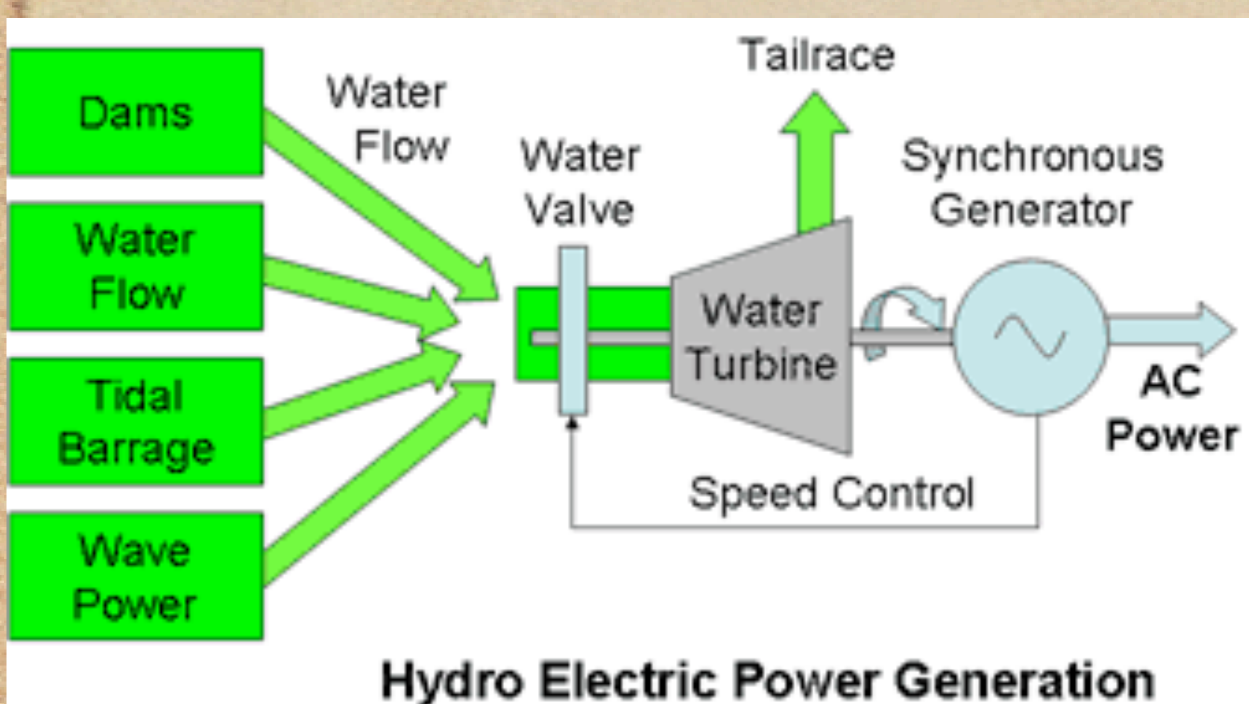
Lecture 23

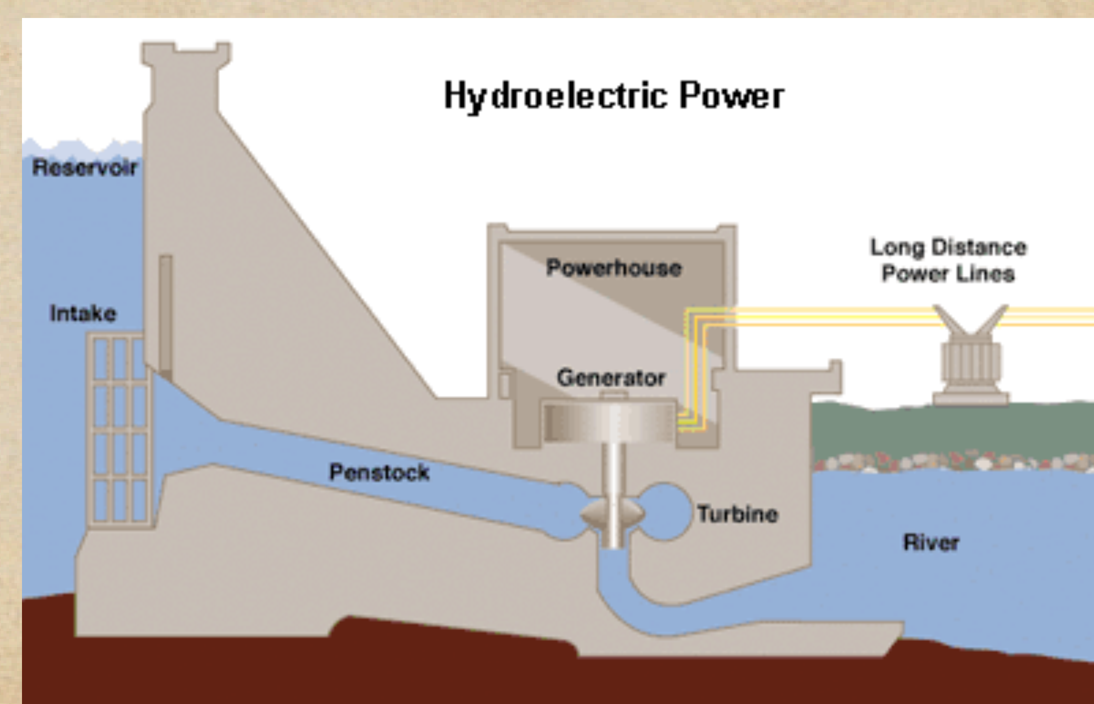
May 25, 2012

Hydro-electric power, using the potential energy of rivers, now supplies 17.5% of the world's electricity (99% in Norway, 57% in Canada, 55% in Switzerland, 40% in Sweden, 7% in USA).

Apart from a few countries with an abundance of it, hydro capacity is normally applied to peak-load demand, because it is so readily stopped and started.

