The implication of renewable power variation for large scale energy storage

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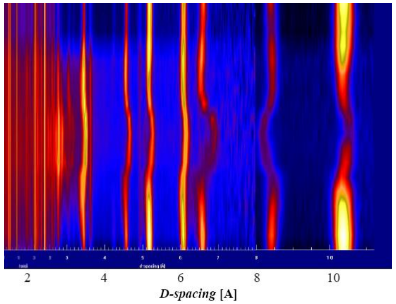
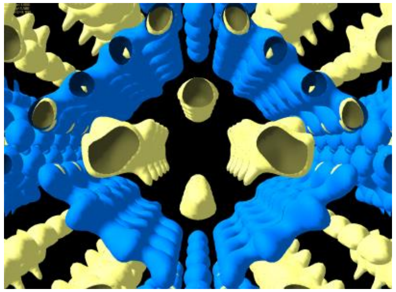
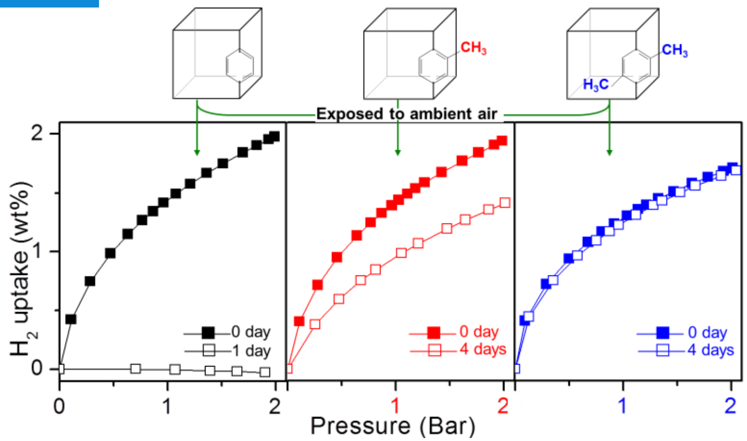


H_2 Gas storage: MOF´s

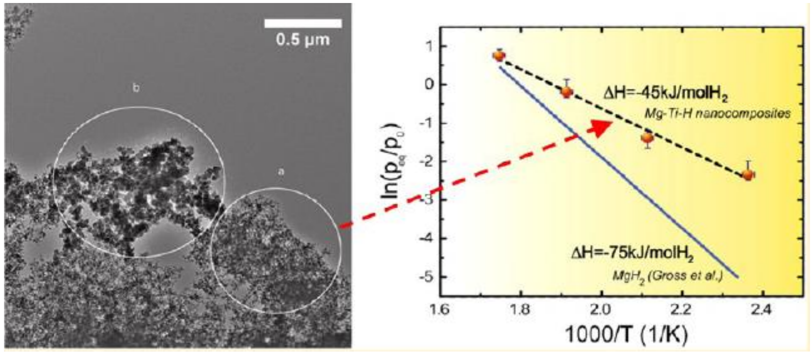
J. Phys.Chem C 114 (2010) 10648





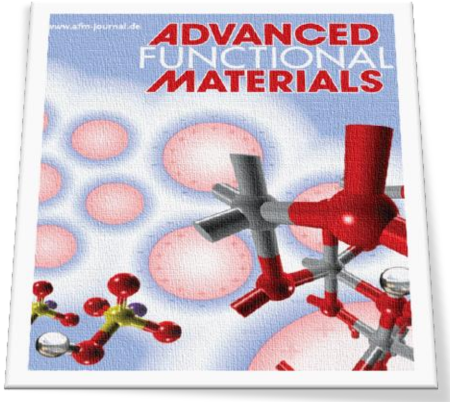
H_2 Gas storage: water stable MOF´s

Chem. Comm. 47 (2011) 5244



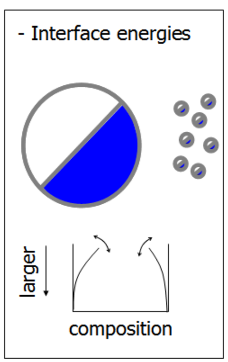
Destabilisation of MgH_2:

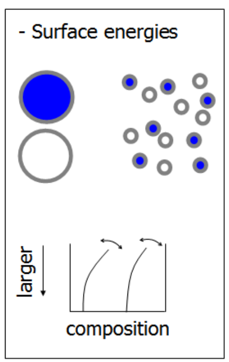
J. Phys. Chem. C 2012
J.Am.Chem.Soc. 2013



Nanoionics: solid state electrolytes

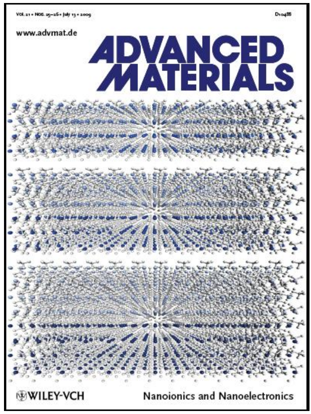
Adv. Funct. Mater. 2010 & 2011

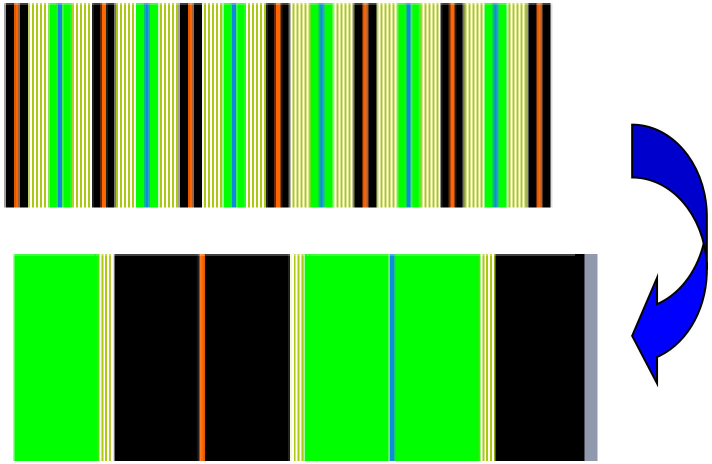




Impact of nanostructuring on Li battery materials

JACS 2005, 2007, 2009, 2011,
Adv.Mat. 2009
Nature 2002, Acc Chem. Res. 2013





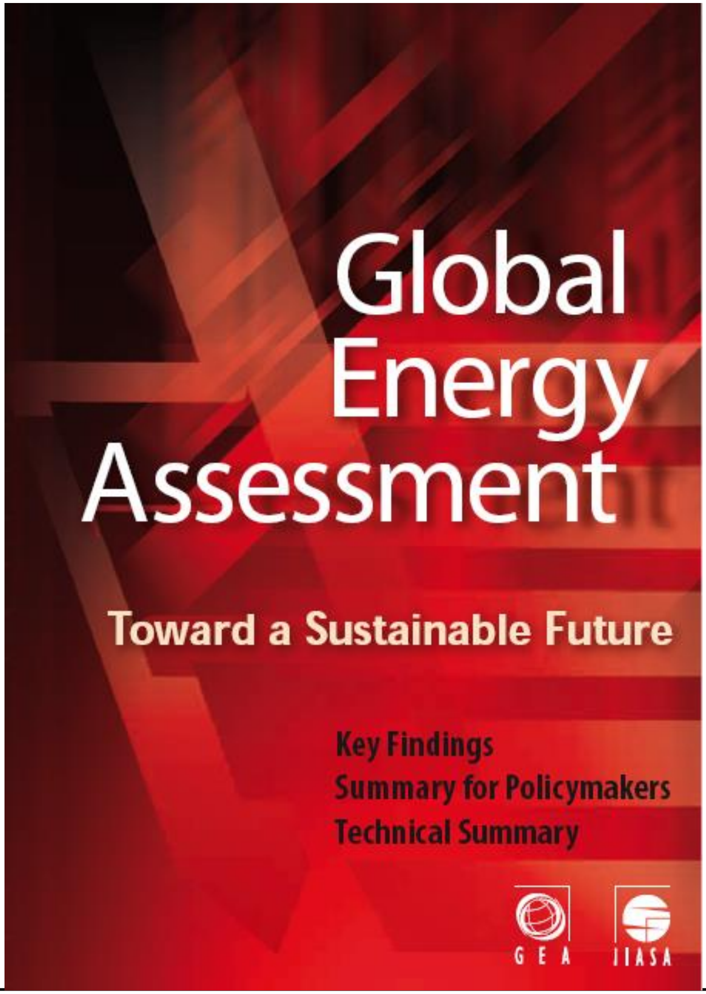
High effective energy density of Li battery + 100%

