

Thoughts on Global Energy



Primary Sources of Energy

- Fossil
 - Oil
 - Coal
 - Gas
- Nuclear
 - Fission
 - Fusion
- Solar
 - Hydropower
 - Biomass
 - Photovoltaic
 - Solar thermal
 - Wind
- Geothermal

Non Renewables

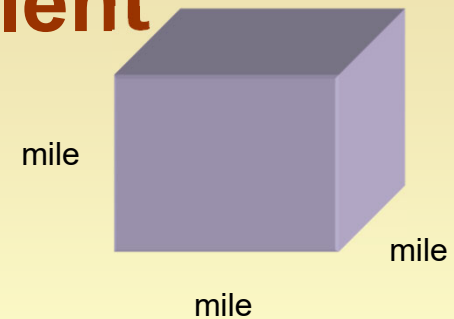
Renewables

How much do we consume?

- ★ Worldwide consumption rate (per second)
 - ✿ 37,000 gals of oil
 - ✿ 150 tons coal
 - ✿ 3.2 Mcf gas
- ★ Units must have come from a veritable tower of Babel!
 - ✿ Therms (or BTUs), Quads, MWh, Barrels (bbl), Tons, Tcf ...
- ★ Lack of uniform units presents a serious impediment to meaningful discussion
- ★ Further confusion caused by the necessity to use millions, billions, trillions, and quadrillions of whatever

Idea: Cubic Mile of Oil Equivalent

- A unit that can be visualized
- 1 cmo \cong 1 trillion gallons of oil
- Also, 1 cmo \cong current annual worldwide oil consumption



1 cmo is equivalent to:

- 26 Billion (10^9) bbl oil
- 6 Billion (10^9) tons of hard coal
- 49.5 Trillion (10^{12}) KWh electricity
- 153 Quadrillion (10^{15}) Btu (Quads)
 - 1 Btu \cong energy from a burning match

Primary Sources of Energy in cmo (2017)

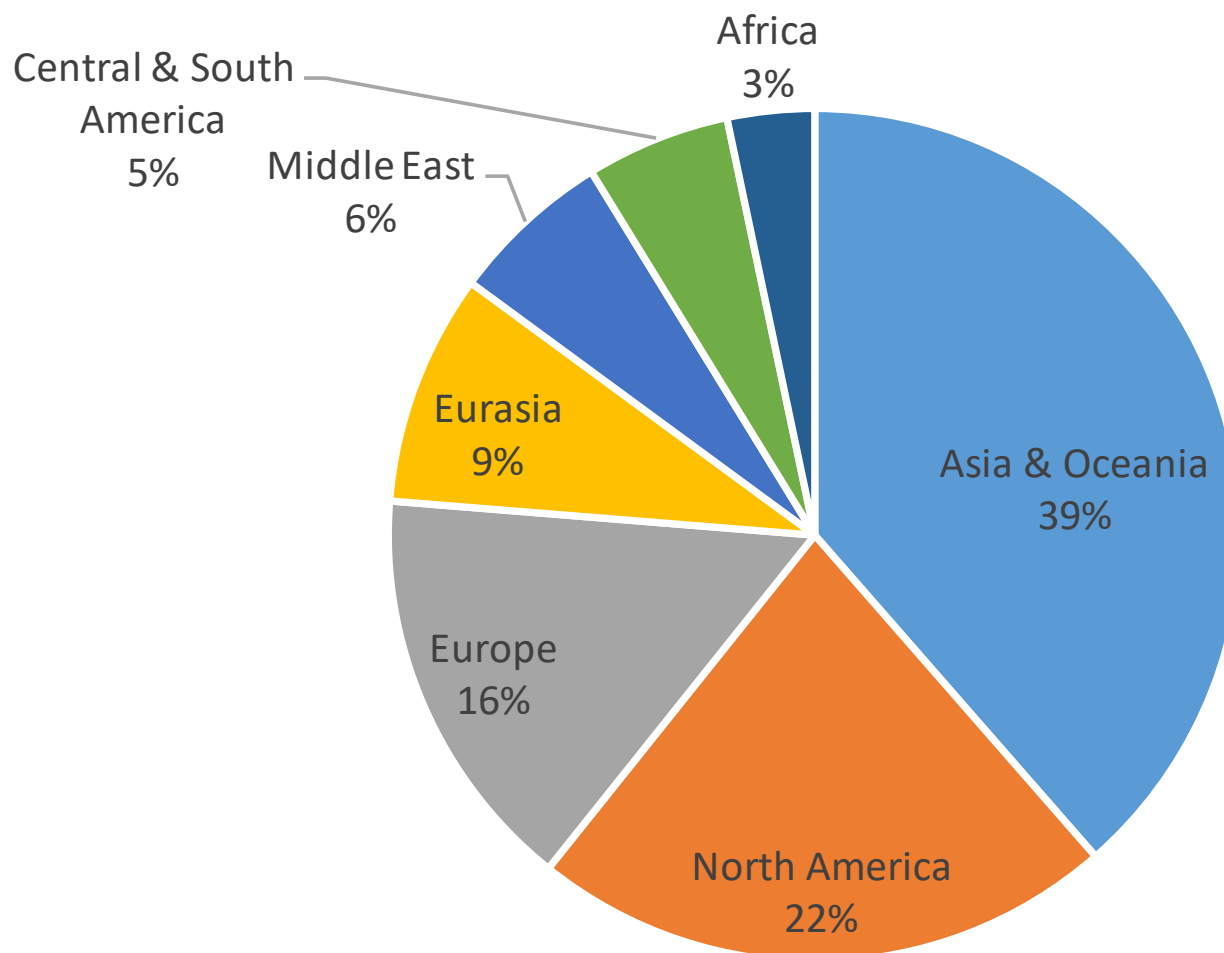
★ Fossil	3.11	
★ Oil		1.03
★ Coal		1.22
★ Gas		0.86
★ Nuclear	.19	
★ Fission		.19
★ Fusion		
★ Solar	.53	
★ Hydropower		.10
★ Biomass & wwaste		.36
★ Wind, solar		.07