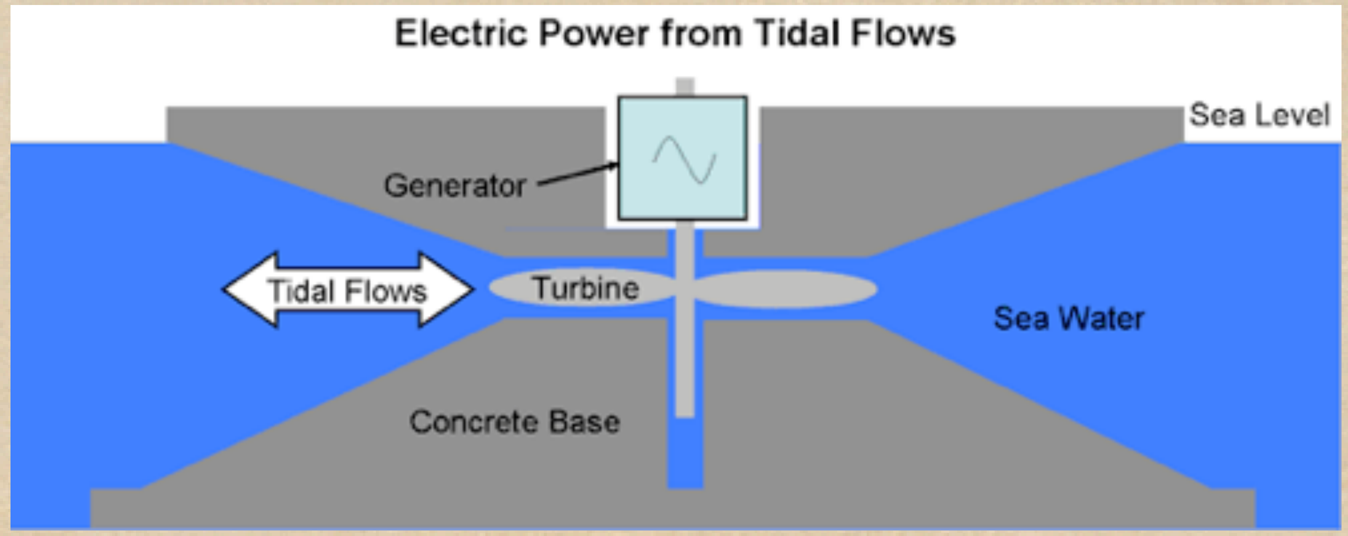
China is expected to grow in this sector.





Harnessing the power of the tides can be achieved by placing bi-directional turbines in the path of the tidal water flow in bays and river estuaries. To be viable, it needs a large tidal range and involves creating a barrier across the bay or estuary to funnel the water through the turbines as the tide comes in and goes out.

Although tidal energy captured in tidal ponds have been used since Roman times to power mills, there are few modern installations. The first plant to utilise tidal energy on a large scale for electricity generation was built at Rance in France in1966. Others followed in Canada and Russia.



The conversion efficiency of a hydroelectric power plant depends mainly on the type of water turbine employed and can be as high as 95% for large installations. Smaller plants with output powers less than 5 MW may have efficiencies between 80 and 85 %.

It is however difficult to extract power from low flow rates.

$$E = Mgh$$
$$g = 9.8 \text{ meter/sec}^2$$

Let x liters of water flow per second.
Hence mass flow is x kg/sec (using density of water - d =1 kg/Liter)
Power = energy /time = M gh/t = (M/t) g h

Head= "h" the height of water

Potential energy of water

$$P = x \times 9.8 \times h$$

x is in litres per sec
h is in meters
P is in watts

River discharge rates:

Amazon = 219 Million Litres/sec

= 219,000 m^3 /sec ($1\ m^3 = 10^3$ L)

Ganges = 42 Mil L /sec

St Lawrence = 10 M L/s

Ohio - Missisippi = 8 ML/s

Problem:

If we can drop the Ohio river by 10 meters, what is the generated power?

$$Power = 8 \times 10^6\ (kg/sec)\ \times 9.8 \times (m/sec^2)\ \times 10(m)$$
$$= 0.8 \times 10^9\ Watts$$

$$Total\ energy\ per\ year = Power \times 365 \times 24\ Watt\ hour$$

$$Total\ energy\ per\ year = 5.6\ TeraWatt\ hour$$

Annual energy generated ~ 4000 TWH

Usually capacities are Gigawatts: (1 Gigawatt= 1000 MW and gives ~ 5.5 TWH in a year)

Grand Coulee	Columbia	7100 MW
John Day	Columbia	2500
Moses-Niagara	St. Lawrence	2160
Hoover	Colorado	2080

Total capacity ~ 80 Giga Watts

Total energy from hydroelectric in US 3000 TWH each year
This is ~10% of total power used in USA ~30 000 TWH each year

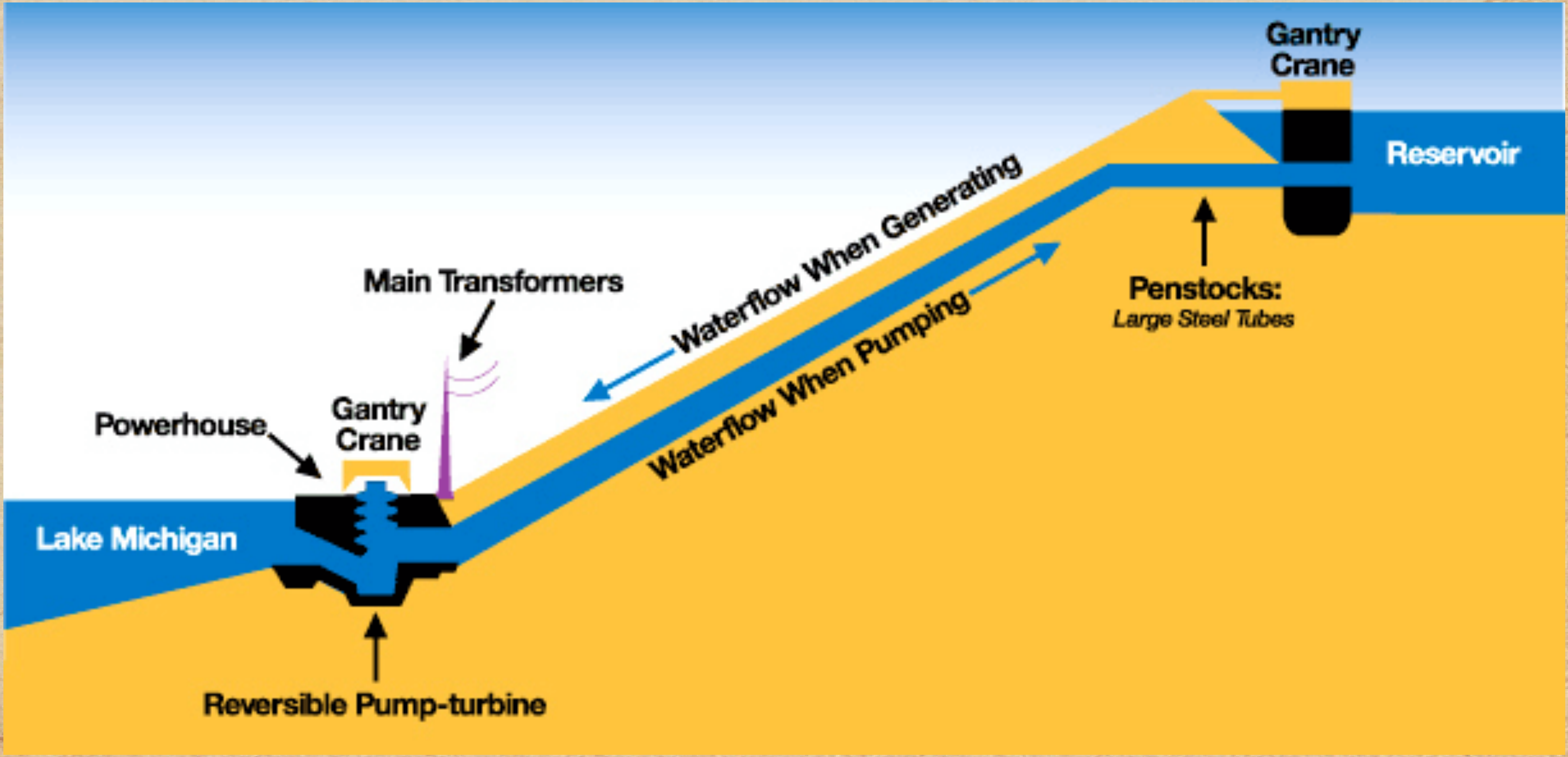
+ves:
- Efficiency
- Water storage
- Recreational :-)
- Pollution free
- Lots of it in certain countries (Nepal 80% !!)