WO Patent 2,013,012,334
Adv. Ener. Mat. 2013, El.Chem.Comm. 2013

General TU Delft:
- Energy as a main research area
- 5 times winner of 3000 mile World Solar Challenge

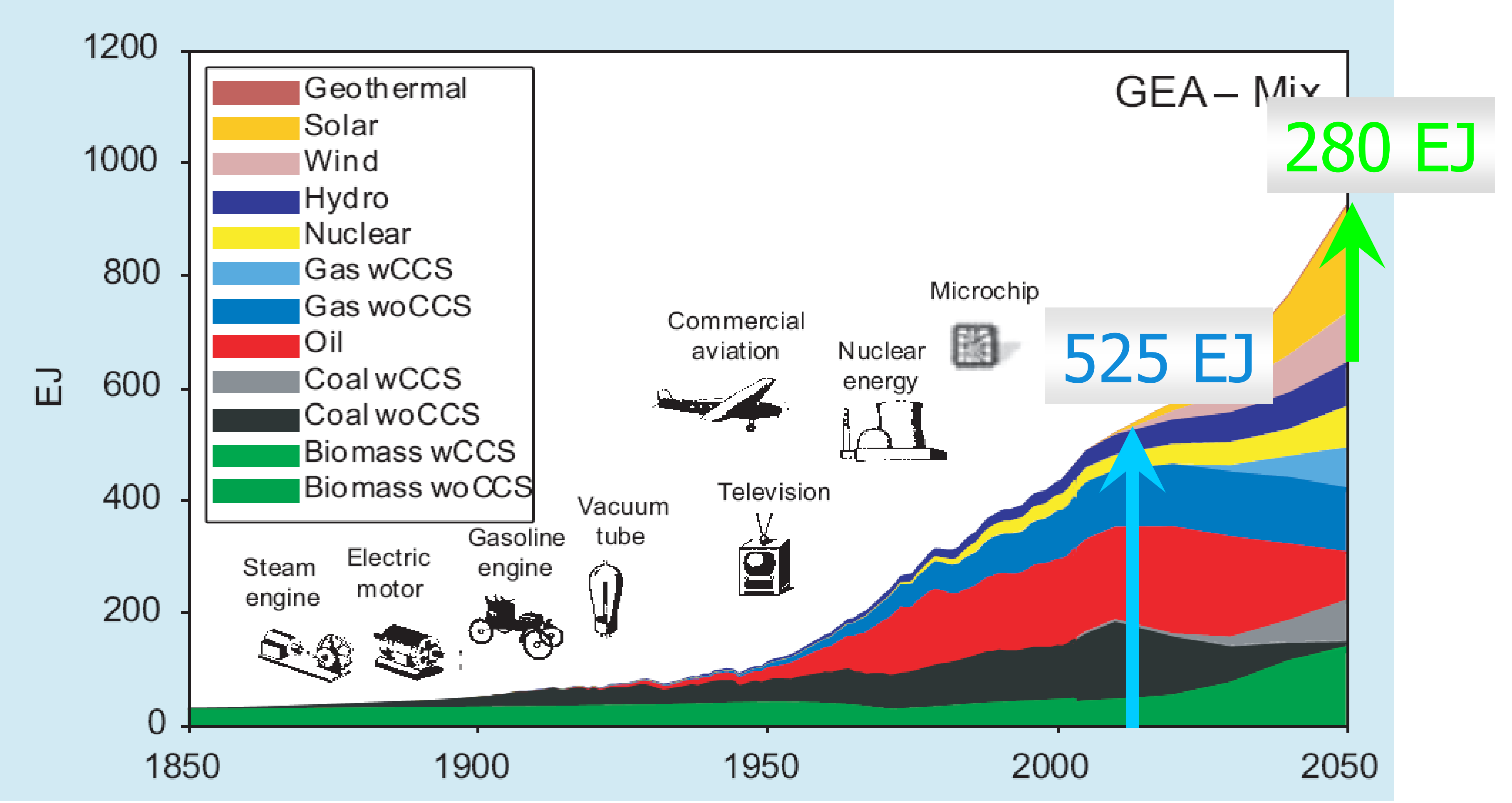
How to get to a number for the future scale for energy storage?

