From Water to Air: Scientific Pathways towards a Clearer, Cleaner Future

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A Scientific Recipe for Saving the World ?

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How serious is the Climate Change – are we doing the right things?

- Are we soon risking pass a ‘**tipping point**’ in current increase of CO_2 and global temperature increase after which there is no path of return ?

- Besides **decabonizing all fuels**, what immediate hands-on actions should be deployed to mitigate the climate problem?

- Which are the realistic ones? Do we **underestimate challenges** and, therefore, cannot correctly assess priority?

- Are qualitative characters of fuels and energy processes using concepts like ’**sustainable**’ and ’**renewable vs non-renewable**’ misleading, if a true critical assessment of global impact is sought for ?

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- **Do ‘green activists’ and political expert panels agree with independent chemists and physicists about priority order?**

- **Do concepts like ‘sustainability’ and ‘renewable’ energies etc make us blind to realistic solutions?**

- **Decision makers (politicians) are often said to be reluctant to react strongly enough in addressing climate change problems. Do scientists have a role here and opportunity to convincingly enlighten people and decision makers?**

Svante Arrhenius, physical chemist,
the first Swedish Nobel Laureate (Chemistry 1903).
Discoverer of ‘The Greenhouse Effect’ (1895).
He predicted that a doubled CO_2 concentration in the atmosphere should increase the temperature 6° C.
S. Arrhenius *‘On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground ‘* Phil. Magazine. Series 5 (1896) 237-276.

In 2020 Sherwood calculated expected increase to 2.6 - 3.9°.

Arrhenius’ theory was verified and improved (heat transfer by convection included) in the 1960-ies by Japanese meteorologist Syukuro Manabe

who received the 2021 Nobel Prize (Physics) for ’Physical models of Earth’s climate’
(shared with Klaus Hasselmann and Giorgio Parisi)

Solar panels

if made of standard crystal **silicon** or (future) crystalline **perovskite** can produce **electricity efficiently in Sahara, Greece, Sicily, Spain** to be

2 **O delivered via power-line nets north to consumers, or**

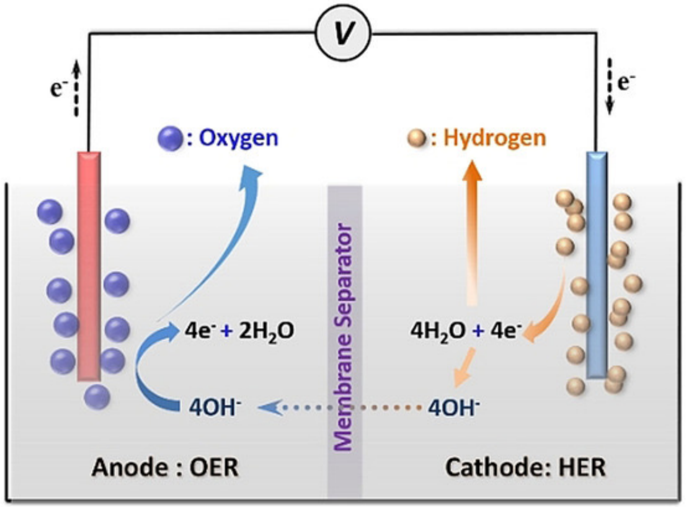
O used to produce hydrogen gas locally by

