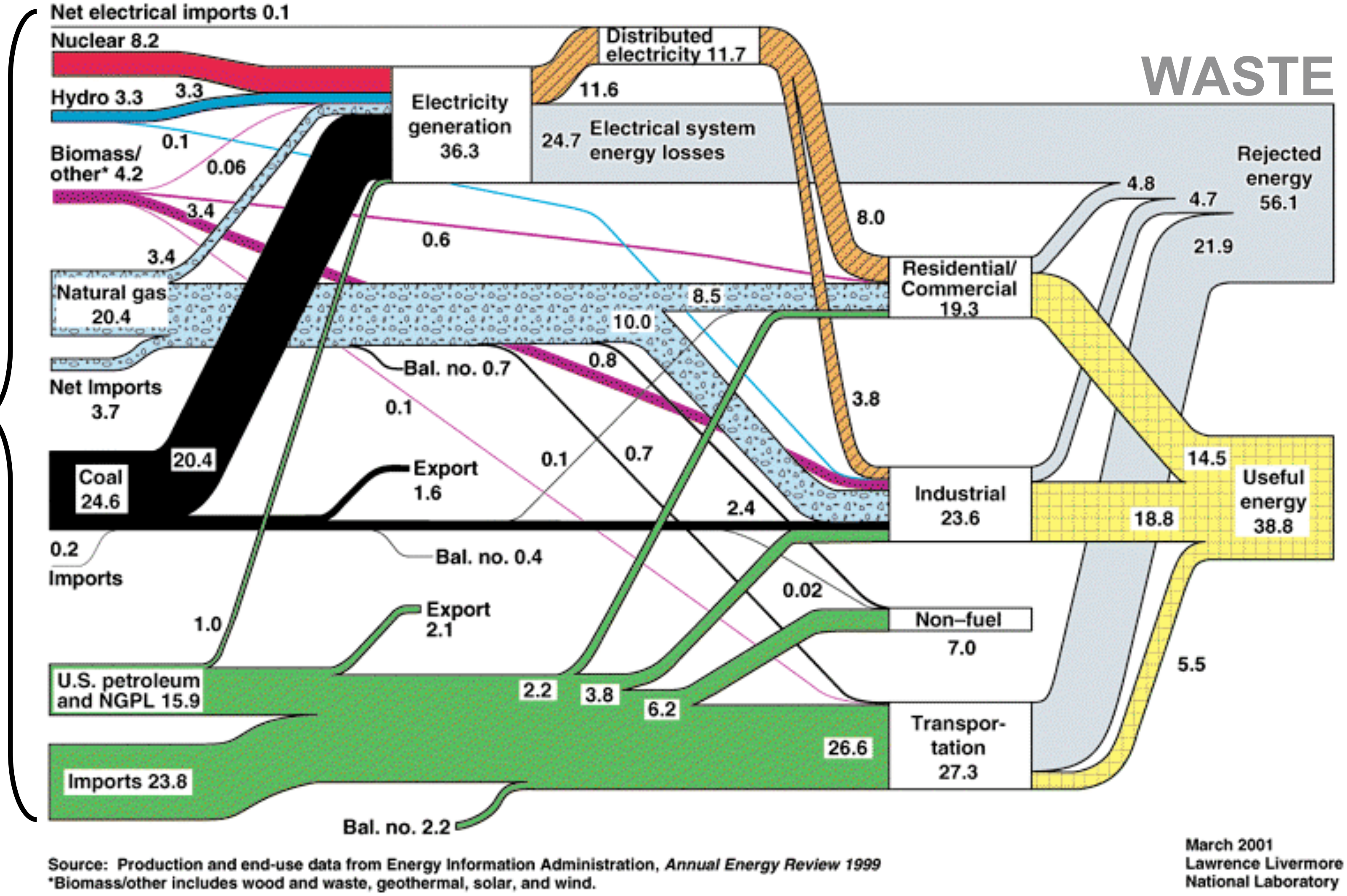
emissions from various fossil fuels & nations



China's increasing use of coal will *push up* the overall *carbon intensity* of the global energy supply