Start from a scenario



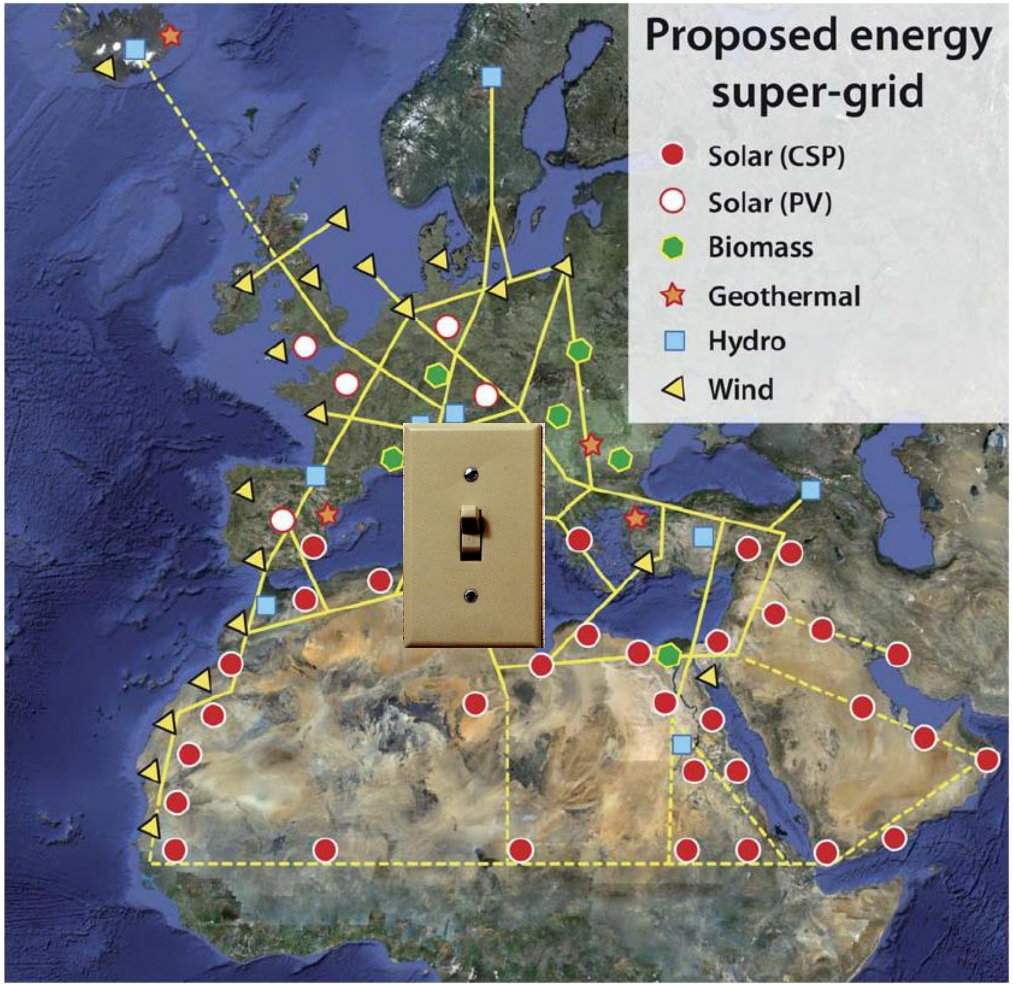
2012

World energy use; Global Energy Assessment 2012