Electrolysis of water

+ pole (anode): 2 OH^- → H_2O + ½ O_2 + 2 e^-

- pole (catode): 2H_2O + 2 e^- → H_2 + 2 OH^-

Overall: H_2O → H_2 + ½ O_2



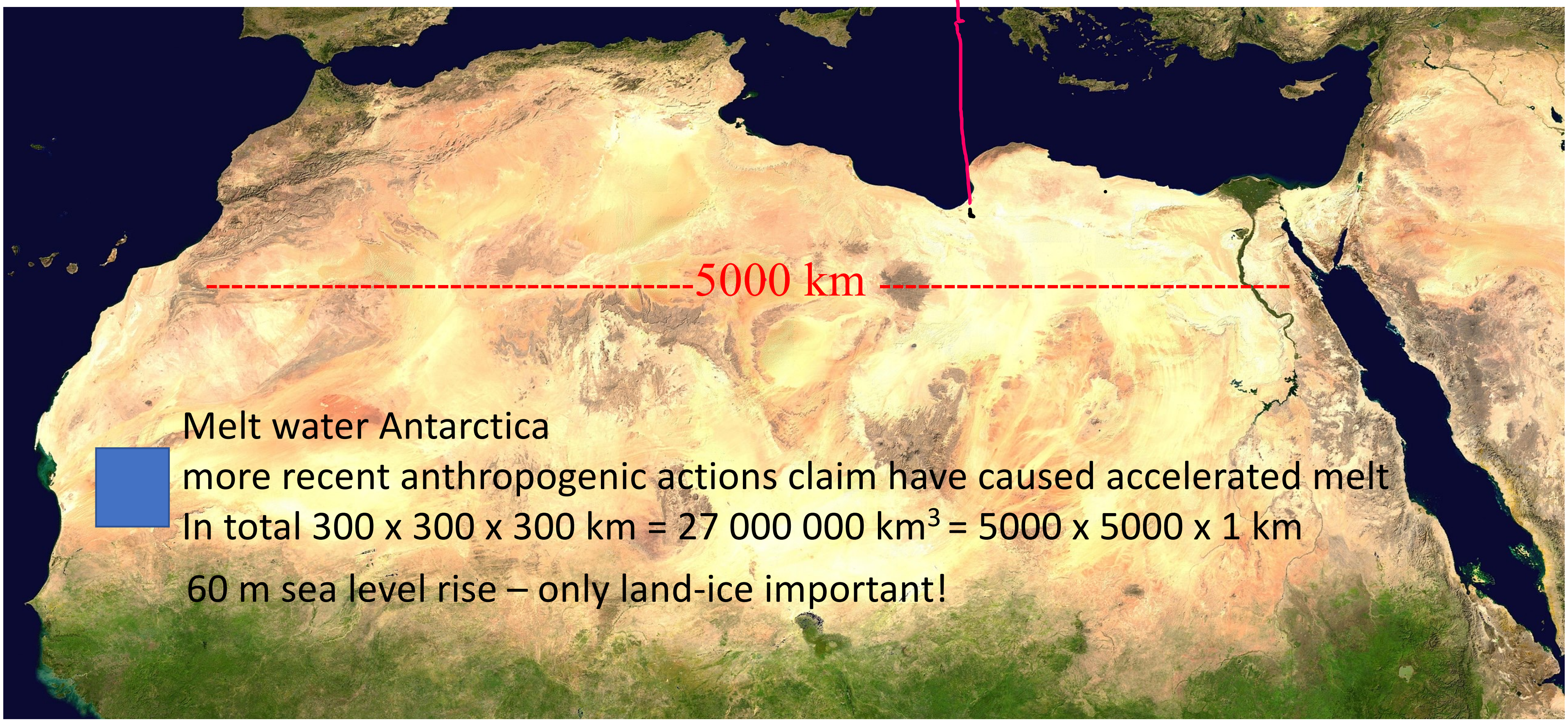
Sweden 1 year: **170 TWh** electric energy

540 TWh total

(Europe 27000 TWh – 70 x 70 km)

6 km x 6 km

= 36 GW over sunny 12 h



Melt water Antarctica

more recent anthropogenic actions claim have caused accelerated melt

In total 300 x 300 x 300 km = 27 000 000 km^3 = 5000 x 5000 x 1 km

60 m sea level rise – only land-ice important!

Solutions ordered (by me) in falling feasibility or environment friendliness

Blue = future

- **Hydro-electric power** in Sweden 60 TWh/year: 35% of our electric energy
- **Hydro-electric energy storage** 'Switzerland model' 0% in Sweden
- **Nuclear power** 35 % of Swedish electricity. Needed until Solar & Hydrogen powers are in place
- **Solar power** imported as electricity or hydrogen from sunny southern latitudes (only 0.4% Swedish sun)
- **Hydrogen power** (including **hydrogen energy storage**)
- **Photosynthesis in plants on land (plant new trees!) and in sea absorbing CO_2 and restoring O_2 in atmosphere**
- **Wind power** intermittent, will need **energy storage** 20 TWh/year = 15%

Also desirable to find solutions that could

- **Mitigate land-ice melting** Antarctica - threat 60 m sea level rise
  Might be combined with new, geographically spread **clean fresh-water reservoirs**, might be used also for hydro-electric energy storage.