Total 3.82

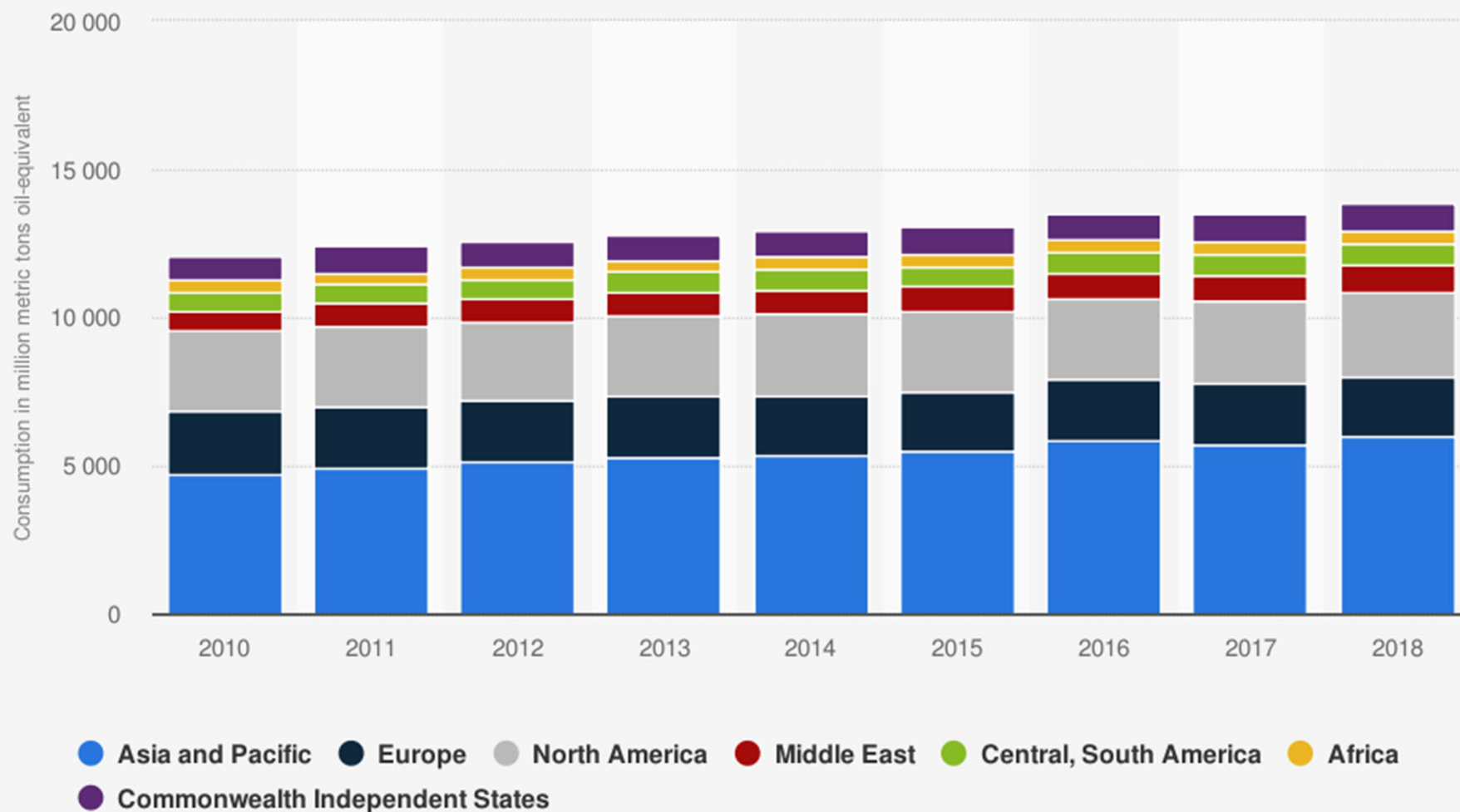
3.11 out of 3.82 cmo or 81% from fossil sources