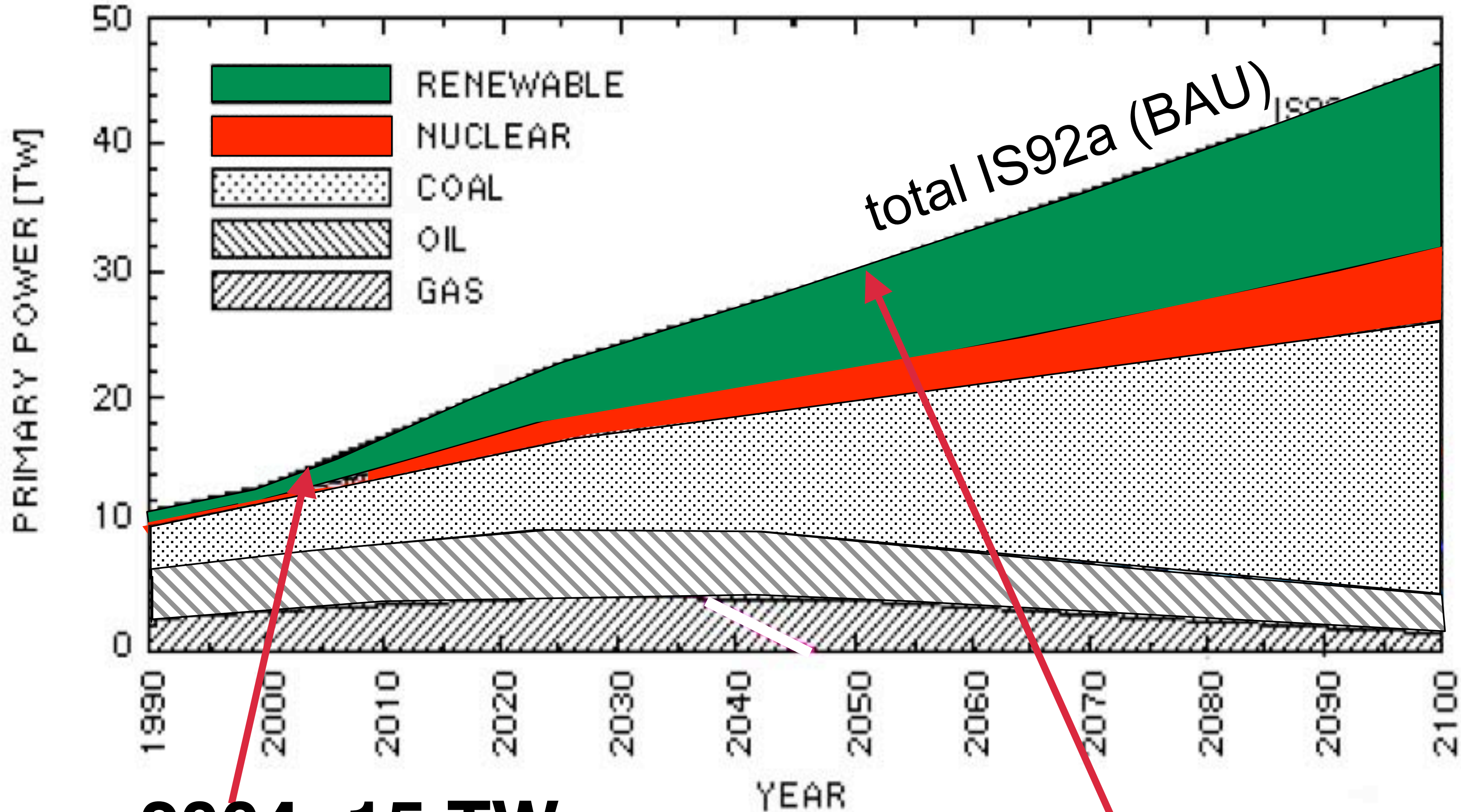
where does the energy go? (US, in %)

yr 2000 consumption
~102 Exajoules (~10^{20} J)



rule of thumb: consumption is 1/3 transportion, 1/3 industrial, 1/3 residential commercial, more than half is wasted

projected energy by source IPPC "BAU"



2004: 15 TW

1.05 TW renewable/hydro

0.92 TW nuclear

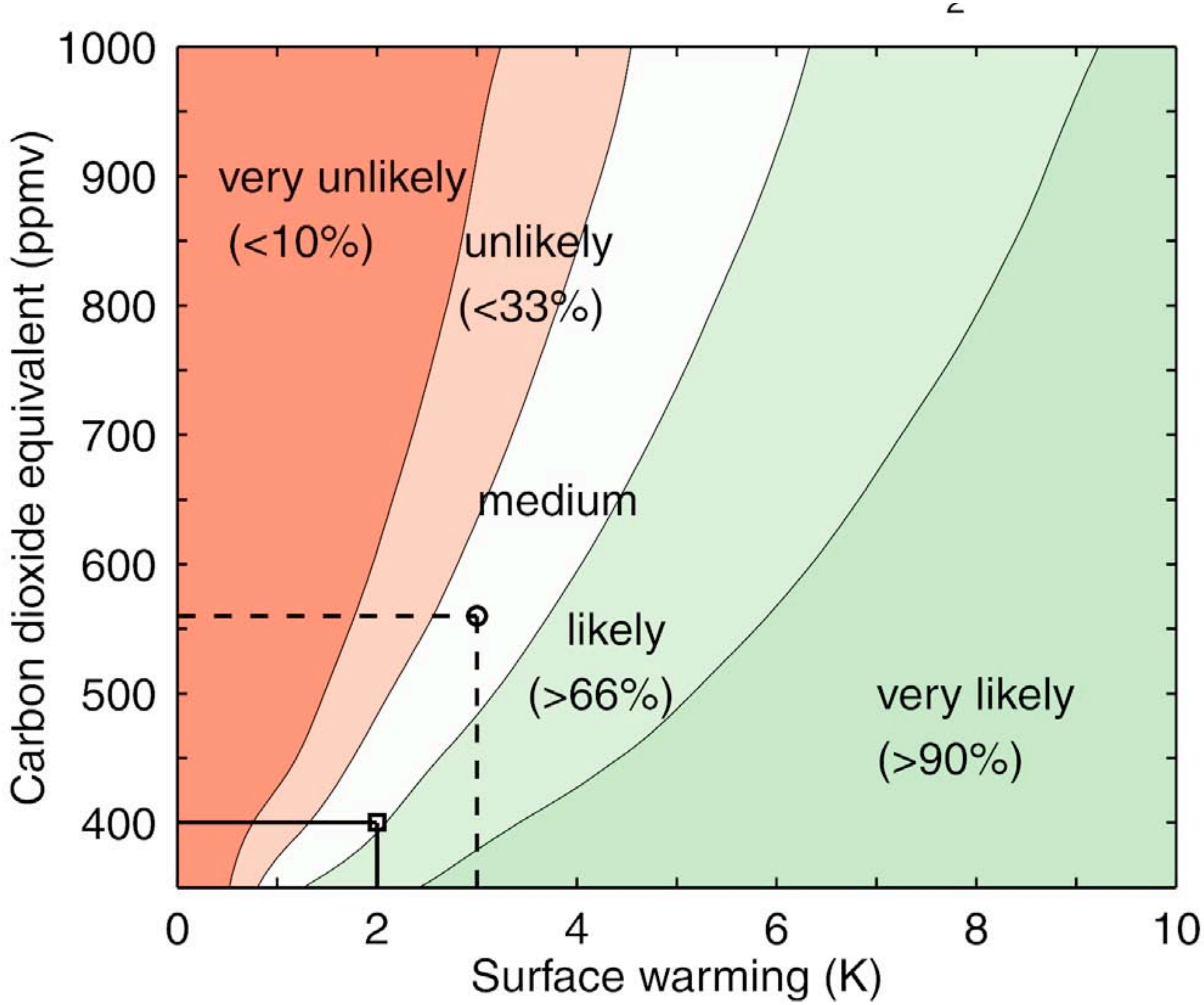
good enough?

