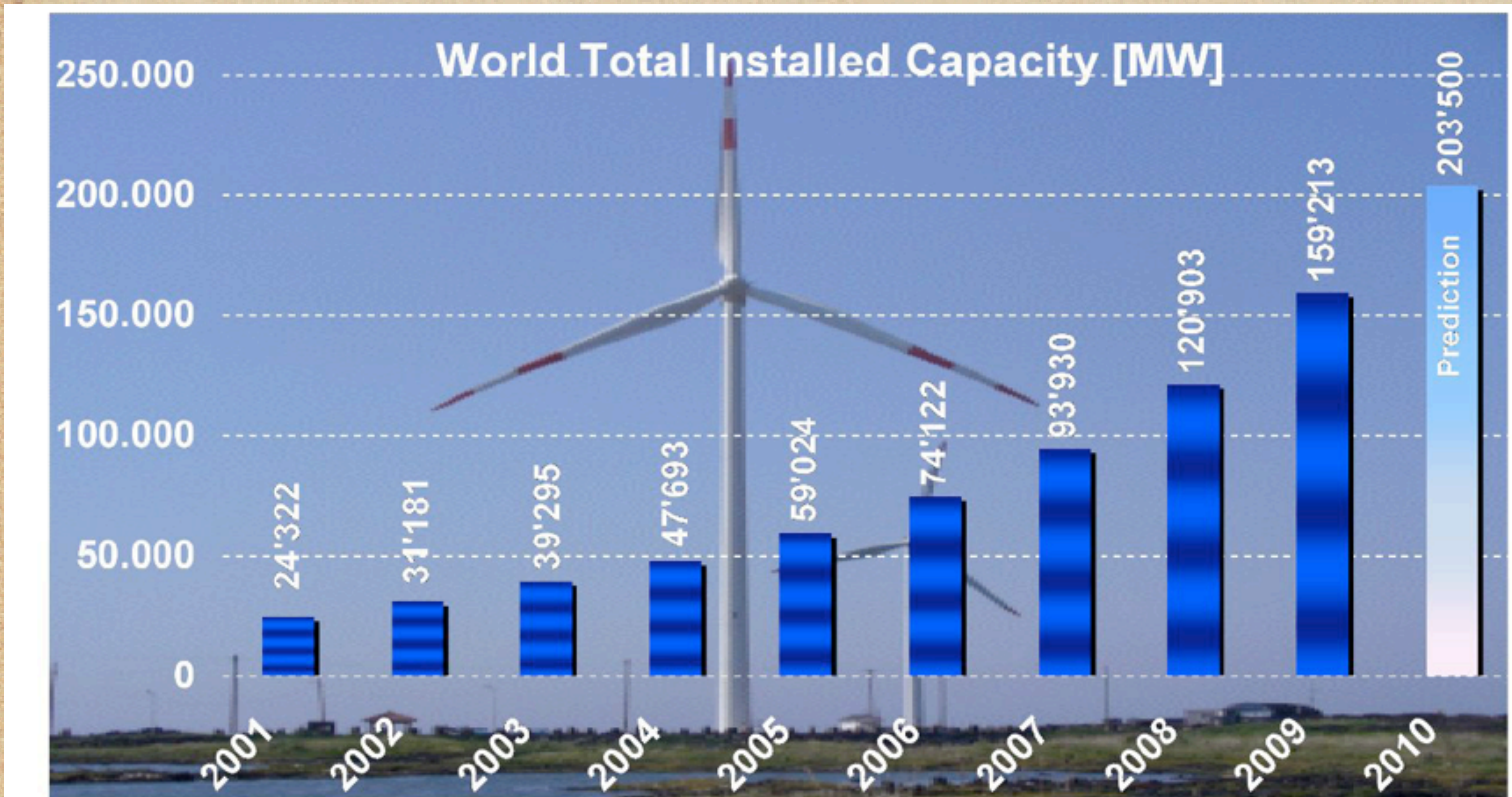
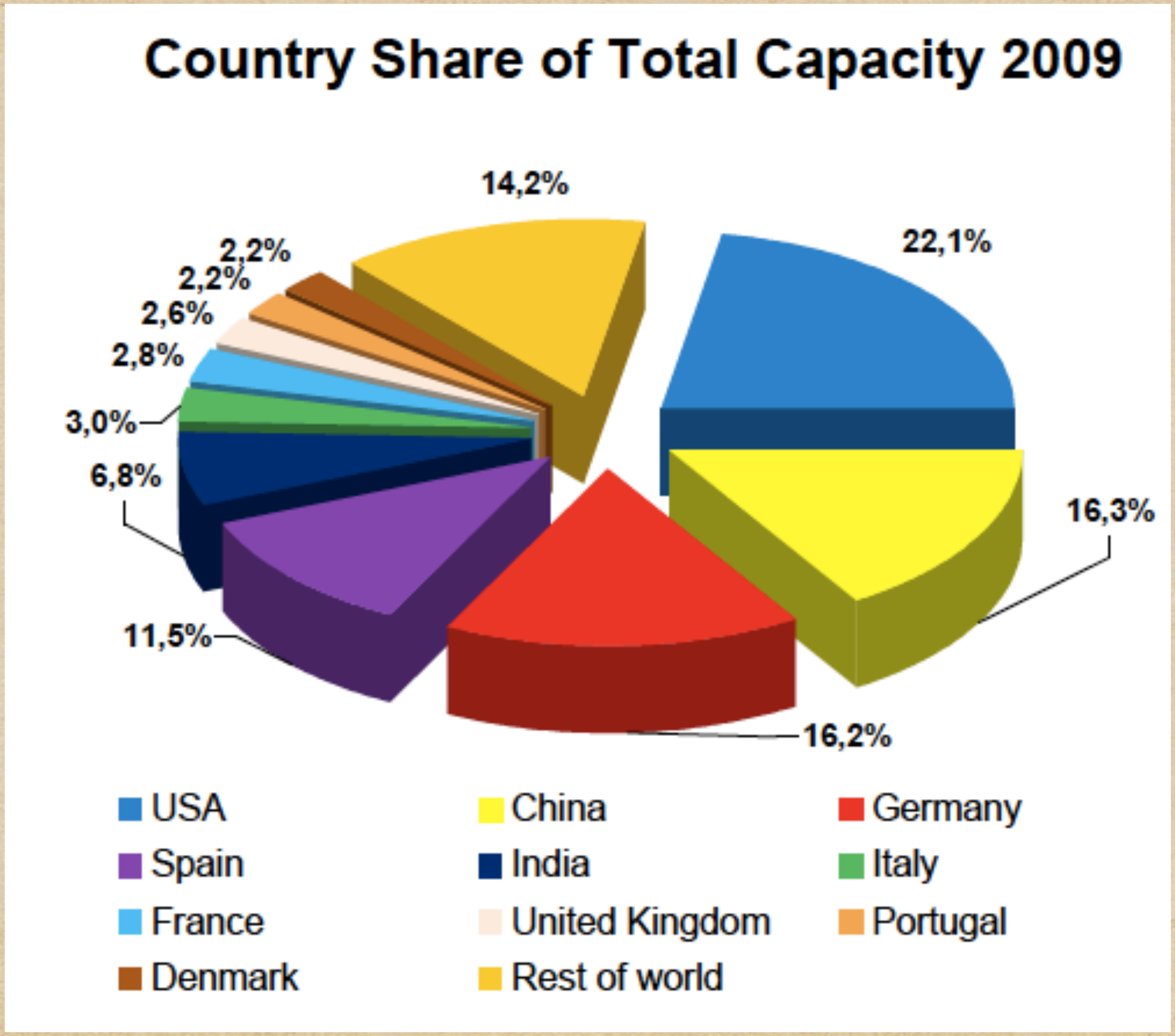
Lecture 16 May 24, 2011
Statistics of Wind power