Crane and Kinderman, 2000

World Energy Consumption 2012



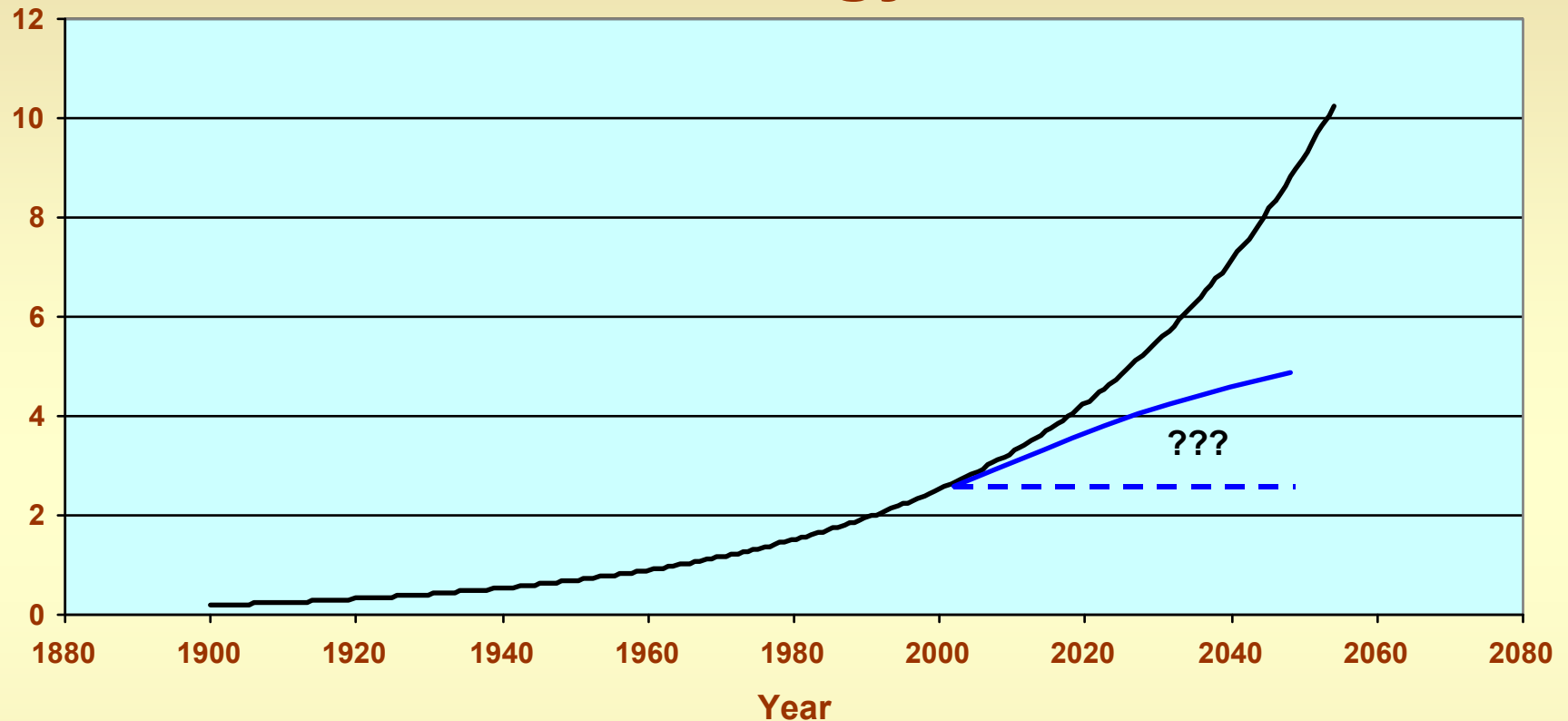
Primary energy consumption worldwide between 2010 and 2018, by region (in million metric tons oil-equivalent)