http://www.iiasa.ac.at/

Renewables…



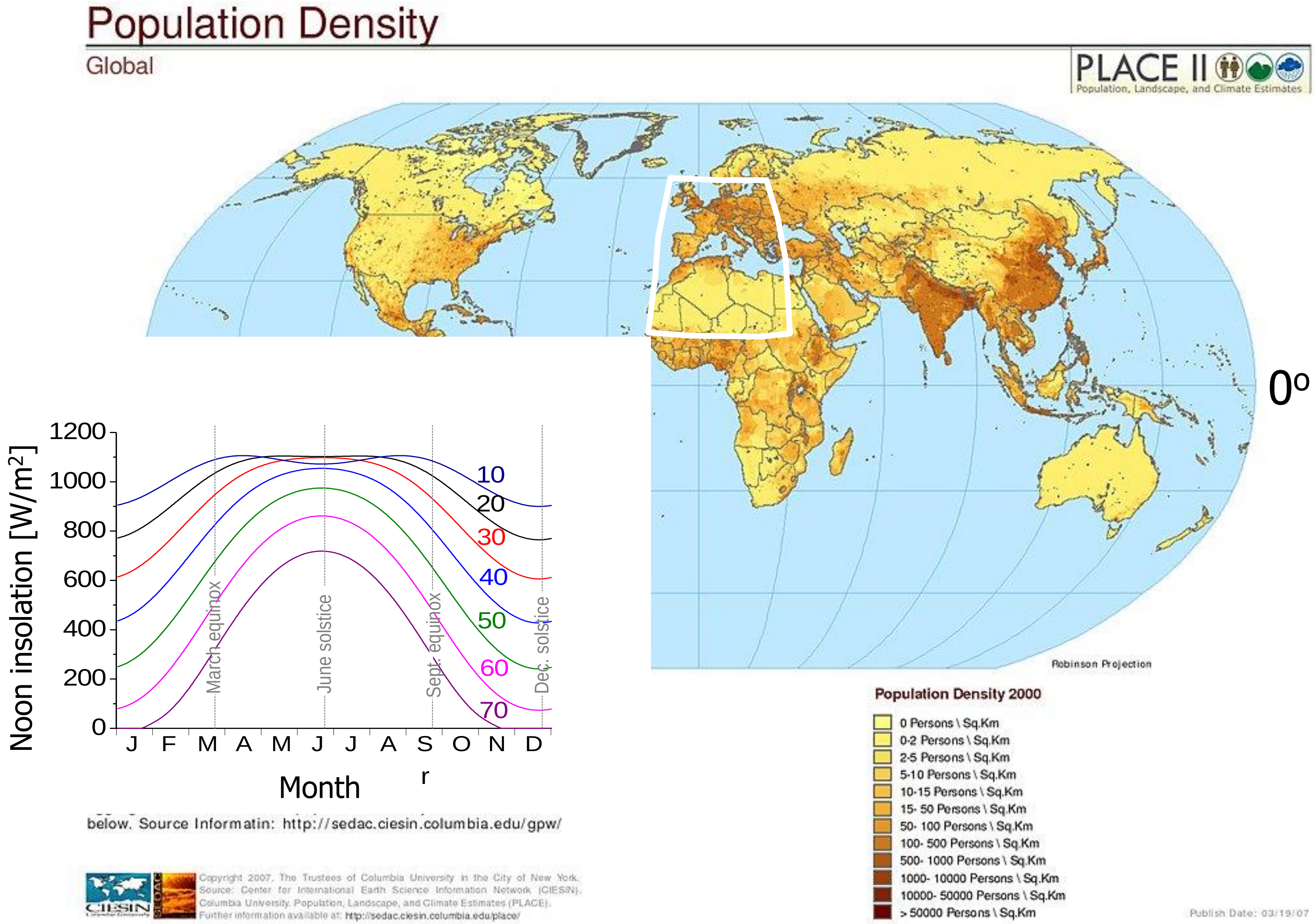
Light switch
on continents!

(day/night and
summer/winter)