- **The trend continued that wind capacity doubles every three years.**
- **All wind turbines installed by the end of 2009 worldwide are generating 340 TWh per annum, equivalent to the total electricity demand of Italy, the seventh largest economy of the world, and equalling 2 % of global electricity consumption.**

159213 MW x 365 x 24= 1395 TWH. Clearly we are using only 1/3rd for operational reasons.


Country Share of Total Capacity 2009
14,2%
22,1%
2,2%
2,2%
2,6%
2,8%
3,0%
6,8%
16,3%
11,5%
16,2%
USA
China
Germany
Spain
India
Italy
France
United Kingdom
Portugal
Denmark
Rest of world

Prospects for a World Powered Predominately by Solar and Wind Energy

Walter Kohn

2011

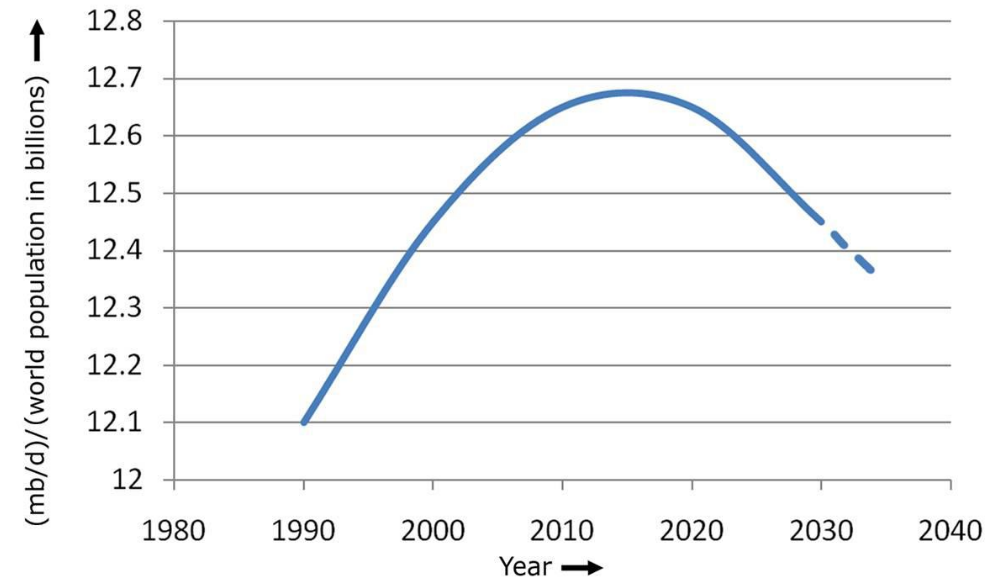
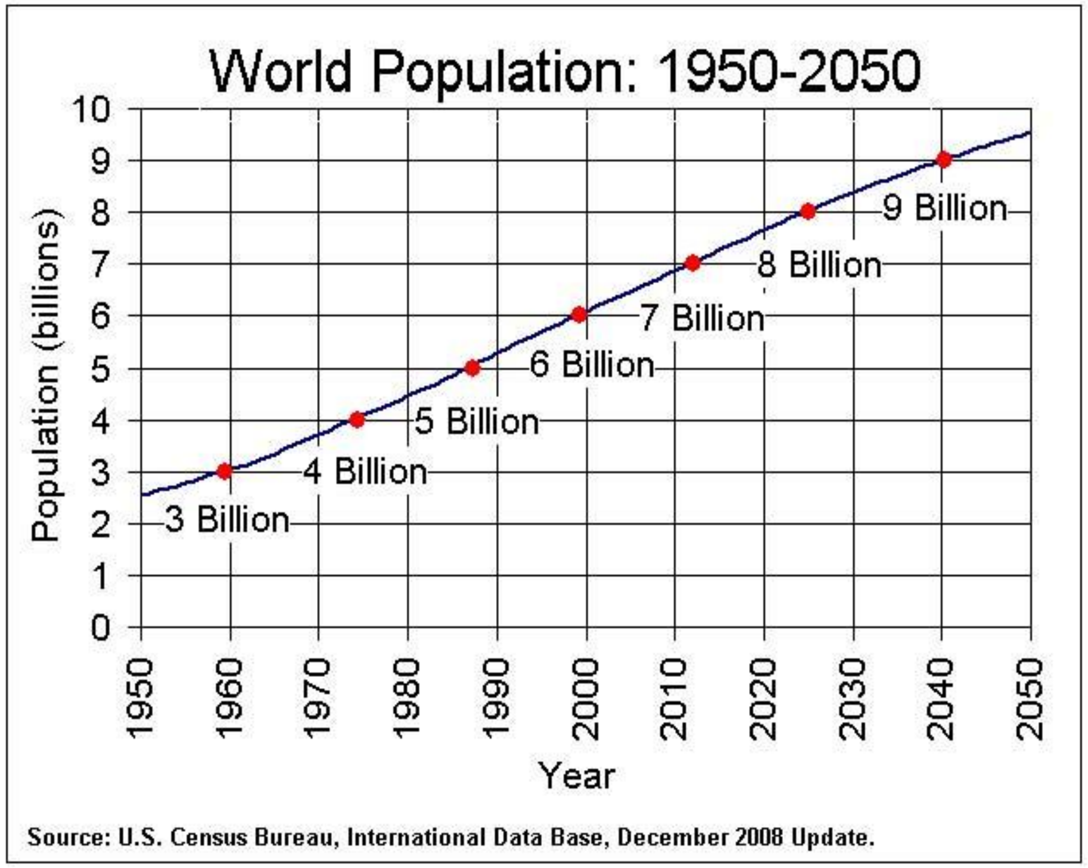


Fig. 4. Global oil production per person



"We have met the enemy and he is us"