Source
BP
© Statista 2019

Additional Information:
Worldwide; 2010 to 2018

Historic Trend in Energy Use



- Doubling every 27 years
- Increases in population and living standards drive the exponential increase in energy consumption
- By 2050, the world will need between 2 and 7 additional cmo's!!!
 - ⇒ Where will this come from??

Switching to Non-Fossil Energy

- ★ What do we do?
 - ★ Hydro
 - ★ Nuclear
 - ★ Wind
 - ★ Biomass
 - ★ Photovoltaic

Let's estimate what it would take to get 1 cmo from any of these sources by 2050

Hydroelectric – to get 1 CMO



- Three Gorges Dam is 18.2 GWe
 - 9 times size of Aswan Dam
 - \$30 billion (US)
 - 15 years (1994 to 2009)
 - Displaced 1 million people from homes
- 18.2 GWe is .003 CMO!
- Need over 300 such dams to get 1 CMO!
 - By 2050, need 1 completed every 2 months

Nuclear – to get 1 CMO



- Diablo Canyon has two reactors of ~1100 MW each
 - Operating for 15 years
 - Studies on earthquake survivability
 - One of two operating nuclear plants in CA
- Provided 1.72×10^7 MW-hrs of electricity in 2003
- 0.00039 CMO
- Need over 2500 such facilities to get 1 CMO!
 - By 2050, need ~5 facilities completed every month



Wind – to get 1 CMO



- Denmark is putting 2 MW windmill/turbines into the North Sea
 - 64 m high at hub, 74 m rotor diameter (210 ft high at hub, 243 ft diameter)
- 10 turbines provided 89×10^3 MW-hrs of electricity for Copenhagen
- 2×10^{-7} CMO per windmill
- Need over 5 million such facilities to get 1 CMO!
 - By 2050, need over 300 such large windmills completed every day!
 - Problems for 2/3 of time wind is not right

Biomass – to get 1 CMO



Biomass Power Plant - Photo credit:
U.S. Department of Energy,
Energy Efficiency & Renewable
Energy Network (EREN)

- Average of 15 tons of biomass per acre per year (in U.S.)
- Average energy content of 7500 Btu/lb
 - Small power plants with low conversion efficiency (~20%)
 - Extra ~75% fossil fuel needed to convert to liquid fuels
- 1.5×10^{-9} CMO per acre (not including efficiency of conversion)
- Need over 680 million acres to get 1 CMO!
 - ~1 million square miles, or a square 1000 miles by 1000 miles
 - Impact on food prices (especially meat, wheat, etc.)



LEGEND

- ★ State Capitals
- Cities 500,000+
- Cities 100,000-499,999
- National Boundaries
- Major Rivers
- Lakes
- Toll Roads and Bridges
- Interstate Highways
- U.S. Highways