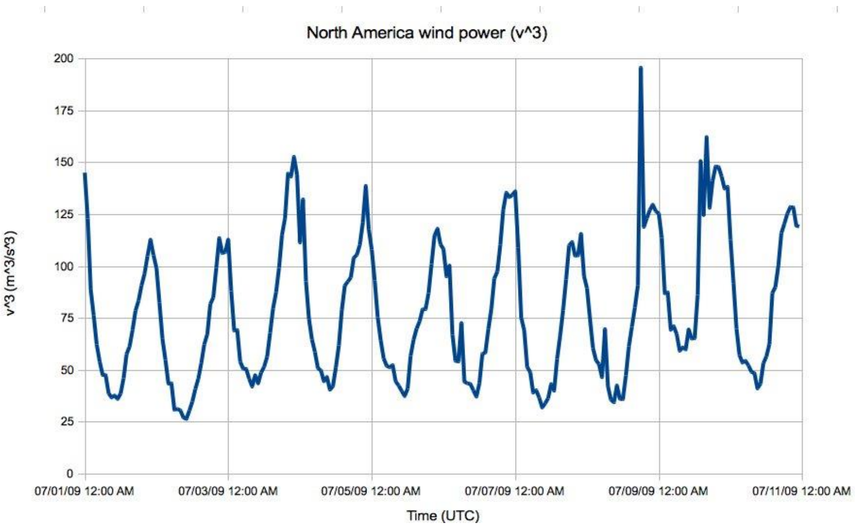
DESERTEC plan

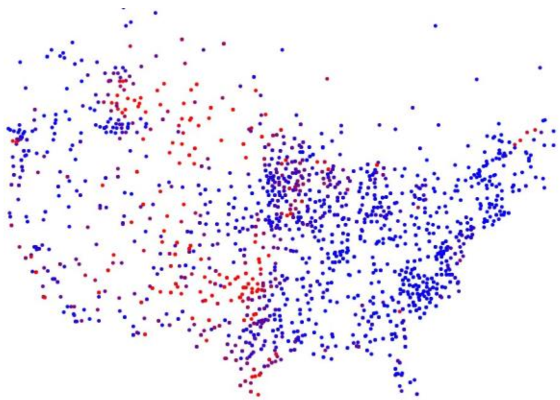
0°

Most people live on the Northern hemisphere above 20°

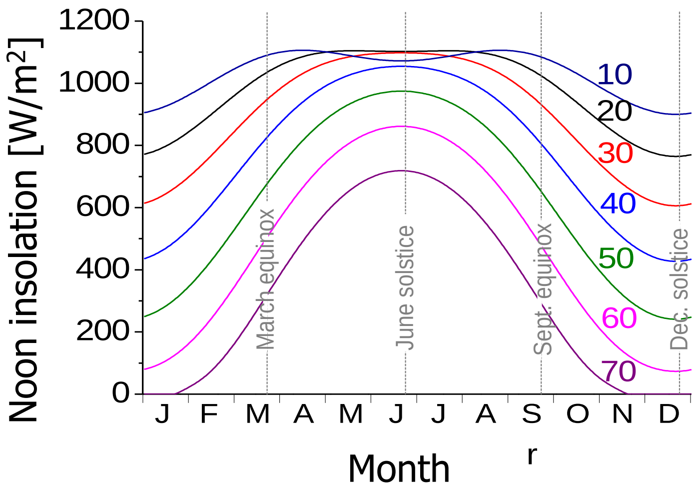


Large area still shows large wind power fluctuations

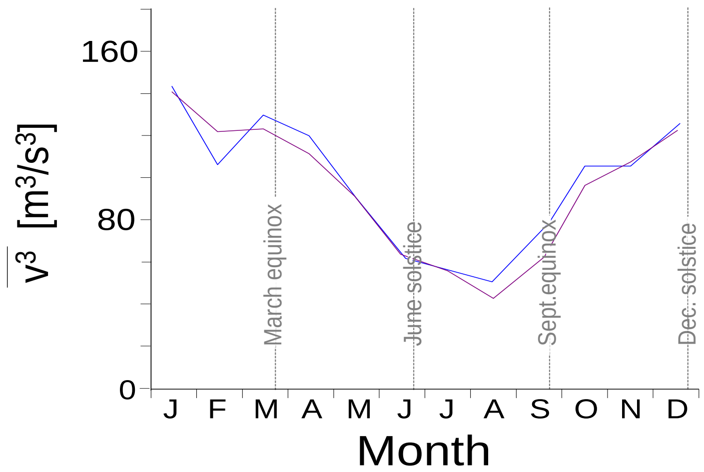


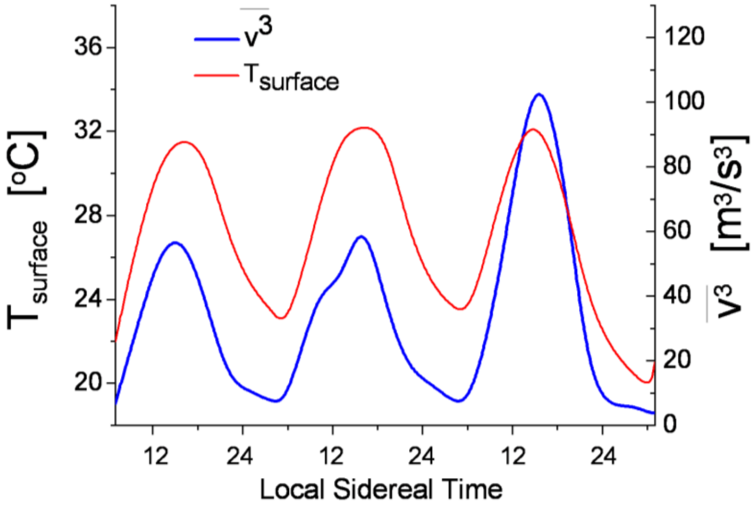


Internet source


Noon insolation [W/m²]
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
