# World Energy Needs and Offshore Potential of hydro energy and pump storage

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**In 2008**, 6,5 Billion people have an overall income of 50.000 Billion US $, use 10 Billion oil equivalent of primary energy, partly through **15.000 TWh** of electric power.

Most is used by 1 Billion people from industrialized countries, with 10.000 KWh/year per capita at a cost of 10 cents per KWh, i.e. 1.000 $/year, 3 % of their income close to 30 000 $ per year (All costs below are in cents of U.S. $ actualized in 2008)

**In the second half of the Century**, we may hope that 10 Billion people will reach this average income per capita ; with a better energetic efficiency but a larger share of it through electricity (electric cars, air conditioning, nuclear and renewable generation).

The yearly needs of electricity per capita may thus reach :

10.000 x 0,5 (better efficiency) x 1,5 = 7.500 KWh

and the global needs 10 Billion x 7.500 = **75.000 TWh/year (five times the present supply).**

**May we get them with an acceptable cost and impact?**

# Electricity resources in 2008

From about 15.000 TWh/year:

- 10.000 are from oil, gas and coal.
- 2.500 from nuclear (U 235).
- 3.000 from hydropower.
- 200 from miscellaneous.

- It is possible at a reasonable cost to transport electricity along thousands of Km but this is used only now for 1 % (low cost hydropower plants in Canada, Russia or Africa.)

- It is possible to store electricity after generation (pumped storage plants between 2 lakes) but it is used now for only 1 %; energy storage is usually before electricity generation (fuel storage or lakes).

But **these two possibilities of storage of electricity after generation and long distance transport are the key of the future utilization of renewable energies** because the cost of these energies may vary by over 5 cents of $ per KWh with the place of generation and because most are intermittent (solar, wind, tides, waves, …)

# Electricity Sources in 2060 or 2080

# for 75.000 TWh/year

- For climate warming and resources exhaustion the fossil fuel (mainly coal and gas) should not be used more than now, i.e. for 10.000 TWh/year.
- Hydropower may increase from 3.000 TWh/year now to 7.000 or 8.000 including tidal energy.
- Biomass, geothermy, waves, will probably supply only few thousand TWh/year.
- Nuclear Plants using Uranium 235 may increase from 2.500 TWh/year up to 5.000 but will be then limited by Uranium 235 resources.
- The total above is 25,000 TWh/year and there is thus a gap of 50.000 TWH/year.
- Nuclear Plants using Thorium or Uranium 238 may be developed after 2040 but thier technology and cost are unknown.

**Is it possible to supply most or whole of 50.000 TWh/year by wind or solar plants?**

# Wind and Solar Possibilities

- The overall realistic potential of renewable energies (solar, wind, hydro,…) is well spread worldwide and over 80 % of people will have a cost efficient relevant source within 1.000 Km range (probably about 500 Km as average).

- Wind farms may be developed as well in rather populated areas (as presently in Germany or Spain), as in desertic areas or offshore where there are many favourable areas with depth within 40m. Generating over 10.000 TWh/year at a direct cost between 4 and 10 cents/KWh appears realistic. The technology is well known. The area per TWh/year is about 40 $Km^2$ with 2 to 5 units per $Km^2$.

- Solar resources are unlimited. Beyond thermal solar for heating and hot water, electricity may be generated by photovoltaic or mirrors and steam. The main future utilization will probably be in desertic areas where sun energy is available 3.000 or 4.000 hours per year. The direct cost will be probably close to 10 cents/KWh. The area necessary for 30.000 TWh/year would be 300.000 $Km^2$, for instance 1 % of the deserts area and 1 ‰ of other places.

**But the key problem of wind and solar electricity is the intermittent supply and the relevant need of storage along 1 or 2 days.**

# Energy storagebetween two lakes

1) Without storage, wind and solar energies may be used one third of time and should be associated with much more fossil fuel power for two thirds. As fossil fuel power will be limited, wind and solar should be very limited.