0 100 Miles
0 100 Km

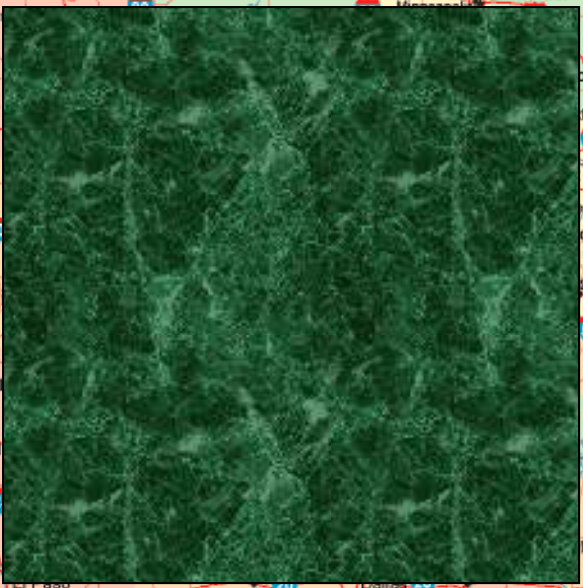
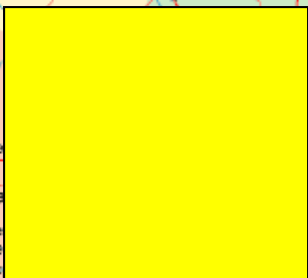
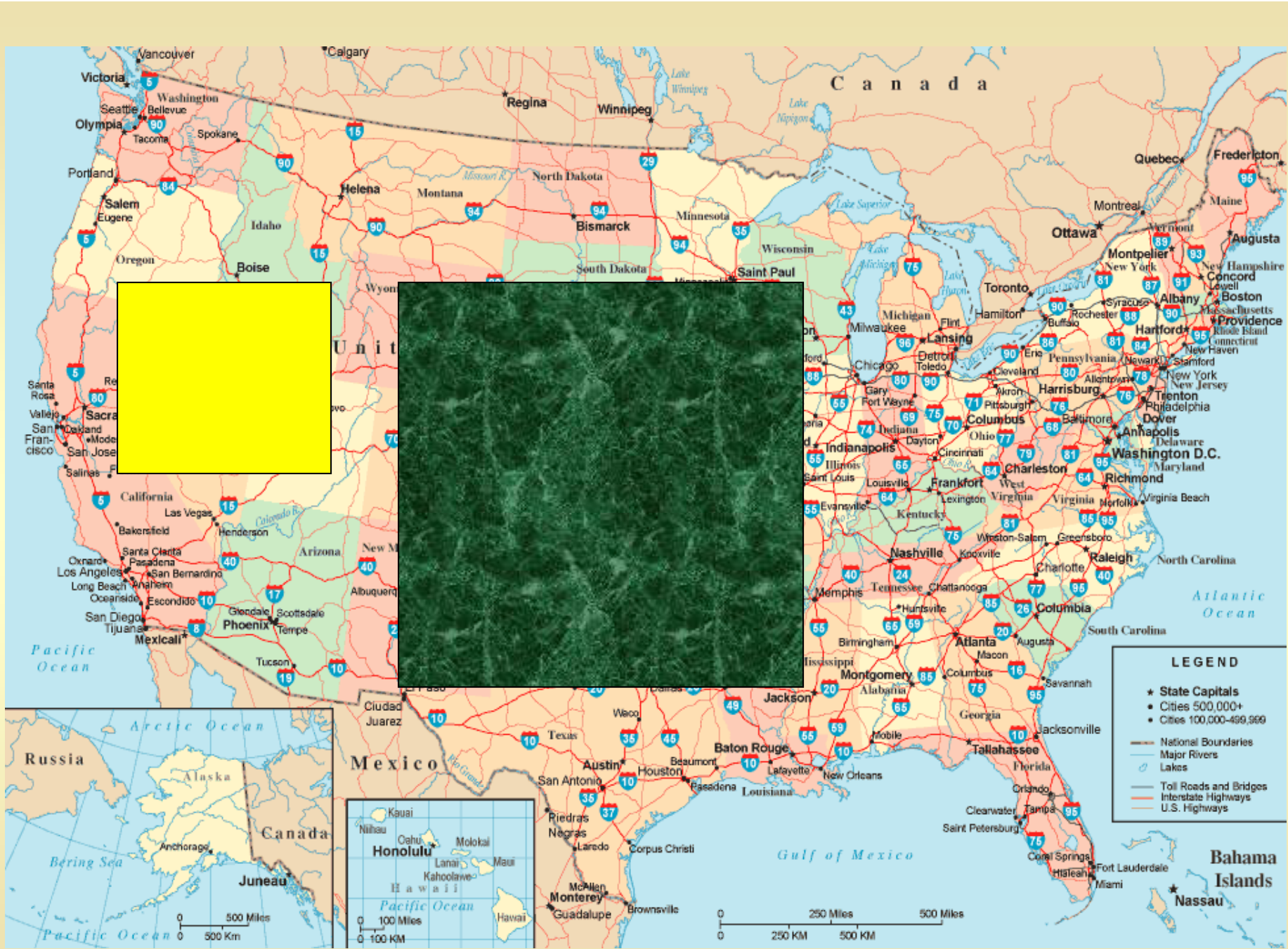
0 250 Miles 500 Miles
0 250 Km 500 Km