Pogo quote of 1971

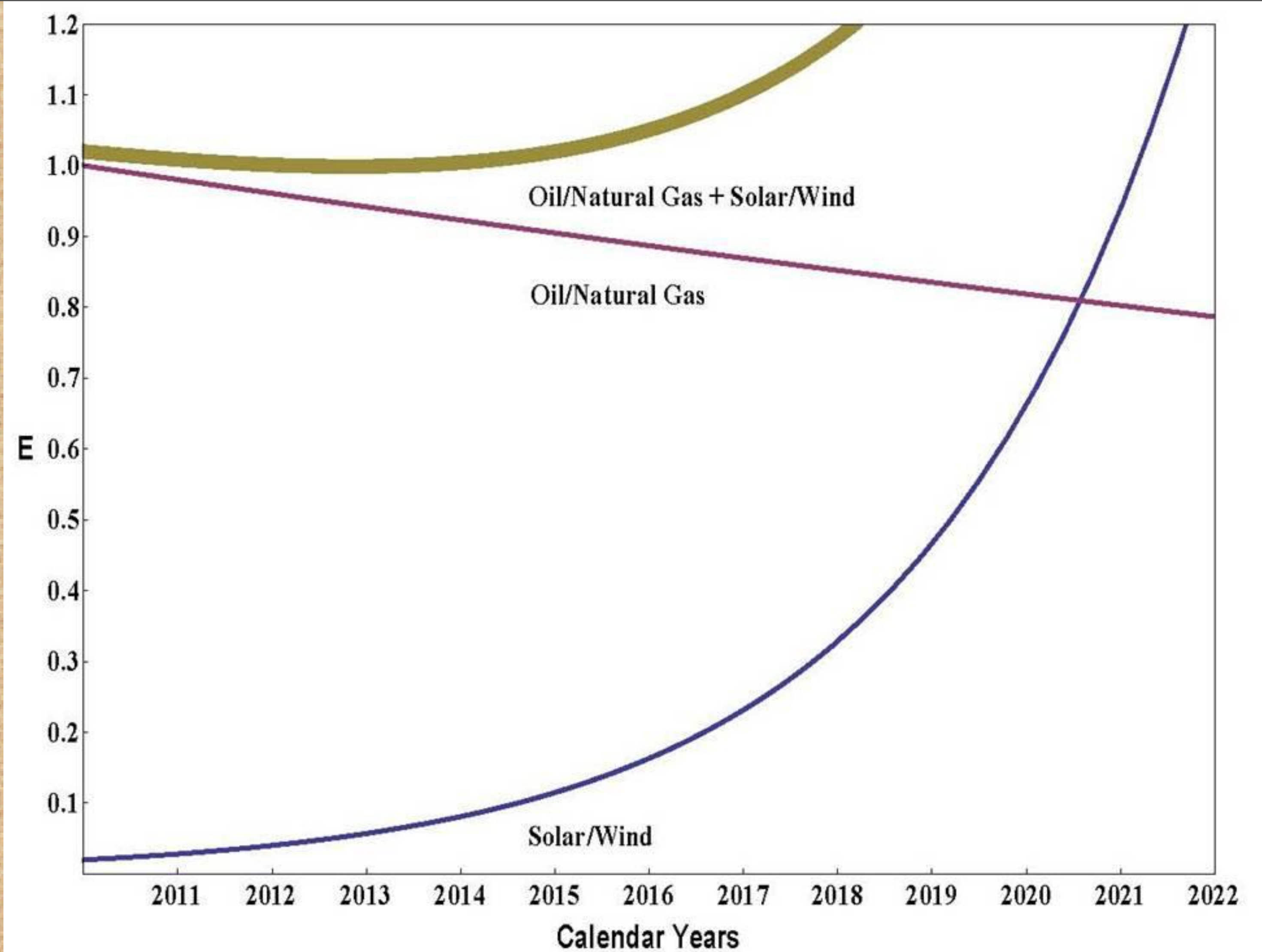


Fig. 5 The energy transition from (Oil/Natural Gas) to (Solar/Wind). We define the transition year as the year (2021) in which solar/wind energy begins to exceed oil/natural gas energy, and becomes the world's dominant energy source. E represents annual rates of energy production, in units of oil/gas production in 2010.

Comments:

1) Kohn's prediction is that 2020 will see a transition to Solar/Wind domination
2) He is predicting a 100 fold growth in the next 10 years!!
3) Can technology fulfil this Kohn's law?
4) More important perhaps than Moore's law in silicon valley.

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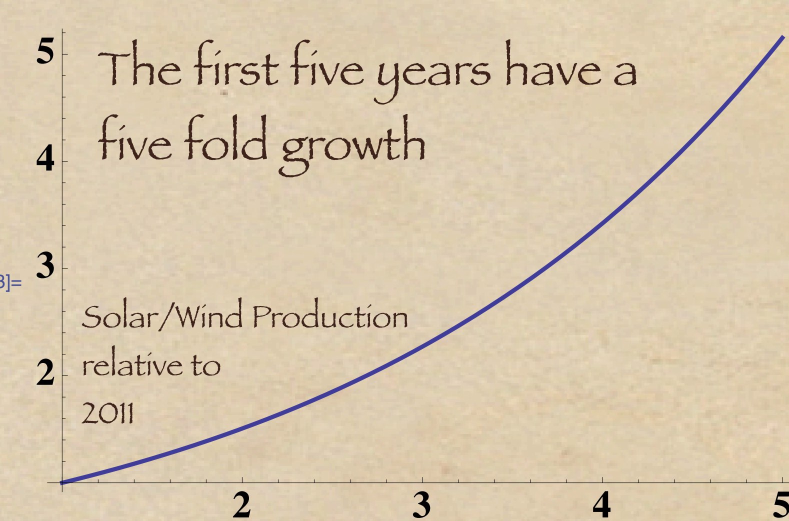
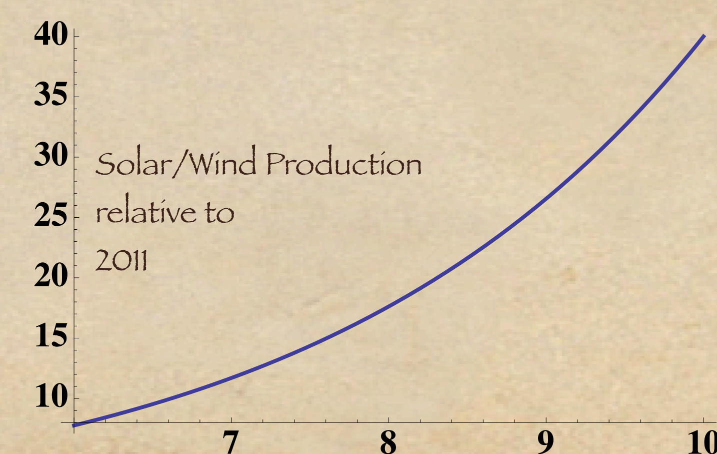
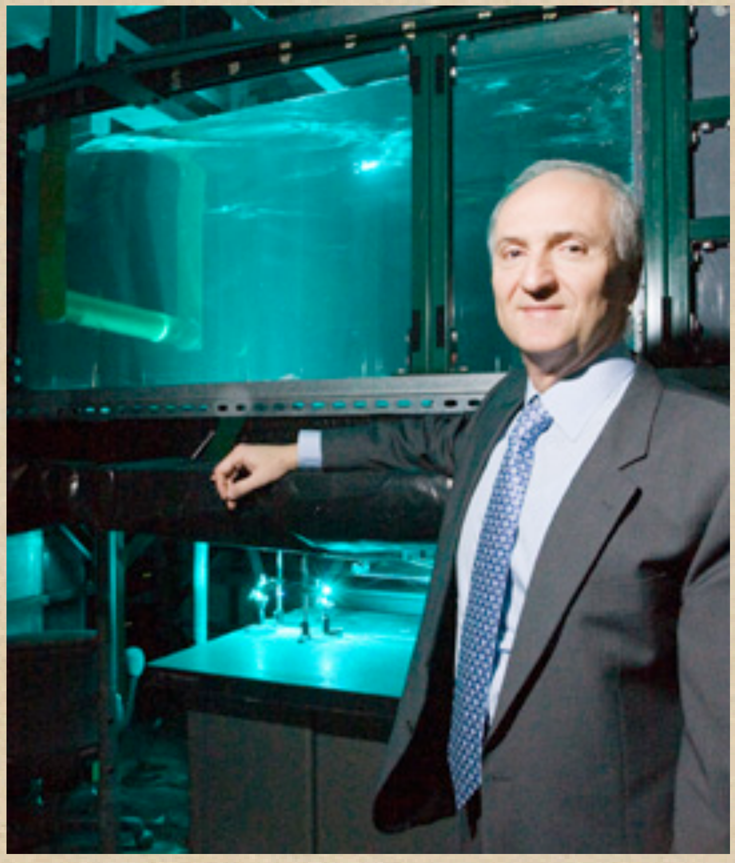