-ves:
- Dam failures catastrophic
- Silting by rivers
- Small dams are not viable with scale,
- Maintenance issues
- Wild and scenic rivers act, and disturbance of wild life/fish

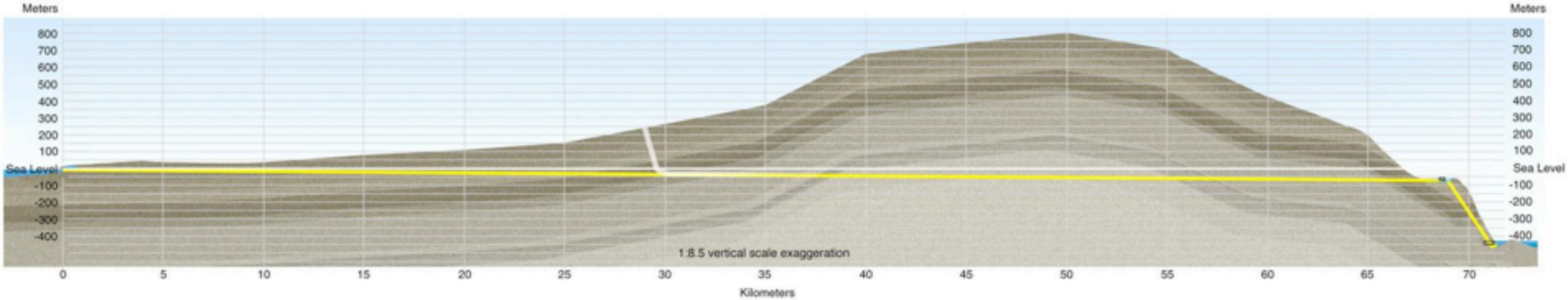
Pumped storage systems:
In tandem with coal plants

Coal fired thermal plants run best continuously, but demand is not uniform
In low usage periods, pump up water in reservoirs.
Grand Coulee dam
Ludington Michigan

Ludington Pumped Storage has a capacity of 1,872 megawatts.