2050: 30 TW

~ 8 TW renewable

~ 2 TW nuclear

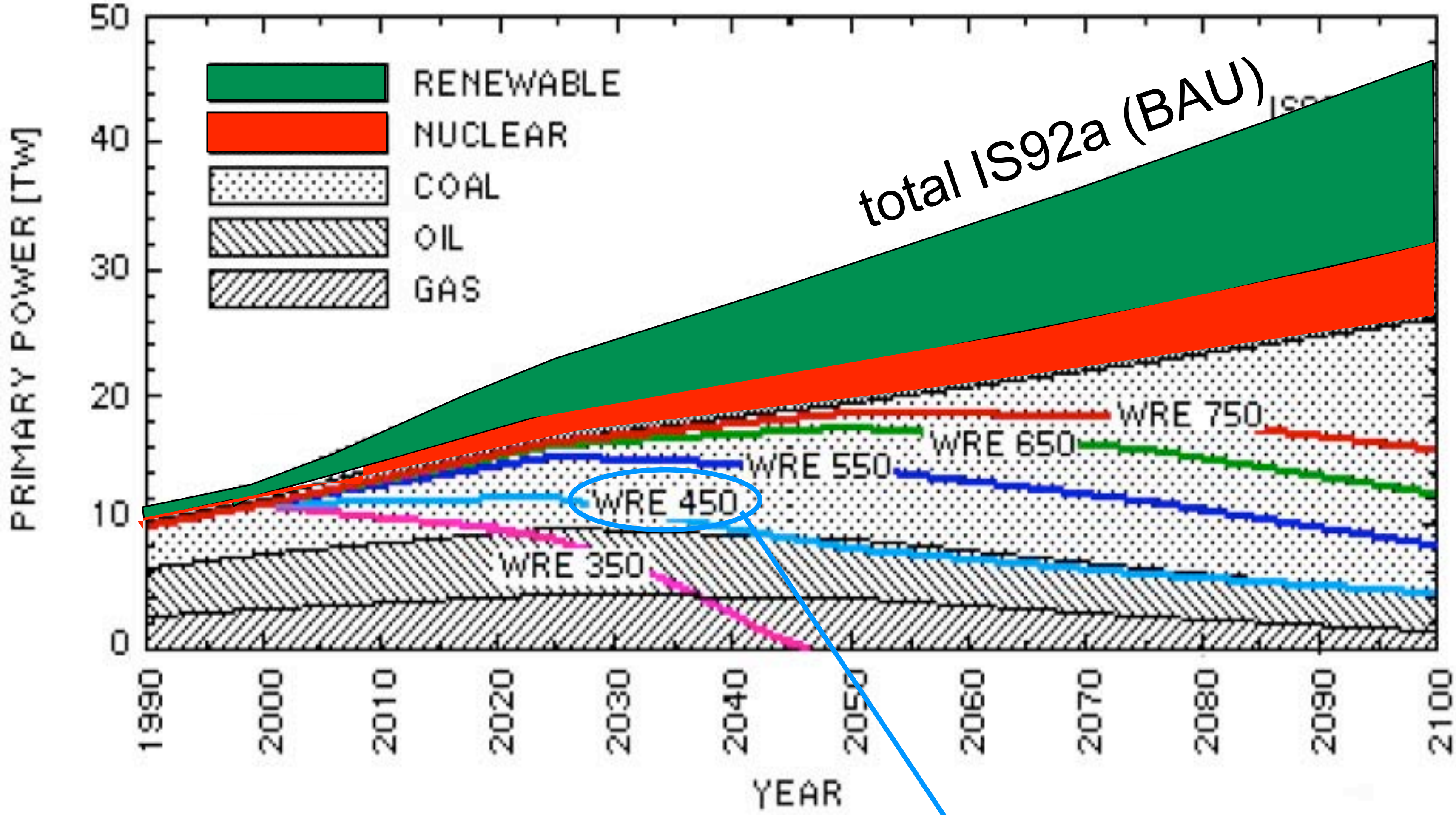
Probability of remaining below a global mean temperature level for a given CO_2 (equivalent) stabilization level, taking into account uncertainty in climate sensitivity and ocean heat uptake. Likelihood terminology from IPCC.