The big catchup though happens after year 6 assuming continuing exponential growth!

http://www.vortexhydroenergy.com/

Energy from waves!!!

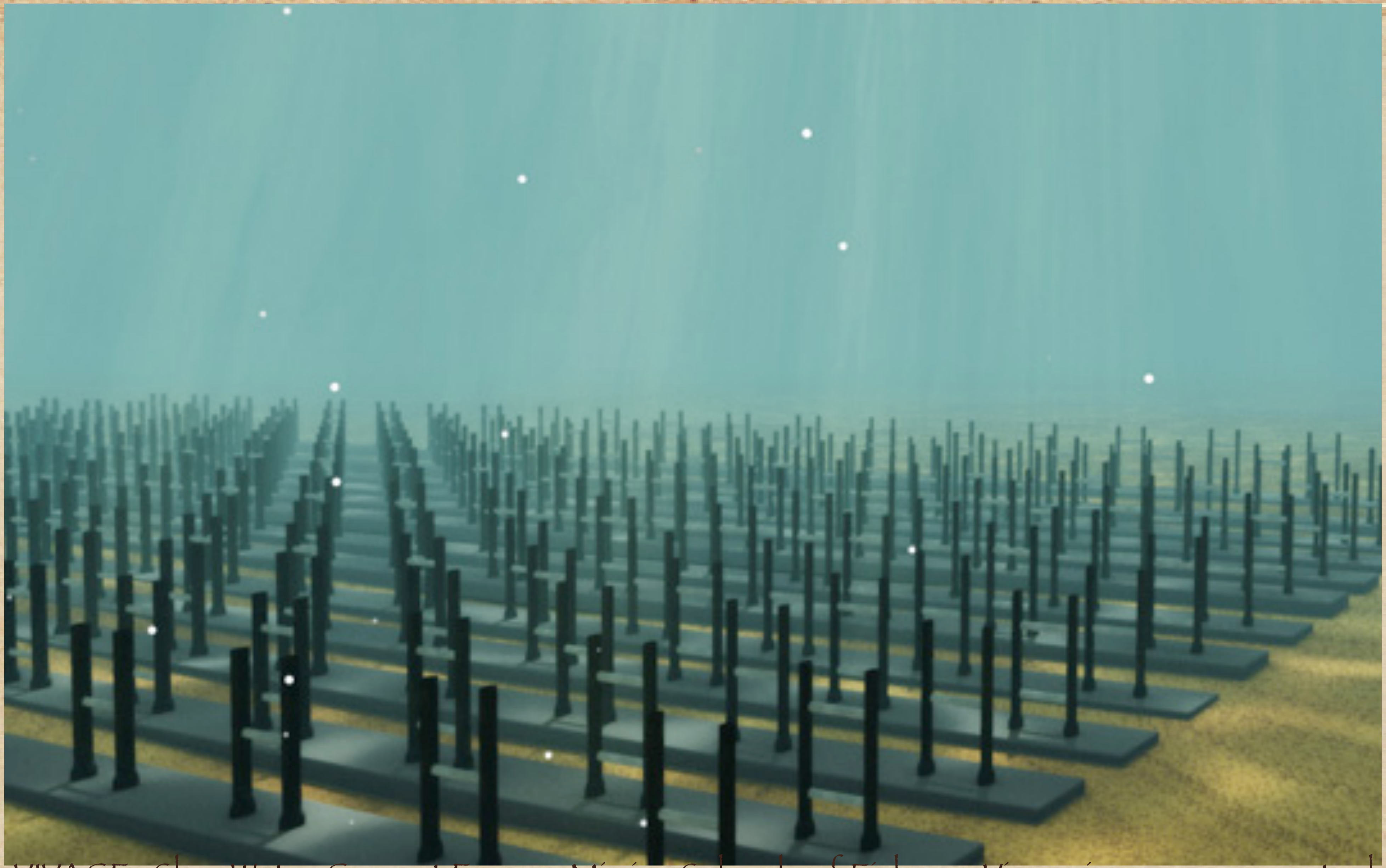


Slow-moving ocean and river currents could be a new, reliable and affordable alternative energy source. A University of Michigan engineer has made a machine that works like a fish to turn potentially destructive vibrations in fluid flows into clean, renewable power.