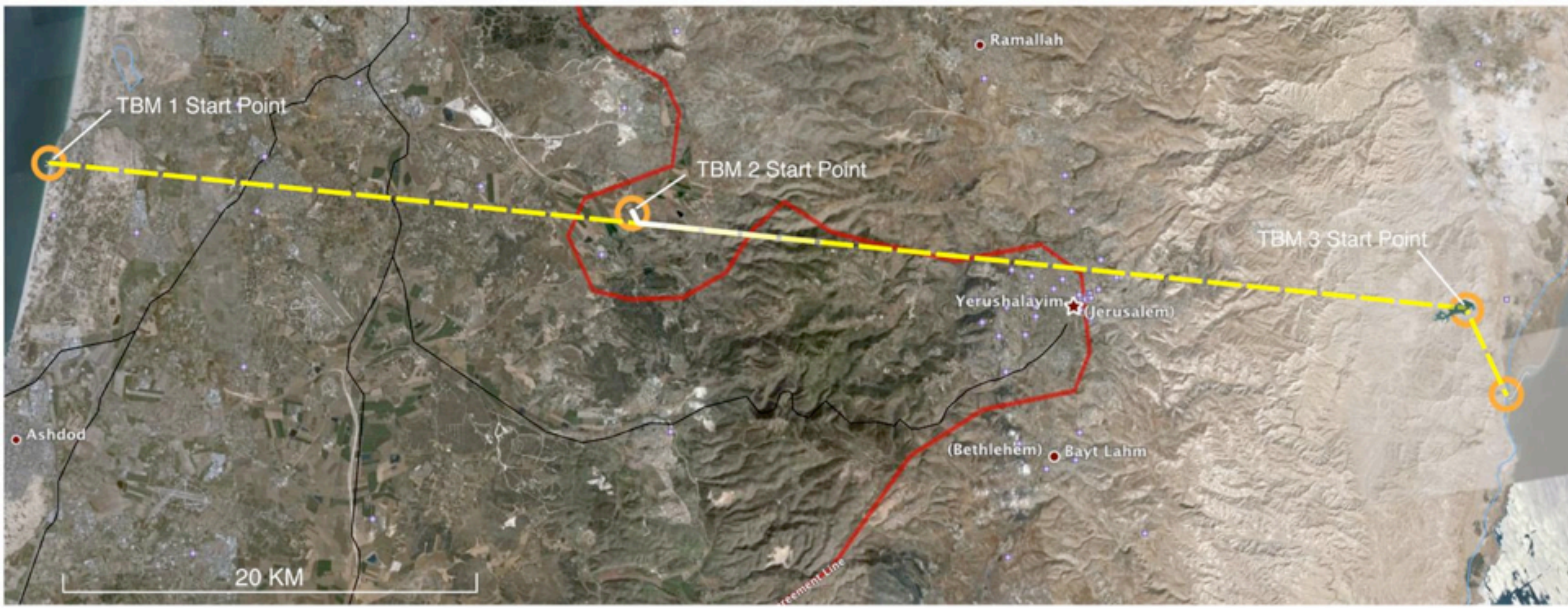


Dead Sea Power Project Overview



Tunnel and Penstock Profile

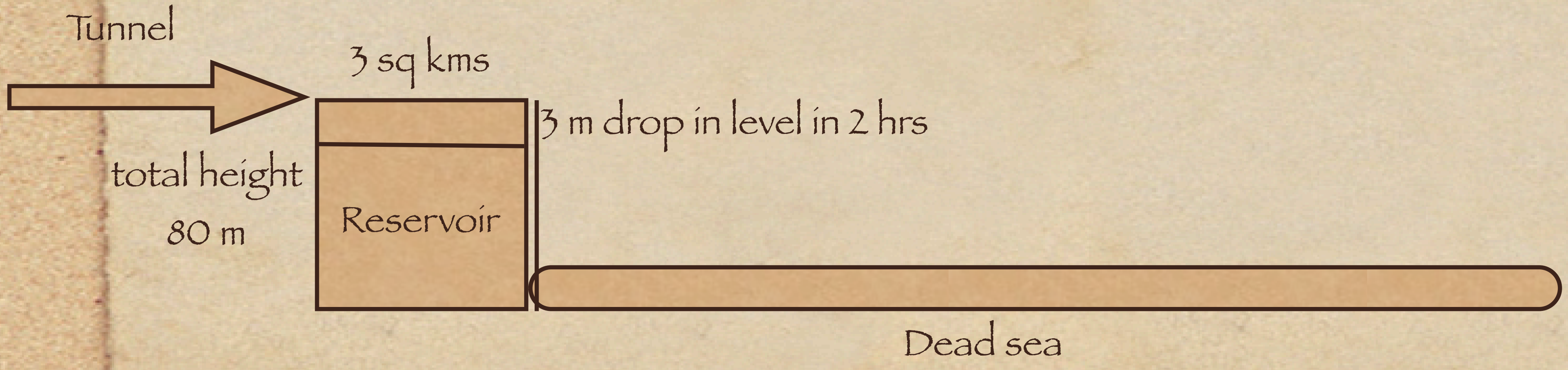
Dead Sea Power Project Overview

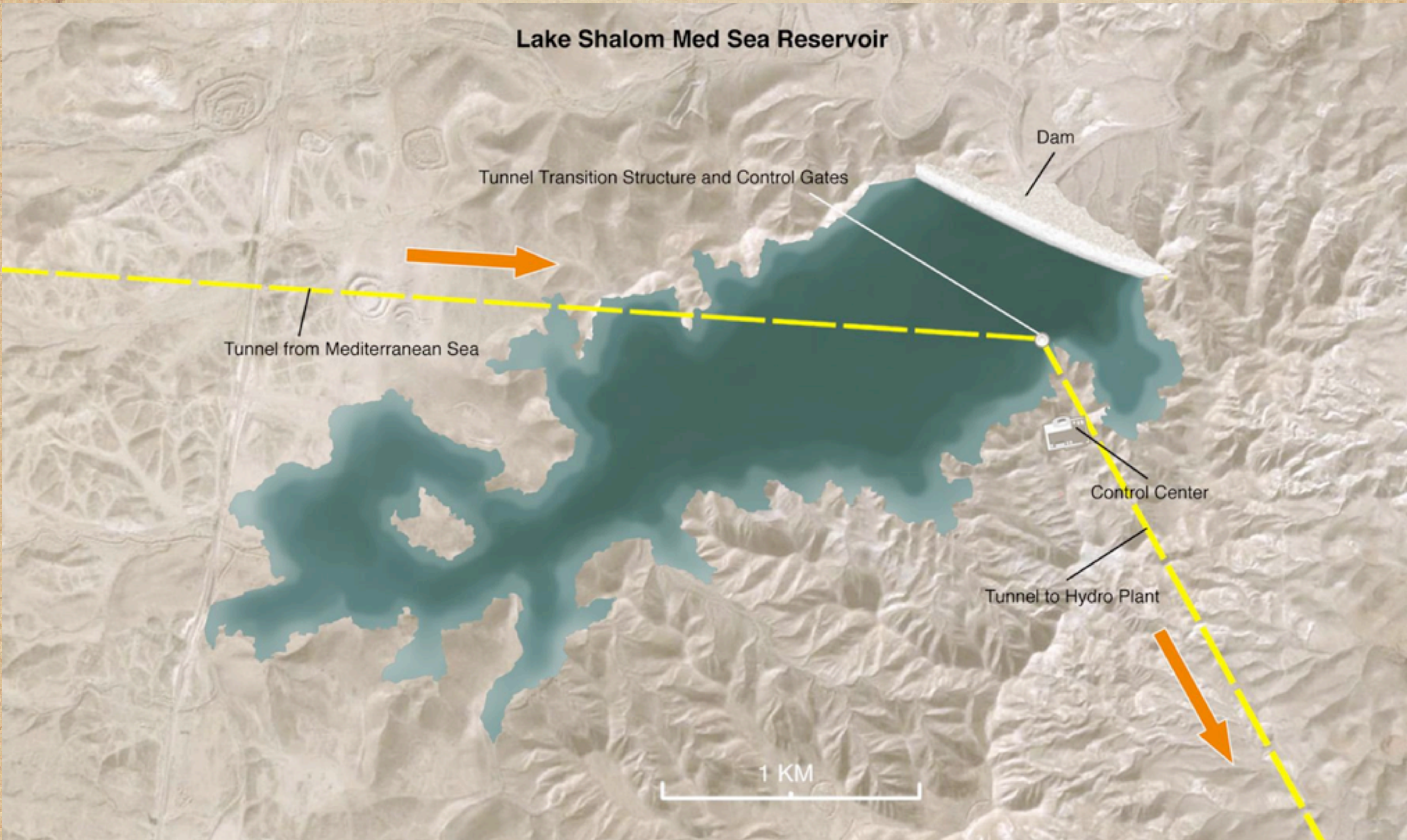


Tunnel Route

From Reservoir to the Dead Sea: The penstock from the reservoir to the Dead sea will be designed to provide enough flow to power 2500 megawatt hydro turbine generator capacity. The power plant can be designed to start at 1800 megawatts and expand to meet increasing demand.

Lake Shalom (Salaam/Peace): The storage reservoir for the tunnel flow will be located in a natural basin on the south branch of Wadi Qumran, by construction of an earthquake resistant dam utilizing spoil from the tunnel boring. The lake will have a surface area of about 3 square kilometers and maximum depth at the dam of 80 meters. Flow from the tunnel will be stored in this reservoir. When the water is released daily during hours of peak demand, the surface elevation will decline about three meters.




Lake Shalom Med Sea Reservoir
Dam
Tunnel Transition Structure and Control Gates
Tunnel from Mediterranean Sea
Control Center
Tunnel to Hydro Plant
1 KM

Let us check these numbers: 2500 MW requires how many litres per second?