Photovoltaic – to get 1 CMO



- ☀ Quite expensive to get electricity
- ☀ Not bad for hot water
- ☀ Average 80 kW-hr/m² of power per year
- ☀ 1.8×10^{-12} CMO per m²
- ☀ Need over 200,000 square miles of photovoltaics to get 1 CMO!
 - ☀ A square 450 miles by 450 miles





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0 100 Miles
0 100 Km

0 250 Miles
0 250 Km





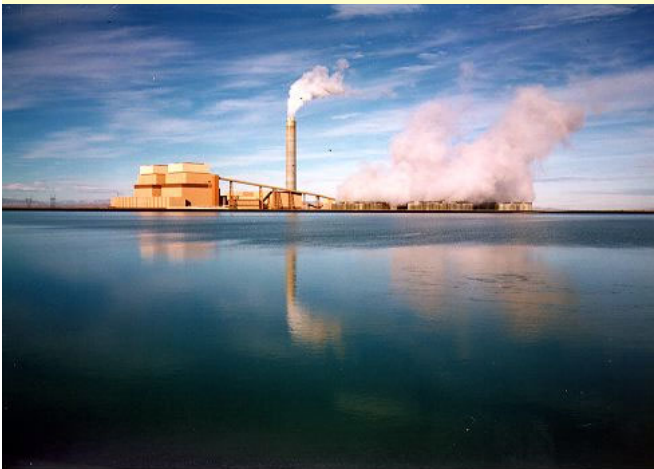
This analysis was for 1 CMO by 2050!

The world may need 2-7!

We have an enormous task ahead of us...

What about fossil fuel options?

Coal – to get to 1 CMO



- ☀ IPP plant near Delta, UT
 - ✿ Two 975 MW facilities
 - ✿ Each burns ~1 million pounds/hr of coal
 - ✿ All converted to DC power and shipped to the LA basin, then reconverted to AC power
- ☀ Assume 36% efficiency, 97% uptime
- ☀ 16.6 million MW-hrs of power per year
 - ✿ .00103 CMO/yr
- ☀ Need 968 such facilities by 2050 to get 1 CMO!
 - ✿ 19 plants per year for 50 years, or
 - ✿ 1.6 plants per month

This is why we use fossil energy!

- ★ Most projections show that the percentage of fossil fuel use will stay relatively constant
 - ✿ We still have to build a lot of facilities!
 - ✿ Rapid building in China
 - ✿ Construction prices have risen 25-30%
- ★ Increased renewables will keep pace with increased energy use and only increase slightly as a percentage of the overall energy use

What Should Be Done?

- Define goals
 - Cost?
 - Environment?
 - National security?
 - Reduce dependence on unstable/unfriendly countries?
- Continue expanding renewable energy using economic judgment
 - How much extra are people willing to pay for fossil fuel alternatives?
- Make fossil fuel use as clean and efficient as possible
 - Rise in natural gas costs -- home heating costs rise
 - Options for cleaner coal – IGCC, oxyfiring, CO₂ sequestration
 - Alternate liquid fuels – biodiesel, (ethanol), coal-to-liquids, biomass-to-liquids
- Nuclear
 - Projected fuel shortage in ~30 years without breeder technology
 - Wastes from breeder technology much smaller
 - handling large quantities of plutonium is a potential terrorist threat

What Else Should We Do?

- Don't make rash statements or decisions, such as:
 - Eliminate dependence on foreign oil
 - Stop using fossil fuel
 - Require 50% of motor fuel from renewable sources
 - Require H₂ as a fuel for a specified fraction of energy
- Continue to search for economical renewable energy
 - Criteria for use of renewables
 - Must be economic without subsidies
 - Must not increase use of fossil fuels
 - Should not increase prices of other sectors (like food)
 - Must not create additional environmental problems
 - Depleted forest area
 - Oxygen-starved area in Gulf of Mexico at mouth of Mississippi River
- Increase use of unconventional oil
 - Oil sands, oil shale, heavy oil
 - Coal conversion to liquid fuels