2) With storage, wind and solar energies may be used over 80 % of time, much more than fossil fuel.

For 10.000 TWh/year of wind energy, a 2 days storage requires a 55 TWh/storage.

For 30.000 TWh/year of sun energy, a 16 hours storage requires a 55 TWh/storage.

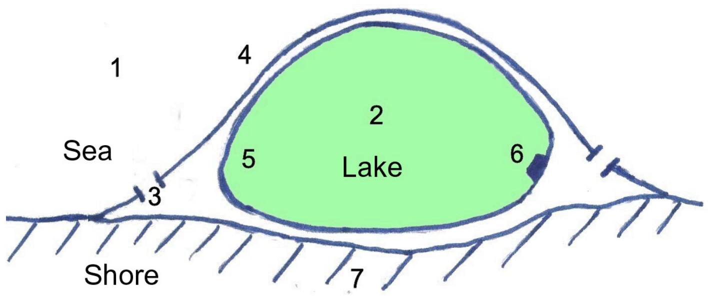
As some storage may be common and as there may be storage is some solar plants, the total storage need may be 80 to 100 TWh. It may be between two lakes:

- Possibly 10 to 20 TWh between 2 onshore lakes, as for 2 TWh now (100 GW x 20 hours)
- Possibly 10 to 20 TWh from sites in rather desert areas operating between an onshore high reservoir and the sea as low reservoir.
- Possibly 50 to 70 TWh from offshore sites operating between a high offshore basin and the sea: As being "green" for favouring renewable energy, precious and with the colour of sea water these basins could deserve the name of "Emerald Lakes".

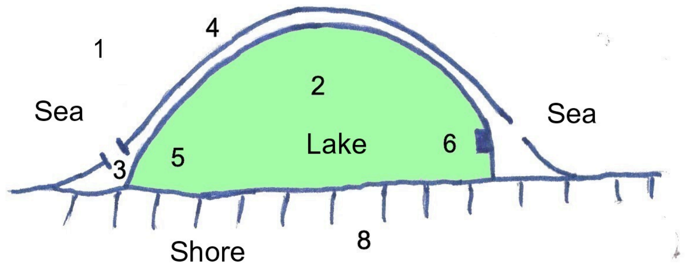
The relevant total pumping capacity will be in the range of 5.000 GW (40.000TWh / 8.640 hours).

# The Emerald Lakes

There are many offshore places worldwide with sea depth of 20 m with sand, gravel or rock used for foundation and for dykes materials. The dykes may be built using large sea dredges in calm water behind a traditional breakwater. All needed technology is well proofed. Preferably the schemes will be close to shore.

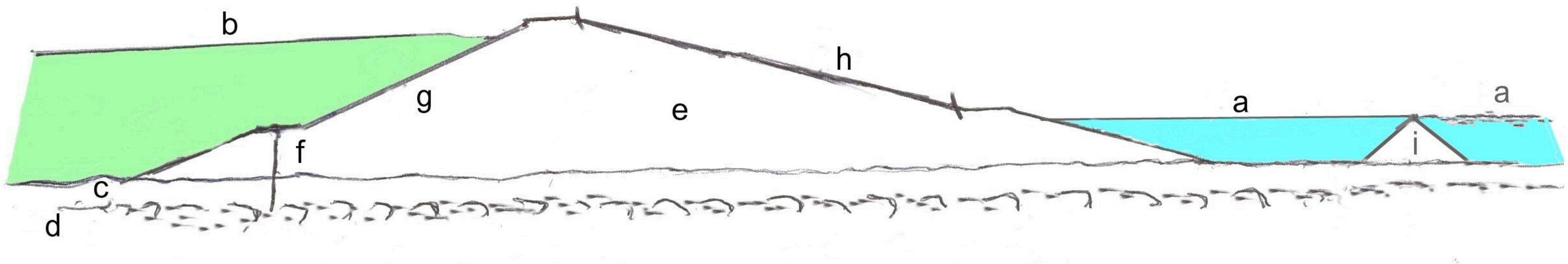



**Usual lay out**




**Lay out in cliff Areas**

1- Open sea
2- Emeralde Lakes
3- Harbour
4- Breakwater
5- Dike (dam)
6- Pumping plant
7- Low shore
8- Cliff