Power rating implies thus. Let the draining rate be "x" kg/sec i.e. "x" liter/sec

$$x \times 9.8\ meters/second^2 \times 80 meters = x \times 784\ watts = 2500 \times 10^6\ watts$$

Require x= 3.18 Million Litres/second

3 square kilometers draining by 3 meters in 1 hour gives a rate of:

$$volume\ of\ discharge = 3 \times 1000 \times 1000\ meters^2 \times 3 meters = 9 \times 10^{63} = 9 \times 10^9 litres$$

If this discharge happens in one hour (3600 sec) then

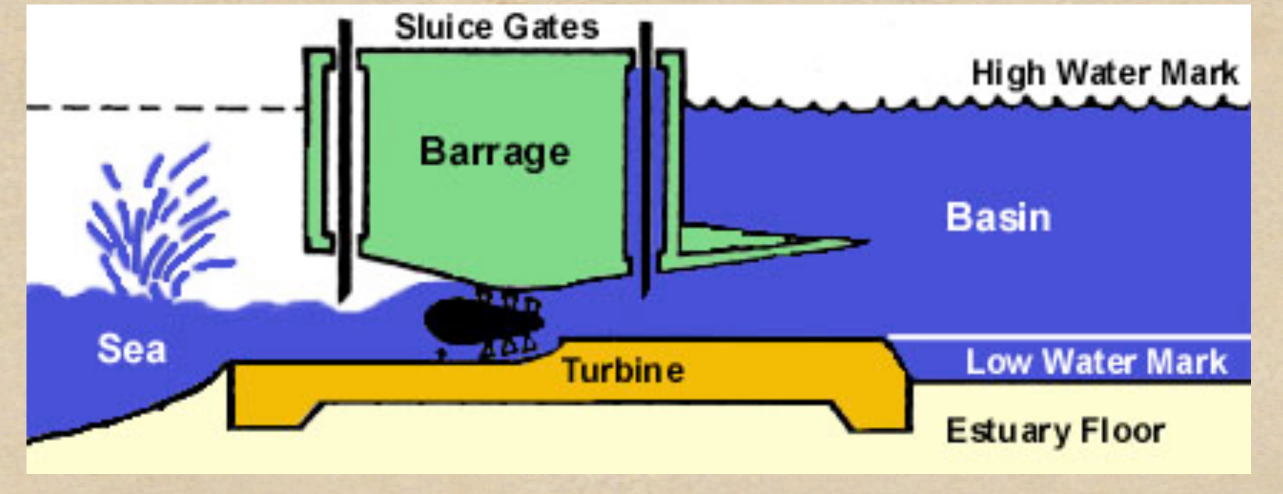
$$x = 2.5 \times 10^6\ liters/sec$$

About right!!

Rance tidal power plant

Location Brittany, France

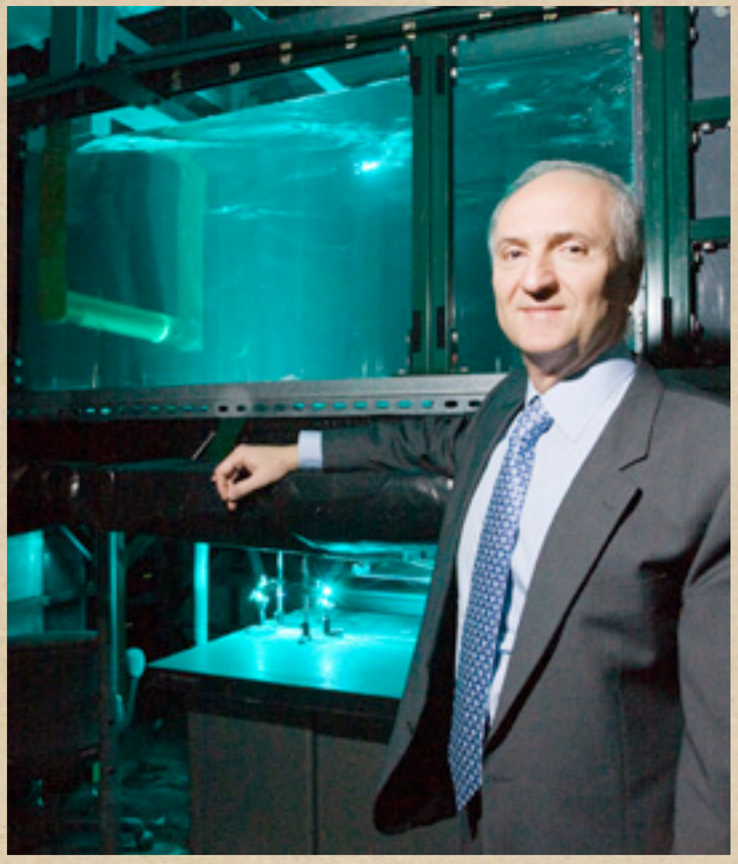
Status In operation
Fuel Tide
Technology Turbine
Turbines 24
Installed capacity 240 MW
Annual generation 600 GWh



- Average range (head) 28 feet
- Maximum 44 ft
- Length of dam 2500 Ft
- Basin area 8.5 sq miles
- Power generated 540 million kWh in one year
- 200,000 tourists per year!!

USA: Prospects are good at Bay of Fundy in NE Alaska

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

Inspired by watching schools of fish dance in the sea!

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."

Geothermal energy

The Geysers, Sonoma /LakeCounty: 70 miles north of San Francisco

2000 MW steam driven,

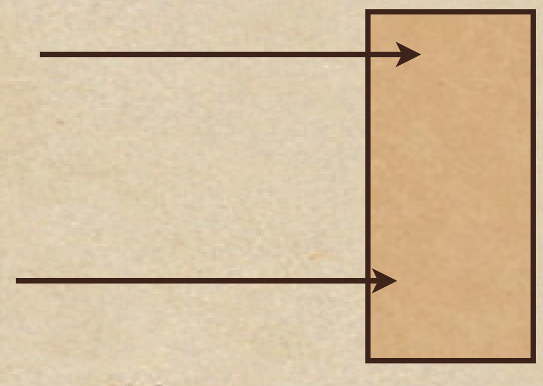
Turns out to be non renewable

~20 years more

Wind power:

$$P/m^2 = 6.1 \times 10^{-4}\ v^3$$

P is the power in kW per square meter
and v the wind velocity in meters per second.
This assumes that the surface is at right angles to the wind



v^2 from kinetic energy and v from amount of wind passing by per second.