The machine is called VIVACE. A paper on it is published in the current issue of the quarterly Journal of Offshore Mechanics and Arctic Engineering

VIVACE is the first known device that could harness energy from most of the water currents around the globe because it works in flows moving slower than 2 knots (about 2 miles per hour.) Most of the Earth's currents are slower than 3 knots. Turbines and water mills need an average of 5 or 6 knots to operate efficiently.

VIVACE stands for Vortex Induced Vibrations for Aquatic Clean Energy. It doesn't depend on waves, tides, turbines or dams. It's a unique hydrokinetic energy system that relies on "vortex induced vibrations."



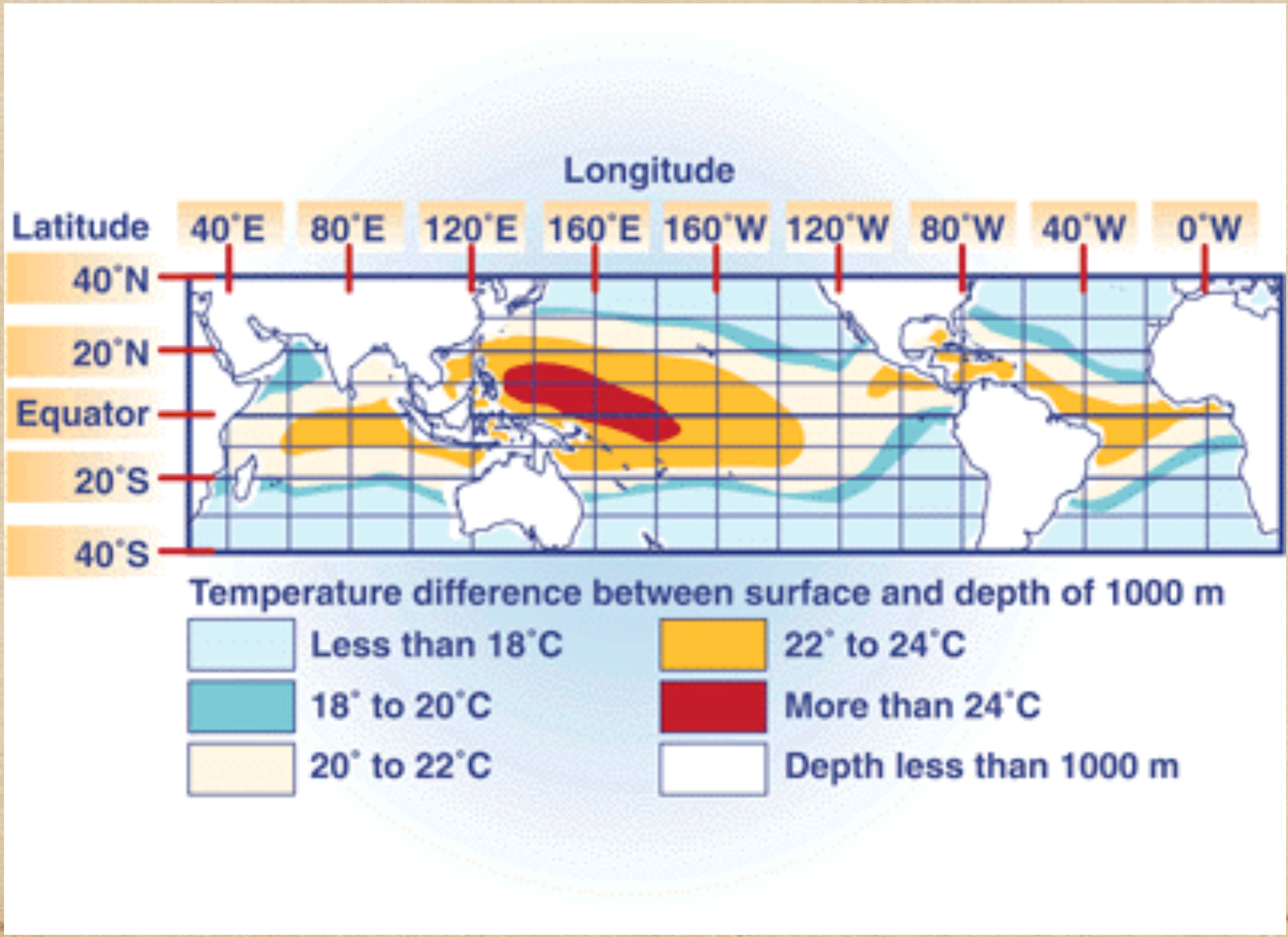
VIVACE: Slow Water Current Energy Mimics Schools of Fish: Vivace is a new energy technology that gets its name from a phenomenon that engineers have been battling for 25 years.