**Dam cross section**

a- Sea level
b- Lake level
c- Natural ground
d- Rock
e- Sand and gravel Dam
f- Diaphragm wall
g- Imperviousness
h- Grass and trees

- Breakwater

# The "Emerald Lakes"

Their storage capacity, in GWh/Km² is about :

$$\frac{10^6 \times 0,5\ H \times 0,75\ H \times g \times 0,9}{3.600 \times 10^6} = \frac{\#\ H^2}{1.000}$$

H being (in m) the maximum head of the lake above the sea level.

For H = 70m, the storage is about 5 GWh/Km²; the total world area required for 70 TWh would be 15.000 Km² (5 % of existing reservoirs area) and the total stored volume 1.000 $Km^3$ (15 % of the present dams storage.

For cost reasons ; each lake would be probably important between 2 and 50 Km², with a pumping capacity in the range of 1 to 10 GW.

# Electricity Storage Cost

For storing half of 40.000 TWh of wind or solar energy, the investment for storage would include :

| | | |
|---|---|---|
| 5.000 GW plants x 800 $/KW | # | 4.000 Billions US $ |
| 1.000 Km3 of onshore or offshore storage | # | 2.000 Billions US $ |
| | | 6.000 Billions US $ |

i.e. an investment of 0,15 $ (6.000/40.000) per yearly KWh of renewable energy and a relevant cost of 1,5 cent per KWh. There is also some loss of power by storage and the total average cost of storage will thus be in the range of 2 to 3 cents/KWh of wind or solar electric power.

This storage may also be used for other intermittent sources (tides, waves) and for optimizing the utilization of all electric energy sources according to needs. It is also giving a great safety for the grids operation and frequency control.

# Cost of electric power in 2080

Including 5 cents for storage and extra transport, the average cost of wind power will probably be about 10 cents/KWh, the cost of solar power 15 cents.

The cost of fossil fuel generation (coal and gas) may be in the range of 10 cents (including partly $CO^2$ storage).

The cost of hydropower will be under 5 cents, most plants investment being already paid for.

The cost of nuclear power, with increased cost of uranium 235, may be close to 10 cents.

The average cost seems then in the range of 12 cents/KWh, applying to 7.500 KWh/year per capita, i.e. about 900 $ (3 % of an average income at this time of 30.000 $). **This is the same percentage for electric power as now for industrialized countries (with a larger part of energy by electric power).**

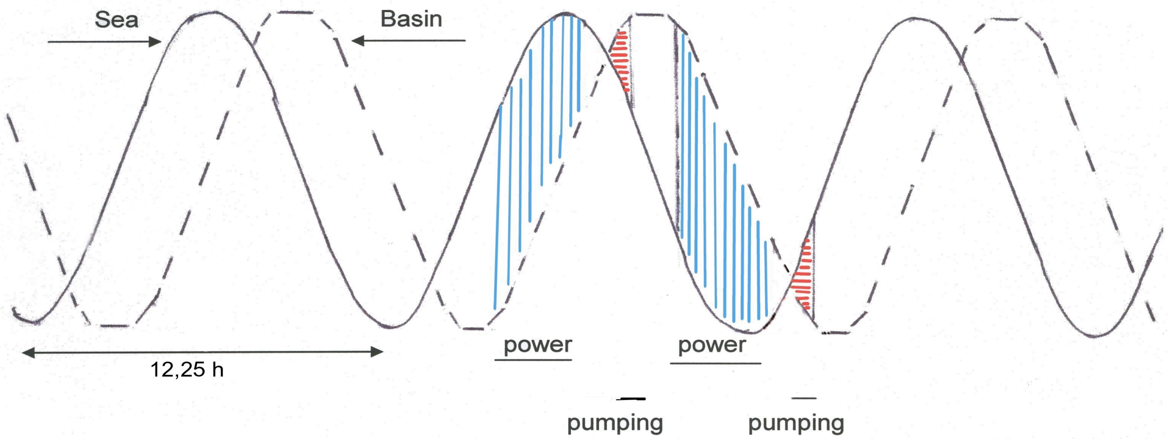
**70% of World future needs of electric power may be renewable at a very acceptable cost.**