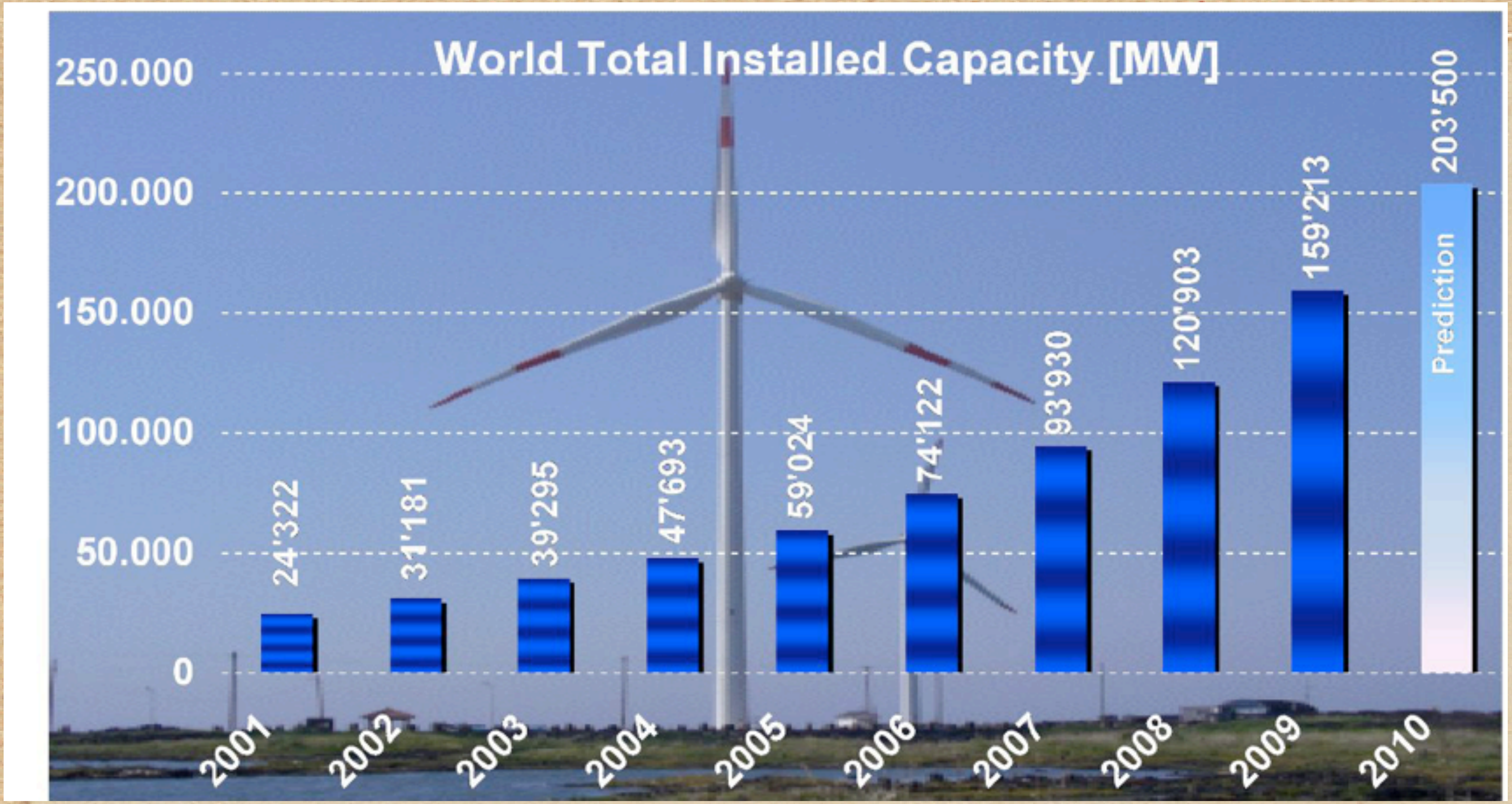
$$30\ mph = 48\ kmph = 13.33\ meter/second$$

$$10\ sq\ meters\ gives\ 2.37\ kW$$

At the end of 2009, worldwide nameplate capacity of wind-powered generators was 159.2 gigawatts (GW).

Energy production was 340 TWh, which is about 2% of worldwide electricity usage; and is growing rapidly, having doubled in the past three years.

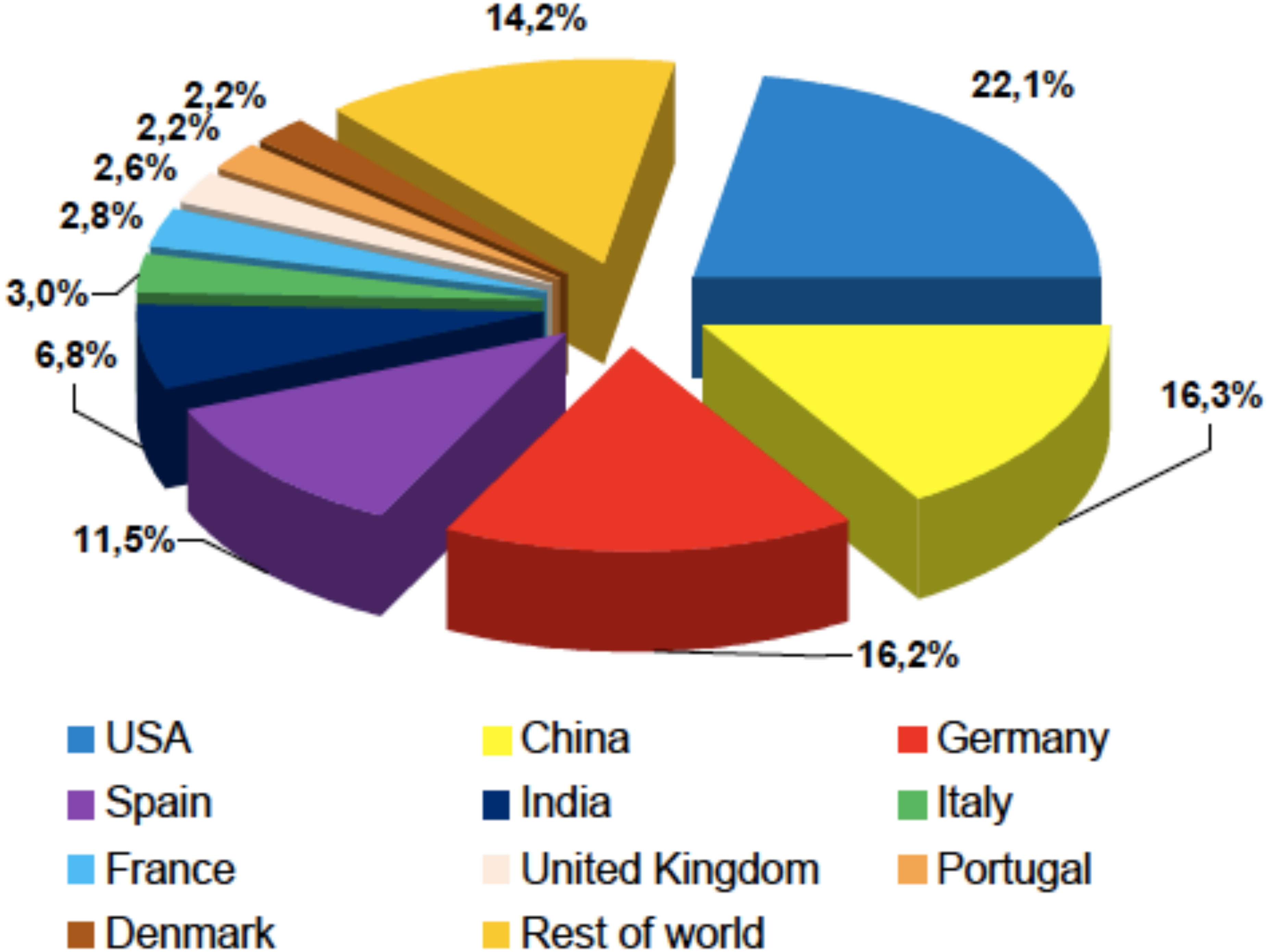
Several countries have achieved relatively high levels of wind power penetration (with large governmental subsidies), such as 19% of stationary electricity production in Denmark, 13% in Spain and Portugal, and 7% in Germany and the Republic of Ireland in 2008. As of May 2009, eighty countries around the world are using wind power on a commercial basis.