Less competitive ”solutions” (yet often mentioned by green activists)

- **‘Biofuels’ and other carbon fuels producing CO_2** (although CO_2 balanced formally on shorter-term basis than fossils, they counteract photosynthetic oxygen) **Abandon!**
- **Fossil gas and ‘bio-gas’** (both methane; worse Greenhouse gas than CO_2) **Abandon!**
- **Thermal energy** (limited to very few places, Island)
- **Salt thermal energy storage** (unpractical)
- **Tidal energy** (very limited)
- **Wave power** (inefficient, intermittent)
- **Carbon dioxide sequestration** (energy uneconomical, potentially hasardous) **Abandon!**
- **Hydrogen gas produced from natural (fossil) gas** (7×10^7 tons/year). **Abandon!**

Hydrogen gas may be compressed (300 bar cylinders) but more convenient storage needs to be developed if hydrogen be used as fuel in cars

O The cleanest conceivable combustion $\mathbf{H_2 + ½\, O_2 \rightarrow H_2O}$ (especially in fuel cells)

O Hydrogen may possibly be stored in solid MOF cage structures at moderate pressures. **Development of new technology !**

O $\mathbf{H_2}$ may be transported north on ships, trucks or trains from southern solar-electricity and water electrolysis to consumers in Europe.

O Or, converted into a **liquid fuel, such as methanol**:

- Hydrogenation of carbon dioxide (taken from air) to produce methanol

$$\mathbf{CO_2 + 3\,H_2 \rightarrow CH_3OH + H_2O}$$

High pressure (gases supercritical) 300 bar, 300 °C thermodynamics 95% conversion

- Methanol can be used as a normal combustion fuel (**needed for aviation**) or in fuel cell (cars). **However, still a carbon fuel (just like biofuels) producing $\mathbf{CO_2}$**.

$$\mathbf{CH_3OH + O_2 \rightarrow H_2O + CO_2}$$

Energy storage

To store energy from intermittent sources (solar, wind) or excess electricity from continuous sources (nuclear) to be saved for periods of higher demand.

- **Pumped hydroelectric energy storage**, gravitational potential energy of water pumped from lower reservoir to higher elevation. First: Engeweiher, Schaffhausen, Switzerland, 1907. During periods of high electrical demand, stored water is released through turbines to produce electric power. Reservoirs usually small compared to conventional hydroelectric dams and generating periods short.

- **Hydrogen**

  Compressed hydrogen in tanks at 350 - 700 bar for vehicles, using fuel cells

  Liquefied hydrogen tanks for cars H_2 liquefied by reducing its temperature to −253 °C

  Metal-organic frameworks, MOFs, crystalline inorganic-organic structures containing metal clusters that may store hydrogen at molecular level. Northwestern University USA report for NU-1501-Al, a hydrogen delivery capacity of 14.0% w/w (46 g/litre). Compare phosphino-borane storage capacity: 0.25 wt%.

How serious is the Climate Change problem – are we doing the right things?

- Are we soon risking pass a 'tipping point' in current increase of CO_2 and global temperature increase after which there is no path of return ? **There is no scientific evidence in support of speculation that the process might be irreversible.**

- Besides decabonizing all fuels, what immediate hands-on actions should be deployed to mitigate the climate problem? Do we underestimate challenges and, therefore, cannot correctly assess priority?

1. **Stop using carbon fuels** (including 'renewable' biofuels etc)
2. Develop **Hydrogen gas** fuel produced by electrolysis of water
3. Develop: **Solar electricity** production at sunny latitudes
4. Continue and subside **Nuclear power** until 1-3 are fully deployed
5. Develop: **Energy Storage** Systems: stored hydrogen energy or pumped hydroelectric energy storage
6. Try hard: Mitigate land-ice melting (Antarctica). Also build other big clean freshwater reservoirs – available to all people.

- **Do ‘green activists’ and political expert panels agree with independent scientists about priority order? There is no consensus about priority!**

- **Do concepts like ‘sustainability’ and ‘renewable’ energies etc make us blind to realistic solutions? One should probably be cautious when applying such concepts! Abandon all carbon fuels, also so-called renewable ones! Abandon ‘carbon capture’ – unrealistic!**

- **Decision makers (politicians) are often said to be reluctant to react strongly enough in addressing climate change problems. Do scientists have a role here and opportunity to convincingly enlighten people and decision makers?**
  Yes, presumably, but the complexity of the problem systems will require great caution.

Conclusions

- There are already feasible solutions – focus on the simplest, with priority of sun light energy converted into electric power and hydrogen by electrolysis of water
- Decrease all CO_2 emissions (from fossil as well as 'renewable' fuels)
- Develop efficient storage banks for electric energy: store H_2 or pump back water into hydroelectric reservoirs
- Solve economic and political challenges to establish required international energy collaborations (e.g. solar energy export from sunny countries)