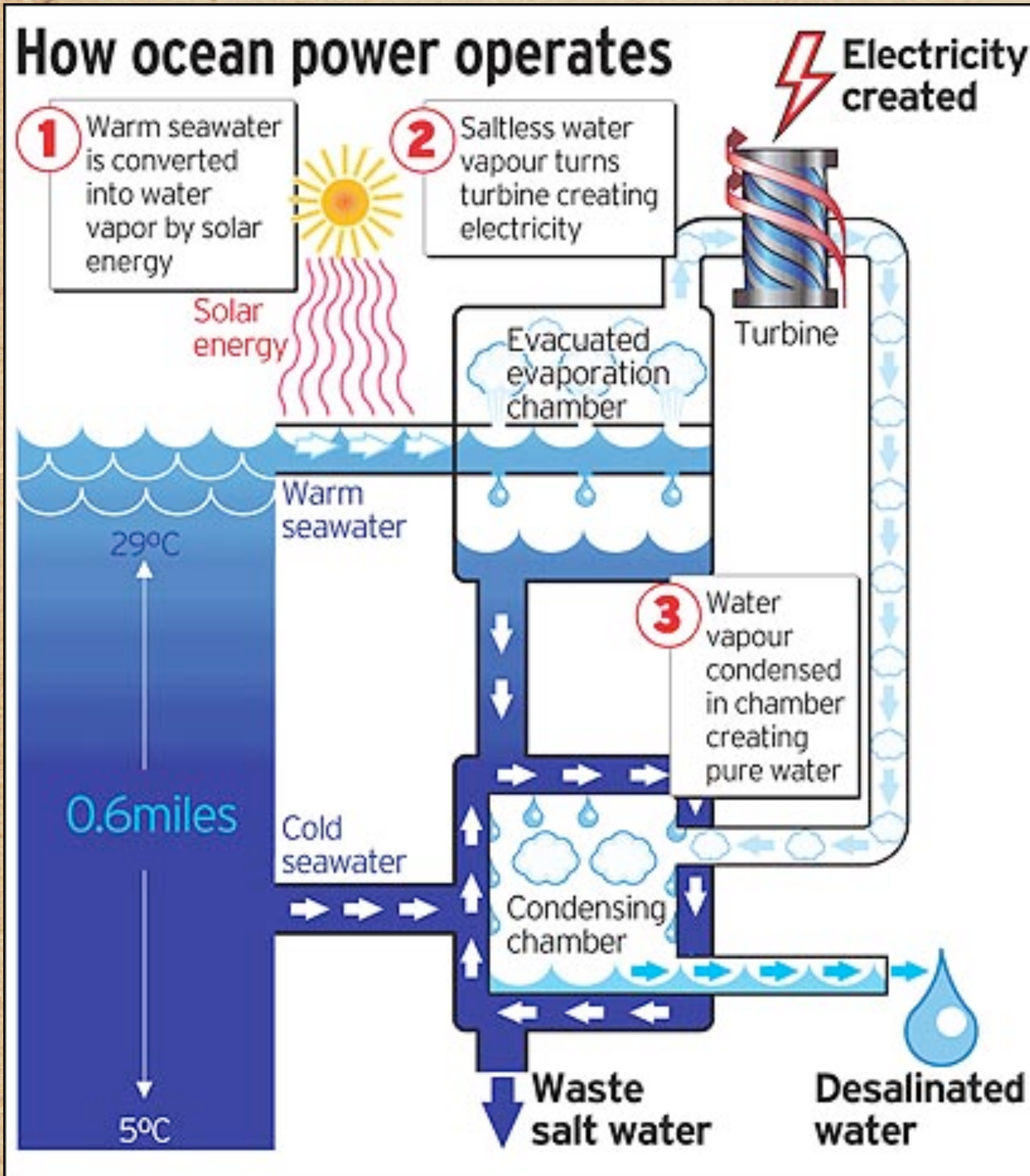
VIV (vortex induced vibrations) destroyed the Narrows Bridge in Washington State in 1940, and the Ferrybridge power station cooling towers in England in 1965.

Ironically it is also the same phenomenon that allows schools of fish to swim as fast as they do. Now Dr. Michael M. Bernitsas and researchers at the University of Michigan are turning this 'threat' into a resource. Rather than suppressing VIV, Vivace actually creates and then harvests energy from VIV, and it does it all using slow water currents, a previously untapped source of sustainable energy.

OTEC
Ocean Thermal Energy Conversion

Water at surface is much warmer than water at 1000m depth. Can we use the temperature gradient of 20°C?





$$\eta = \frac{T_H - T_C}{T_H}$$

$$\eta = \frac{15}{300} \sim 5\%$$

If we cool 1000 gallons of water by 2ºC, the power generated is 32 MW.
At 5% efficiency this gives 1.6 MW output as usable power.

Offshore plants could produce Hydrogen that can be transported by ships..

Not a big player as yet, and rather cool response in US to this technology.

Lecture 16

Continued

May 24, 2011

Biofuels/Biomass

Motivation

All of a sudden, you know, we may be in the energy business by being able to grow grass on the ranch! And have it harvested and converted into energy! That's what's close to happening.

GWB: Feb 2006

Ford T was built to run on either ethanol or petrol!!
And then we discovered the middle eastern oil fields!