- **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



Prospects for a World Powered Predominately by Solar and Wind Energy

Walter Kohn
2011

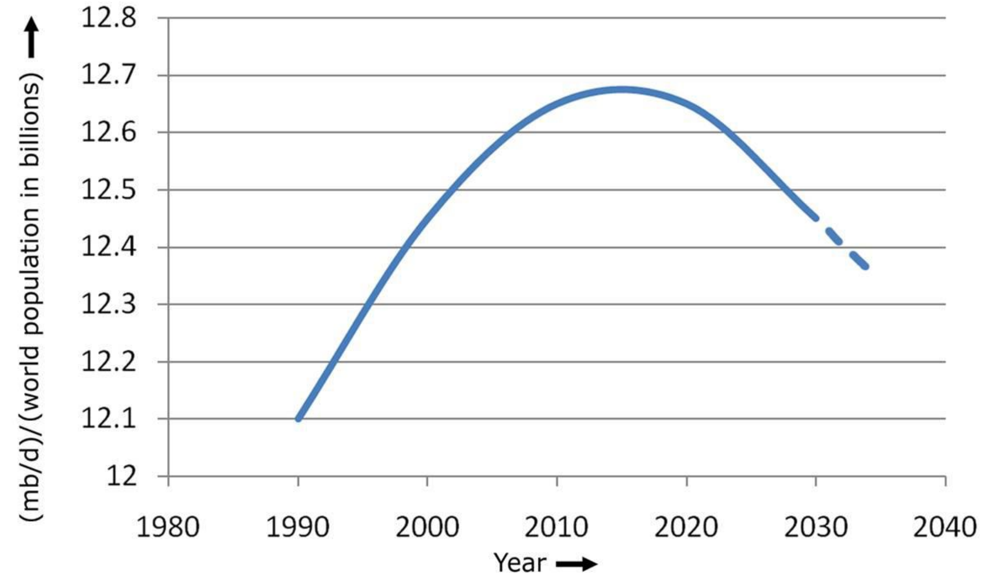
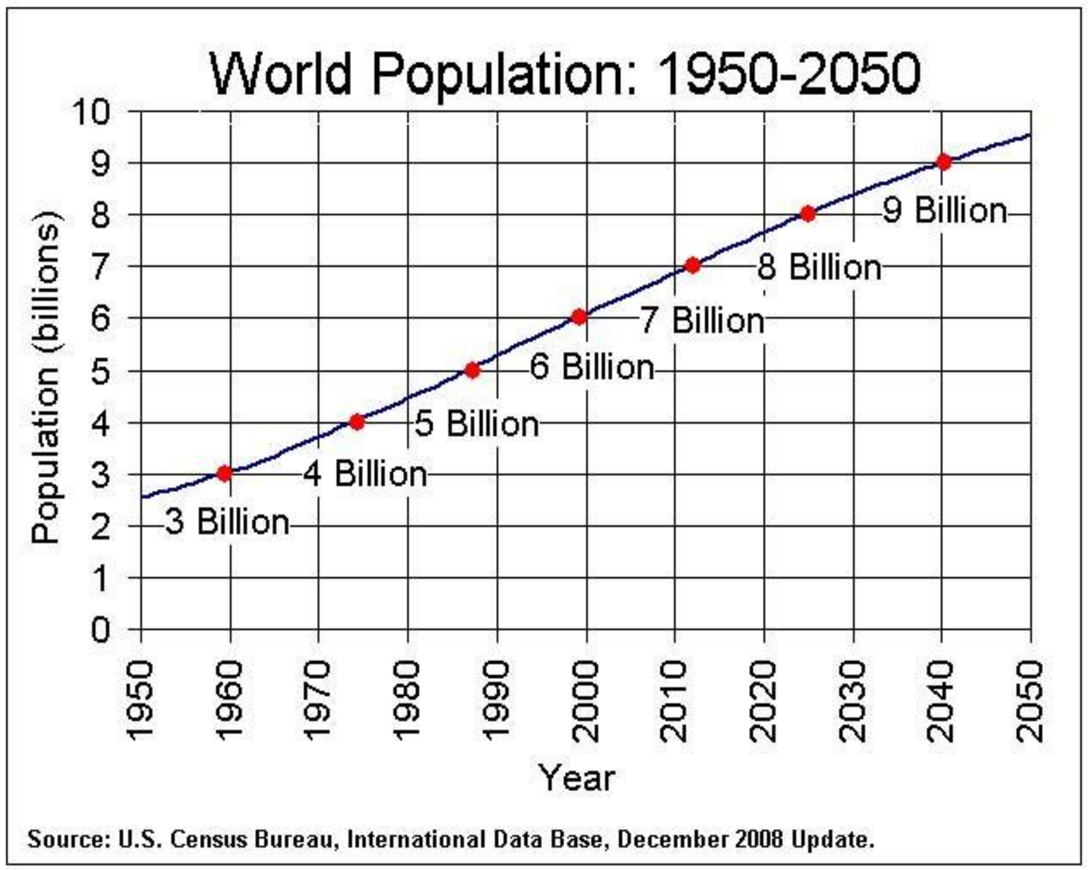


Fig. 4. Global oil production per person



"We have met the enemy and he is us"