# Tidal Power

Tidal power was more expensive than oil or gas power in 2000. It will be cost effective in the future in many places where:

- The average tidal range is over 4 or 5 m.
- The length of dykes (in Km) is under 20 or 30 % of the basins area (Km²), which is possible for large basins along shore (over about 100 Km²).

It is possible, operating single basins both ways, to keep the natural tidal conditions (shifted by 3 hours). As dykes will be low and most often 10 Km offshore, they will be hardly seen from inland. Avoiding tempests and extreme high water levels and favouring aquaculture and tourism, they could be wellcome in many places.



# Tidal Schemes

- Construction methods are the same as for Emerald lakes (with lower dykes).
- The production per $Km^2$ will be close (in GWh/year) to 0,4 $H^2$ (H being in m the average tidal range).
- Bulb units or Orthogonal Russian turbines may be used. The cost of plants will be reduced by large quantities of same units and by the possibility of transporting by sea very large elements.
- The tidal plants may be combined for storage with Emerald Lakes used also for wind and solar energy.
- The average total cost will probably be close to 10 cents/KWh.

# Worldwide tidal potential

The theoretical potential is very high, in the range of 20.000 TWh/year but it is only possible to use a reduced part of it.

1) It seems possible to generate 500 TWh/year in populated areas, mainly in East Canada, South East China, Northern France, West India, Northern Russia and U.K. For keeping onshore natural tidal conditions, using single basins along shore operated both ways may be the prefered solution.

2) There are also possibilities for 500 TWh/year in desertic areas (North and West Canada, Alaska, South Argentina, Northern Australia, Eastern Siberia) with either a transport of power along thousands Km or local industrial utilization (hydrogen, aluminium,…). Associating a high basin and a low basin may supply power full time and be acceptable there.

3) The total world area of tidal basins may reach 30 or 40.000 Km² (i.e. 40 Km² per TWh/year, to be compared with 100 Km² per TWh/year for existing hydropower onshore lakes).

# Future overall Hydropower Investments 2010-2080 (2008 Value)

Cost (Billion U.S. $)

| | |
|---|---|
| - Onshore hydropower: 4.000 TWh/year (1.000 GW) | 2.000 |
| - Tidal plants : 1.000 TWh/y (300 Gw) | 1.000 |
| - Stored wind or sun energy. (20.000 TWh/year with 5.000 GW capacity) | 6.000 |
| | 9.000 |

i.e., 150 Billion $/year (increasing from 30 in 2010 to 200 after 2040).

This overall Hydropower investment will be one per thousand of the future world income (about the same percentage as the average since 60 years).
It will be less than 10% of the world investments for energy.

# Conclusion

The world Electricity needs may well be multiplied by 5 along the century.

- Renewable (hydro, wind, solar) may supply 60 to 80 % of these needs with an acceptable cost and impact. 40 % will be supplied or stored by Hydropower.

- The hydropower investments may raise from 30 Billion $/year in 2010 up to 200 Billion $/year after 2040.

- Over half of future hydropower investments will be offshore.

- These invetsments will be used a century or more.

**HYDROPOWER HAS A GREAT FUTURE**