Photosynthesis

Biomass

- 5 billion yrs ago, the atmosphere had H_2, He, N, CO_2, NH_3 and water but no oxygen
- 3 billion years ago we had oxygen and plant life, H_2, He escaped the earth.
- Photosynthesis is key, anaerobic processes (no Oxygen required) created carbohydrates

$C_x(H_2O)_y$ are carbohydrates, e.g. $C_6H_{12}O_6$ fructose

Light= ENERGY

$$6\ CO_2 + 6H_2O + 674\ \text{kcal} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Glucose

We may thus think of carbohydrate production by sunlight through this reaction.

A rough rule:

4300 cal energy needed to grow a gram of carb.

A mole is a gram molecular weight:
e.g. O_2 mole has 32 gms H_2 mole has 2 gms
CH_2O mole has 30 gms
(C=12,H=1,O=16 total 30)

Respiration: opposite of PS

$$Carbodydrate + O_2 \rightarrow Energy\ (ATP)$$

Rate of carbohydrate production, agriculture, grains -> Alcohol-> Gasohol

We can say something quantitative about the total agricultural production on the basis of the solar constant!

$$Solar\ constant = 0.5cal/min/cm^2$$
$$47\%\ reaches\ earth$$
$$\sim 500cal/(cm^2 \cdot day)$$

$$\sim 500 cal/(cm^2 \cdot day)$$
$$25\%\ correct\ wavelength\ for\ PS$$
$$70\%\ absorption\ by\ foliage$$
$$35\%\ light\ useful\ for\ PS$$
$$\sim 6\%\ of\ total$$
$$\sim 30\ cal/(cm^2 \cdot day)$$

Convert cal to grams using a rough rule:
4300 cal per gram of carb giving
75 gm/(m^2 x day)

Experimentally one finds about 70 gm/(m^2 . day) of grain production averaged over many species

This comes out as ~5% of total energy, pretty close to our estimate of 6%!!

- Hubbert's data says total solar power available for PS is 40 TW.
- We can calculate the total potential production from this as 8×10^{16} gm/year on earth.

$$15\ tons/(acre \cdot year) \times 350 \times 10^6\ acres\ = 5.25 \times 10^9 Tons/year$$
$$at\ 4300\ (cal/gm) \sim 79 \times 10^{15} BTU$$

$$79 Quadrillion BTU\ versus\ 98 QBTU\ used!!$$

Gasohol: 10% ethanol + petrol. Good for combustion efficiency and is promising.

Nuclear Energy

- Vast possibilities
- Much worry about safety, partly based on experience
- Further ideas for safer harvesting
- Need to know the basics:

$$^{236}_{92}U \rightarrow ^{90}_{36} Kr + ^{143}_{56} Ba + 3n + \ 199 Mev$$

Fission reaction: Need to understand the symbols and concepts.

General name	name	Charge	Mass	Mass x c^2 $E = m\ c^2$
Nucleon Strongly interaction (Hadrons)	proton	+e	1.007 u	983 Mev
	neutron	0	1.008 u	984 Mev
Leptons	electron	-e	.00054 u	
	neutrino	0	~small	

$c = 3 \times 10^8\ m/sec$

u=1.66x10 $^{-27}$ kG

$$1MeV = 10^6\ eV\ = 1.6 \times 10^{-13} J$$

Nucleus

A nucleus consists of Z protons and N neutrons.
Its mass is close to (but not exactly) (A+Z) u.
Their nomenclature is as follows:

$^{A}_{Z}(\text{Symbol})_{N}$

or sometimes simply as

$^{A}_{Z}(\text{Symbol})$

Nomenclature:
A= Mass number
Z= Atomic (or proton) number
N= Neutron number

(Thanks for correction in class today)

Example of abundant oxygen

$^{16}_{8}O_8$ or more simply $^{16}_{8}O$

In nature we also find other "isotopes" of Oxygen

$^{17}_{8}O_9$

$^{18}_{8}O_{10}$

$^{14}_{6}C_8$

A few important nucleii, and their isotopes

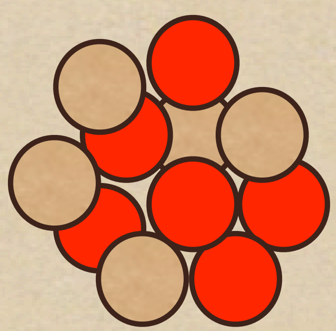
$Hydrogen\ {}^1_1H$ Stable hydrogen

$Deuterium\ {}^2_1H$ Stable heavy hydrogen

$Tritium\ {}^3_1H\ \ halflife =\ 12\ years$

Helium	$^{4}_{2}He$ $^{3}_{2}He$	
Carbon	$^{12}_{6}C$ $^{14}_{6}C$	~ 5600 yrs
Uranium	$^{238}_{92}U$ $^{235}_{92}U$	
Plutonium	$^{244}_{94}Pu$ $^{239}_{94}Pu$	

Radius of a nucleus ~ 10^{-15} m, i.e. a fermi



Strong interaction forces bind the nucleons together, overcoming their Coulomb repulsion by an even stronger attraction.

Binding energy and mass defect.

The reason a nucleus is stable is due to the binding energy. We can say:

$E_{nucleus} = E_{nucleons} - E_{Binding}$

or

$E_{Binding} = E_{nucleons} - E_{nucleus}$

$M_{defect} = E_{Binding} / C^2$