at equilibrium

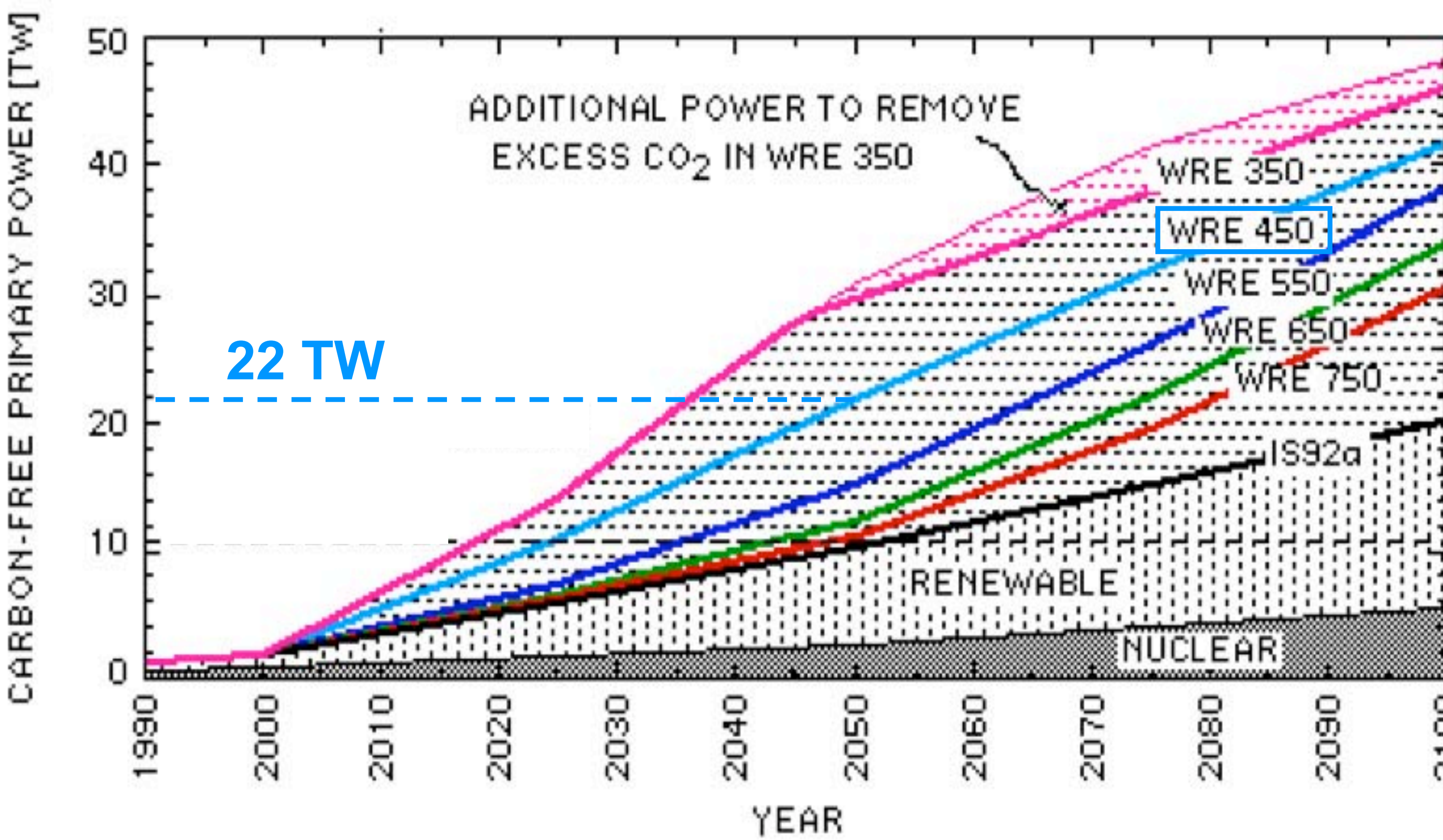
Knutti et al., 2005

now consider fossil C use limits for given stabilization CO_2 concentration



for example, stabilization at 450 ppm requires more renewable + nuclear and less fossil fuel in the global energy mix

projected carbon-free energy to achieve stabilization



in order to stabilize CO_2 at 450 ppm we need more carbon-free energy than the *total* global energy production today

"the science, engineering and policy challenge of the millennium"

meeting the global C-free energy demand:

- we can't do it by conservation alone (since the future energy demand is greater than the existing one), but we must conserve massively to reduce demand growth
- it will take a broad portfolio of energy technologies and efficiencies to reduce and meet the demand (no "magic bullet")
- even nuclear power has real limitations
- the source with the greatest theoretical potential is the sun (we will want to replicate and then beat *photosynthesis*)
- carbon capture and sequestration must be developed and scaled up

the nuclear option

- consider the task of implementing 10 TW of power generation (v. 0.9 TW today)

- would require construction of a new 1 GW (electricity) plant every 1.6 days for 45 yrs!

- at a 10 TW generation rate, we would run out of uranium on land in 10 yrs (and, in fact, would be out of land U 30 yrs into plant construction phase due to use during ramp up)

- will need to extract uranium from sea water (abundant) or consider more advanced fuel cycles....

solar energy potential

- *Theoretical:* 1.2×10^5 TW solar energy potential

  (1.76×10^5 TW striking Earth; 0.30 Global mean albedo)

  •Energy in 1 hr of sunlight ~ 15 TW for a year

- *Present:* ~ 0.015 TW, ~0.22 TW incl. biofuels

- *Practical:* Onshore potential of ~60 TW

  (assumes 10% conversion efficiency)

the practical potential is enormous!

solar land area requirements

- $1.2x10^5$ TW of solar energy potential globally
- Generating 20 TW with 10% efficient solar farms

requires $2x10^2/1.2x10^5$ = 0.16% of Globe = $8x10^{11}$ m^2

(i.e., 8.8 % of US)