Pogo quote of 1971

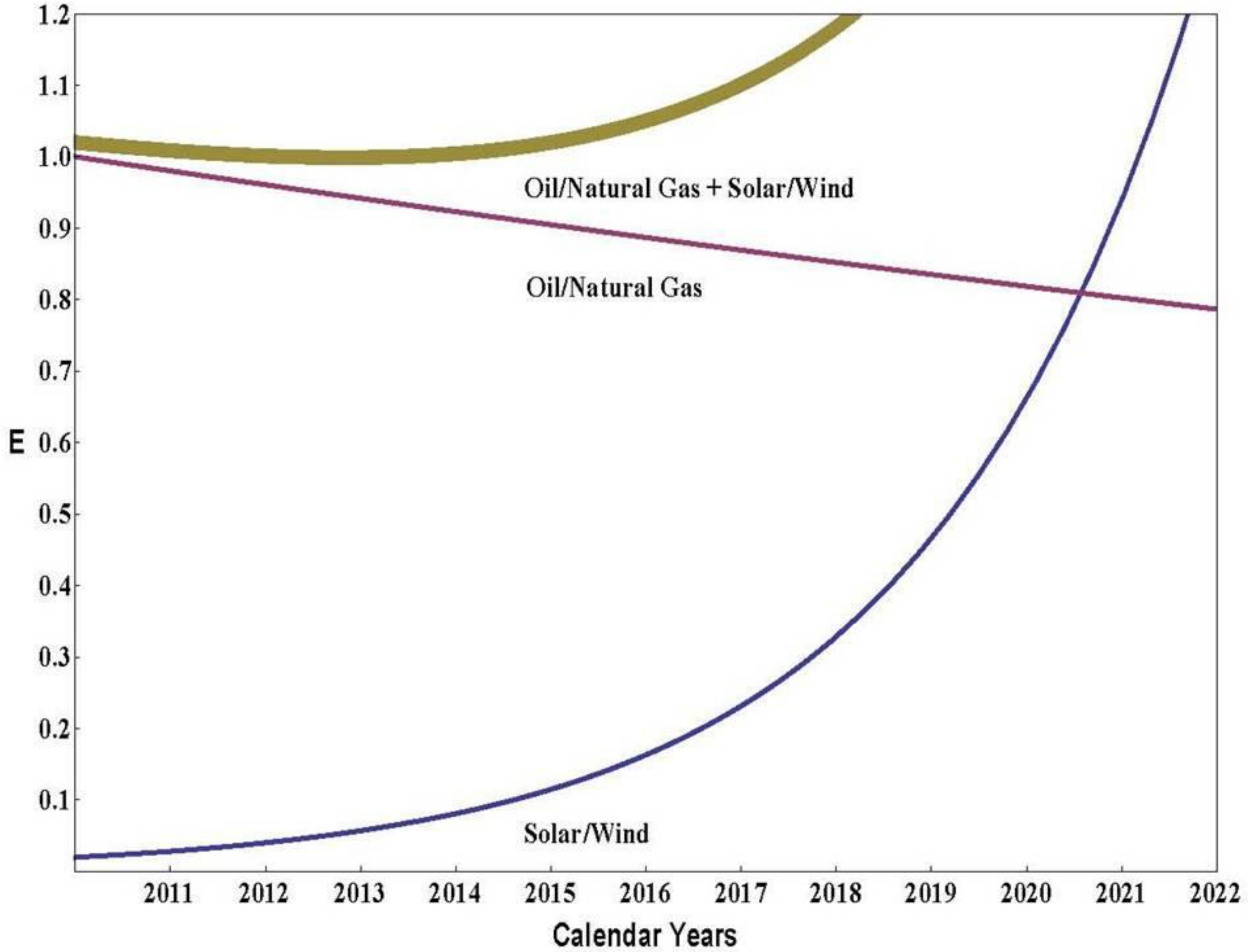
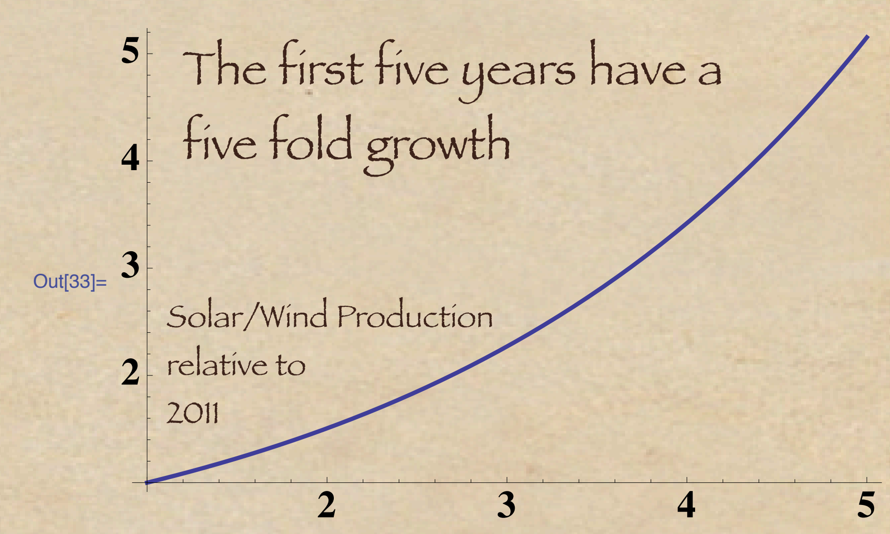
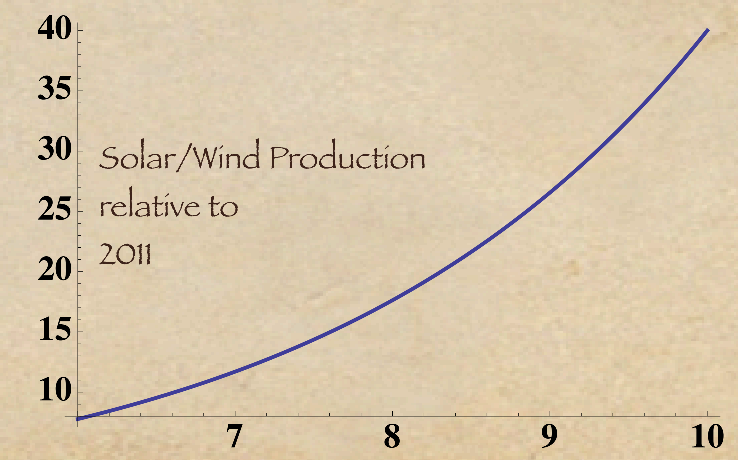


Fig. 5 The energy transition from (Oil/Natural Gas) to (Solar/Wind). We define the transition year as the year (2021) in which solar/wind energy begins to exceed oil/natural gas energy, and becomes the world's dominant energy source. E represents annual rates of energy production, in units of oil/gas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





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