- Generating 12 TW (1998 Global Primary Power) requires

$1.2x10^2/1.2x10^5$= 0.10% of Globe = $5x10^{11}$ m^2

(i.e., 5.5% of US)

solar land area requirements

solar land area requirements

6 boxes at 3.3 TW each

solar cost

- current Si-based PV: ~\$0.35/kWh
- fossil-derived electricity: \$0.02-0.05/kWh

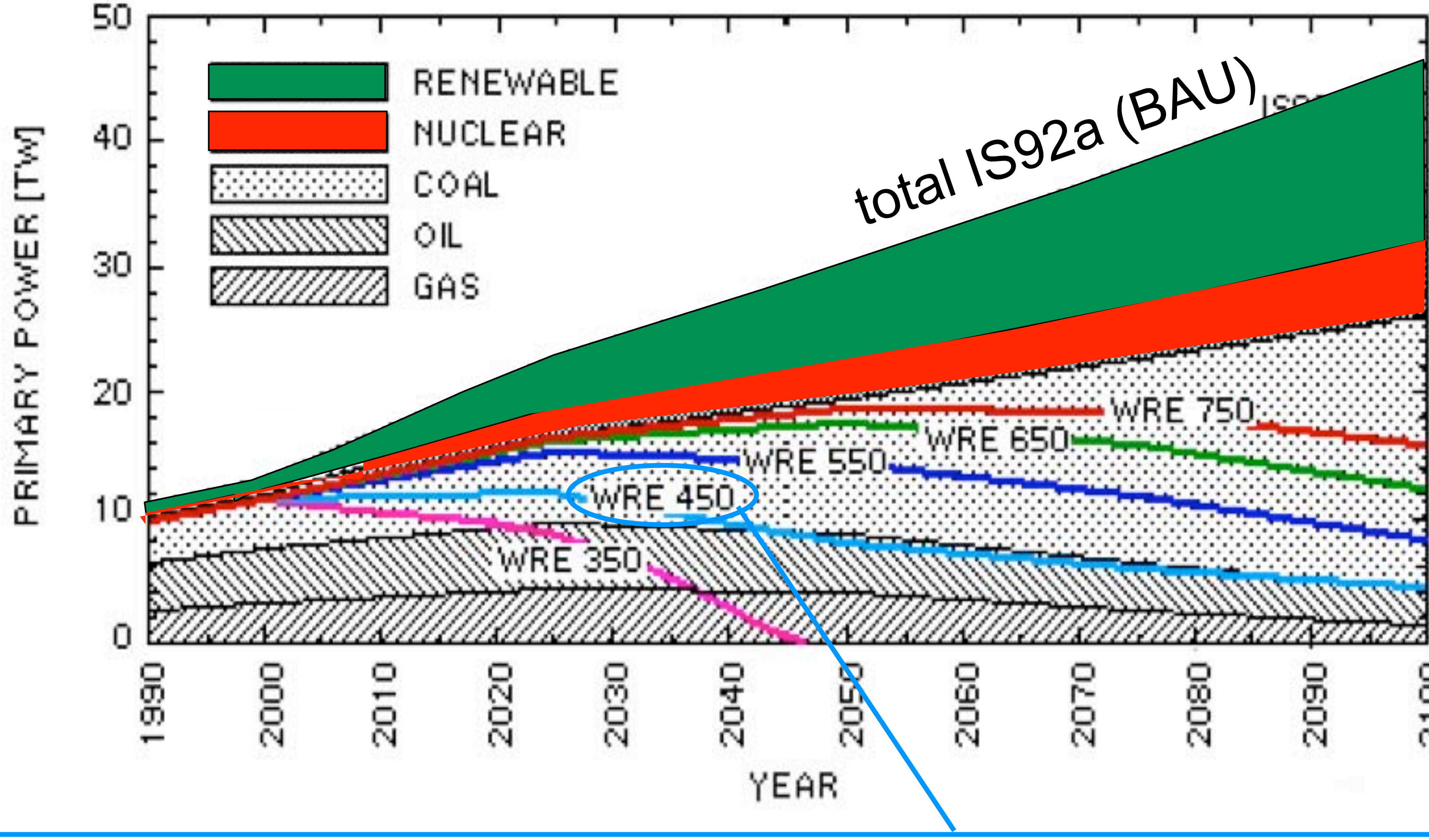
- PV system: ~\$300/m^2
- paint: ~\$1/m^2

- cost needs to drop by more than factor 10 to become competitive at scale

carbon sequestration

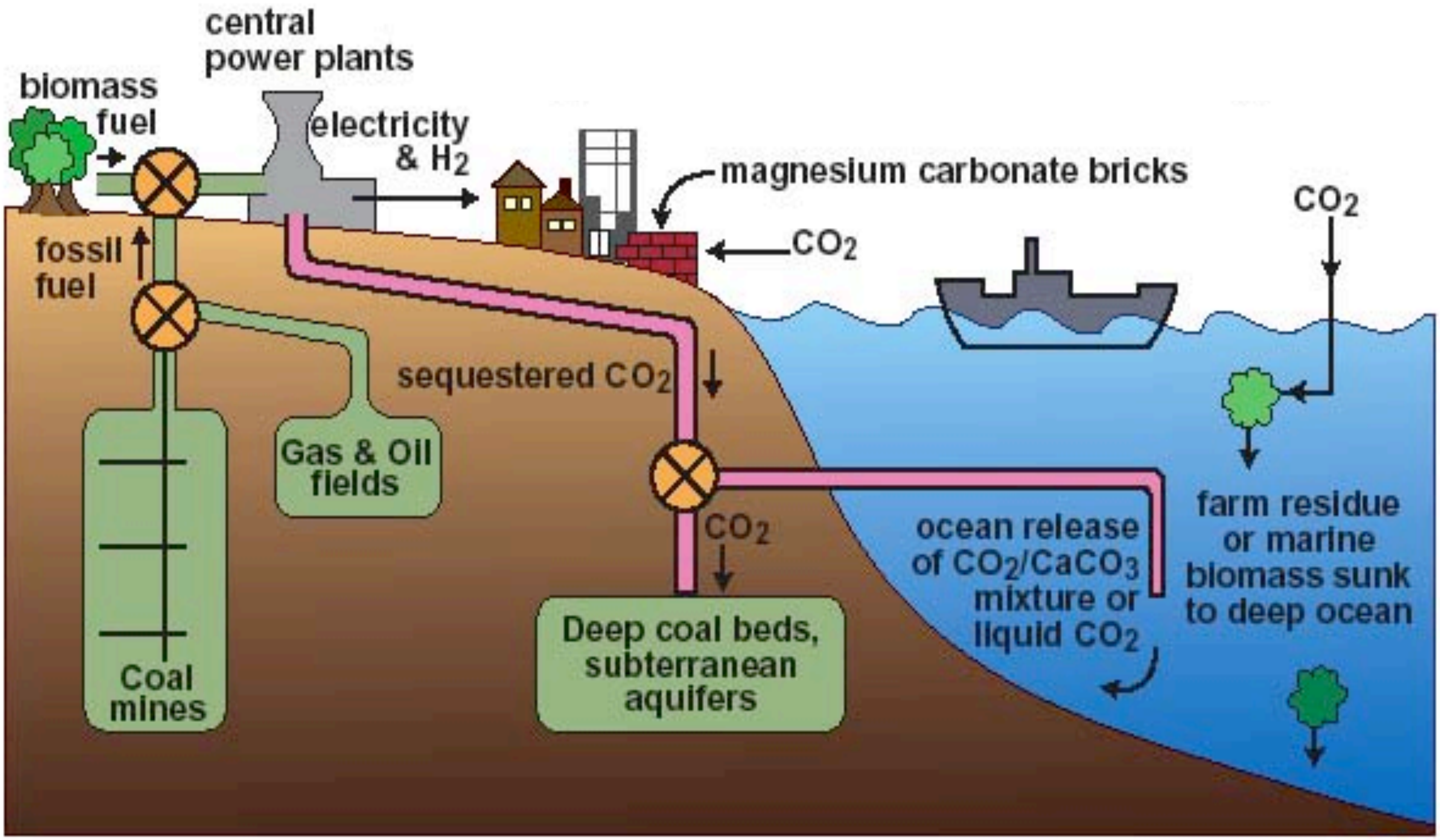
- refers to capturing CO_2 at the smoke stack or from ambient air and storing it in some stable form or in some tight reservoir...
- best application is as part of (or retrofit to) coal "fired" power plants
- this must be considered for 2 big reasons
  - 1) coal is most abundant and cheap fossil energy source and will be widely used (note China today), we need options for using it with low or no CO_2 emissions
  - 2) new technologies may not be deployed quickly enough to stabilize atmospheric CO_2 concentrations at desired levels, so we will want to extract it from the atmosphere (i.e. we need to hedge our bets)

sequestration is our hedge against likely C-free energy gap



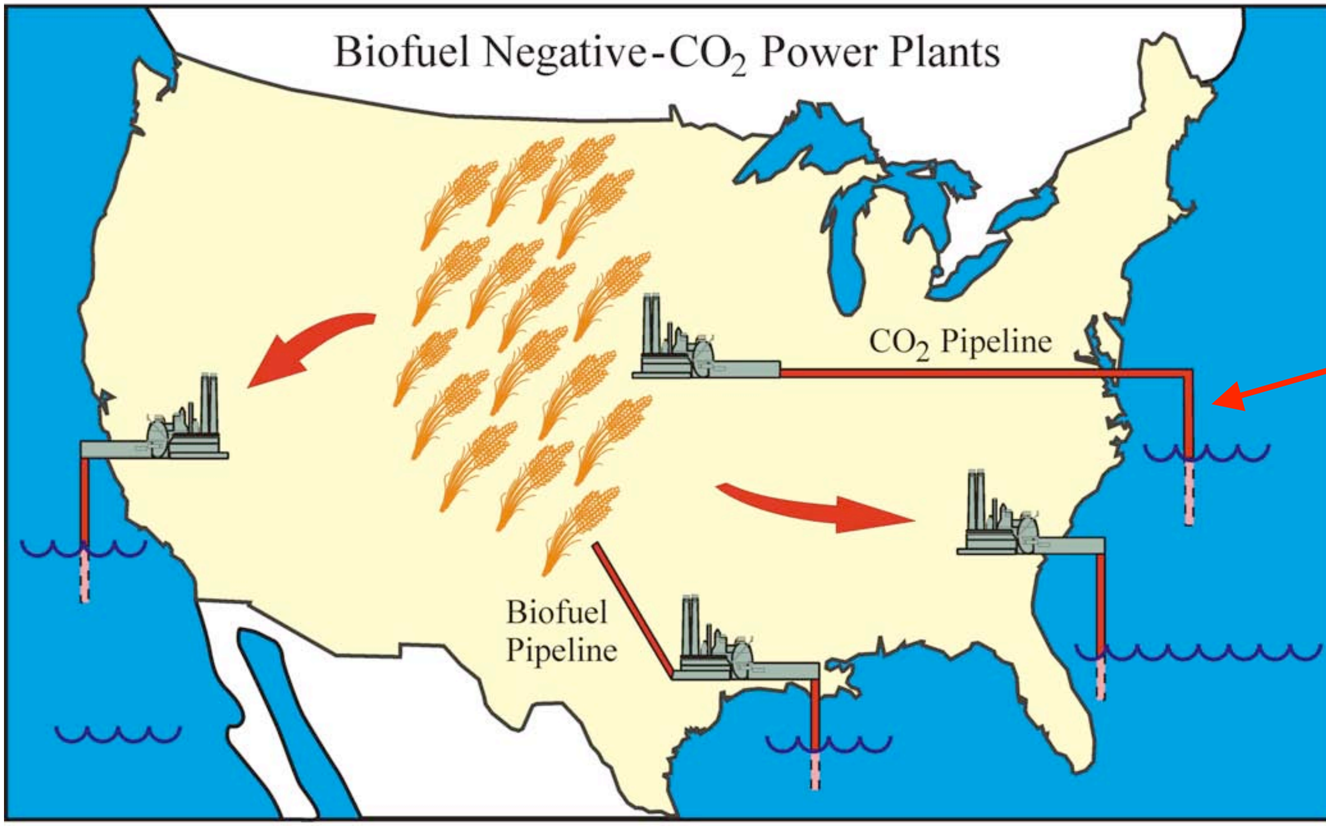
for example, stabilization at 450 ppm requires more renewable + nuclear and less fossil fuel in the global energy mix

carbon sequestration



removing CO_2 from ambient air will be more difficult than capturing CO_2 from concentrated sources (shown here)

clicker question:

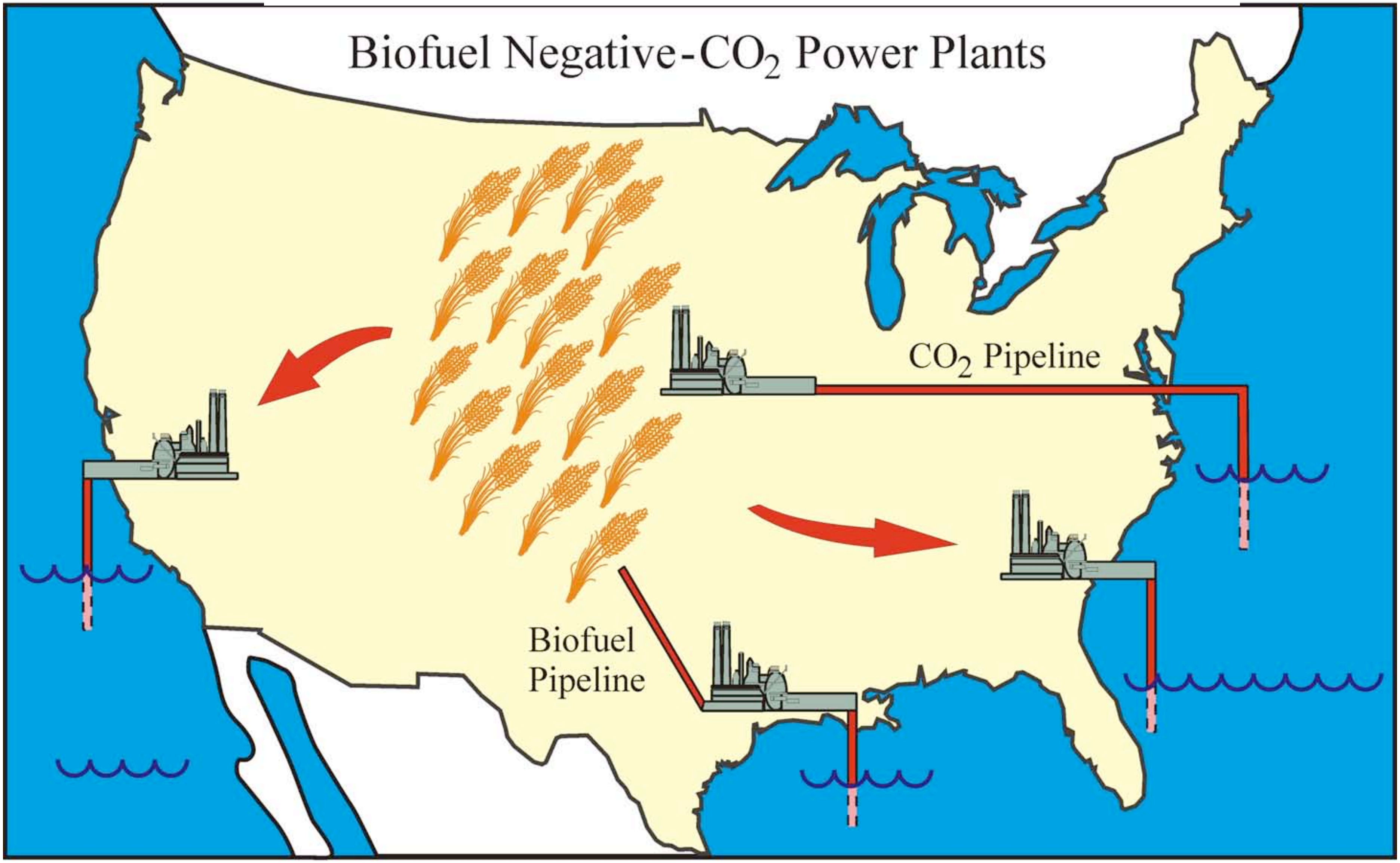


sequestration in marine sediments

the power generating scheme above is "CO_2 negative" because:

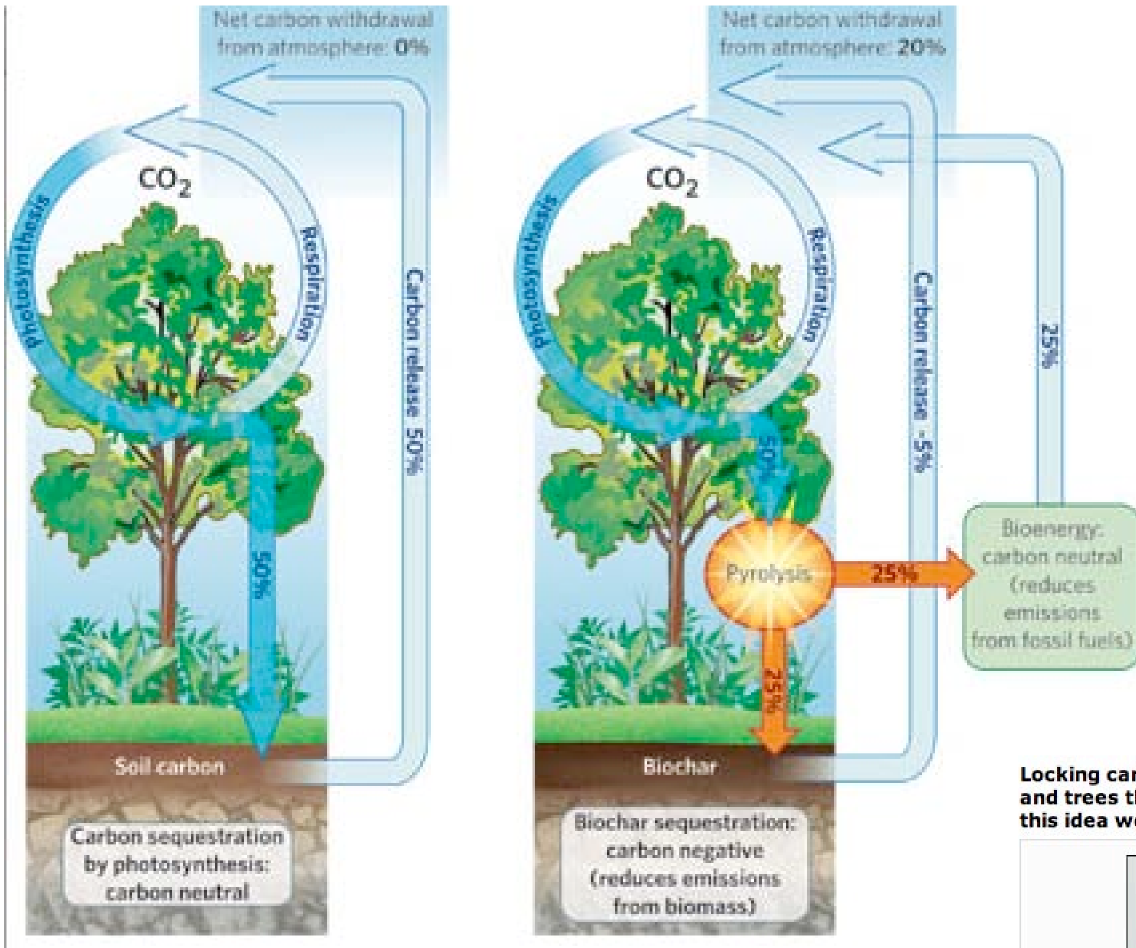
a) power is derived from C extracted from the atmosphere by biomass, **b**) combustion CO_2 is captured and sequestered, **c**) the process mimics the natural cycle of P and R, **d**) <u>*both* a) and b)</u>, **e**) it can't be net CO_2 negative

red, white and blue solution



Cellulos ic Biofuels Electrical Power Generation
Fail-Safe CO_2 Sequestration in Deep-Sea Sediments

add biochar ……….?



low tech sequestration

boosts soil C storage and productivity

biochar is produced by pyrolysis (similar to combustion, but oxygen is not needed) of organic materials such as agricultural waste

Locking carbon up in soil makes more sense than storing it in plants and trees that eventually decompose, argues Johannes Lehmann. Can this idea work on a large scale? ▲ Top

J. LEHMANN

Sequestering 'biochar' in soil, which makes soil darker in colour, is a robust way to store carbon.

key points

- energy use scales directly to GDP
- as population grows and the rest of the world tries to "catch up" with US living standards (as *per capita* GDP) the global energy demand will increase dramatically- from 15 TW now to *at least* 30 TW by 2050
- in order to meet this demand without unacceptably severe climate consequences, much of it will have to be C-free
- the problem is so big that no single strategy will work
- solar has the biggest potential of the "renewables" but development is needed
- the temptation to use coal is enormous, thus carbon capture and sequestration is essential
- the longer we wait to expand the supply C-free energy, the bigger problem because ~half of any C emitted in the interim accumulates in the atmosphere and remains there for hundreds to thousands of years

next week

- In-class exercise (based on homework 4)
- bring lap tops
- *emissions pathways to climate safety*

learning goals

•be able to estimate future energy demand based on population, per capita GDP, and energy intensity

•based on the above, be able to describe how the drive for prosperity in the developing world will influence the future energy demand

•be able to describe the relationship between energy use and C emissions, and the relative “carbon intensity” of different fuels

•be able to describe the “gap” between the future energy demand and the energy that can be provided from fossil fuels for a given atmospheric CO_2 stabilization target

•be able to suggest some large-scale sources of C-free energy that might help fill such a gap

•be able to describe the value of carbon capture and sequestration as a hedge against filling the energy gap