March equinox
June solstice
Sept. equinox
Dec. solstice
J F M A M J J A S O N D
Month

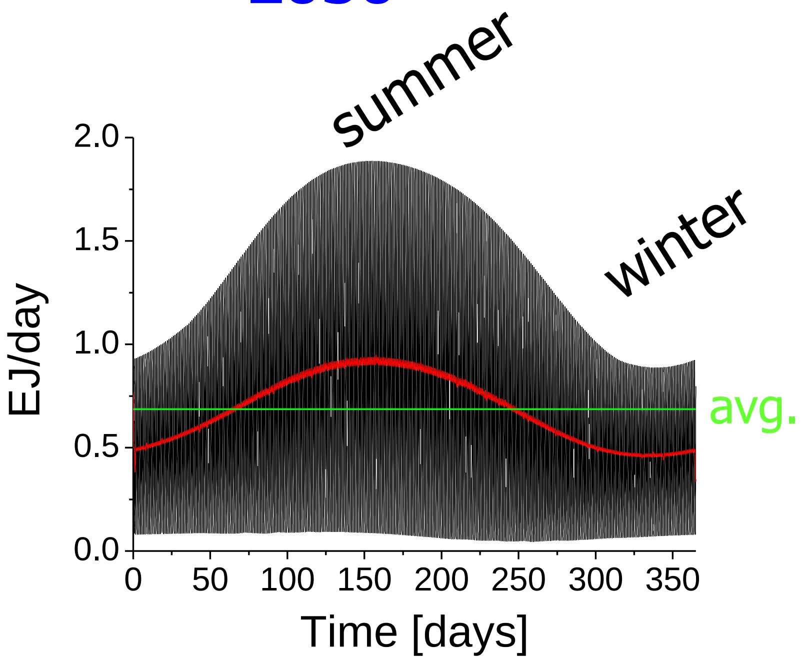
r

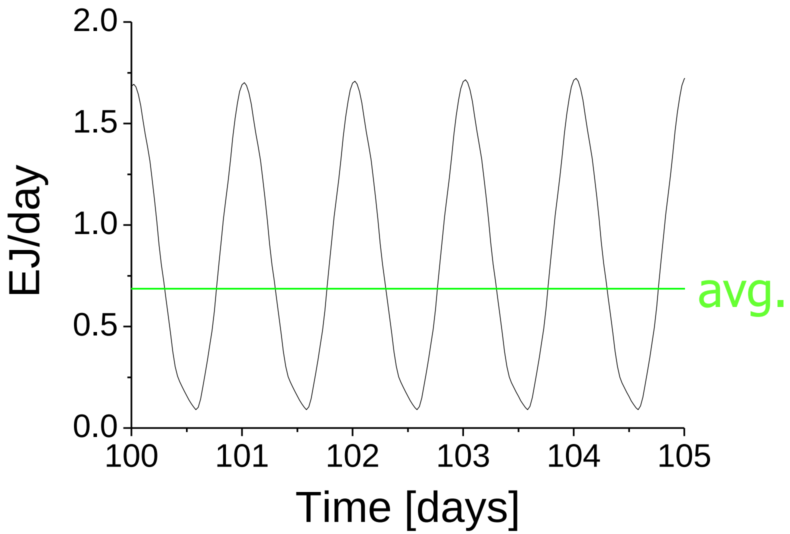

$\overline{v^3}$ [m³/s³]
160
80
0
March equinox
June solstice
Sept.equinox
Dec. solstice
J F M A M J J A S O N D
Month


$\overline{v^3}$
$T_{surface}$
$T_{surface}$ [°C]
36
32
28
24
20
120
100
80
60
40
20
0
$\overline{v^3}$ [m³/s³]
12 24 12 24 12 24
Local Sidereal Time

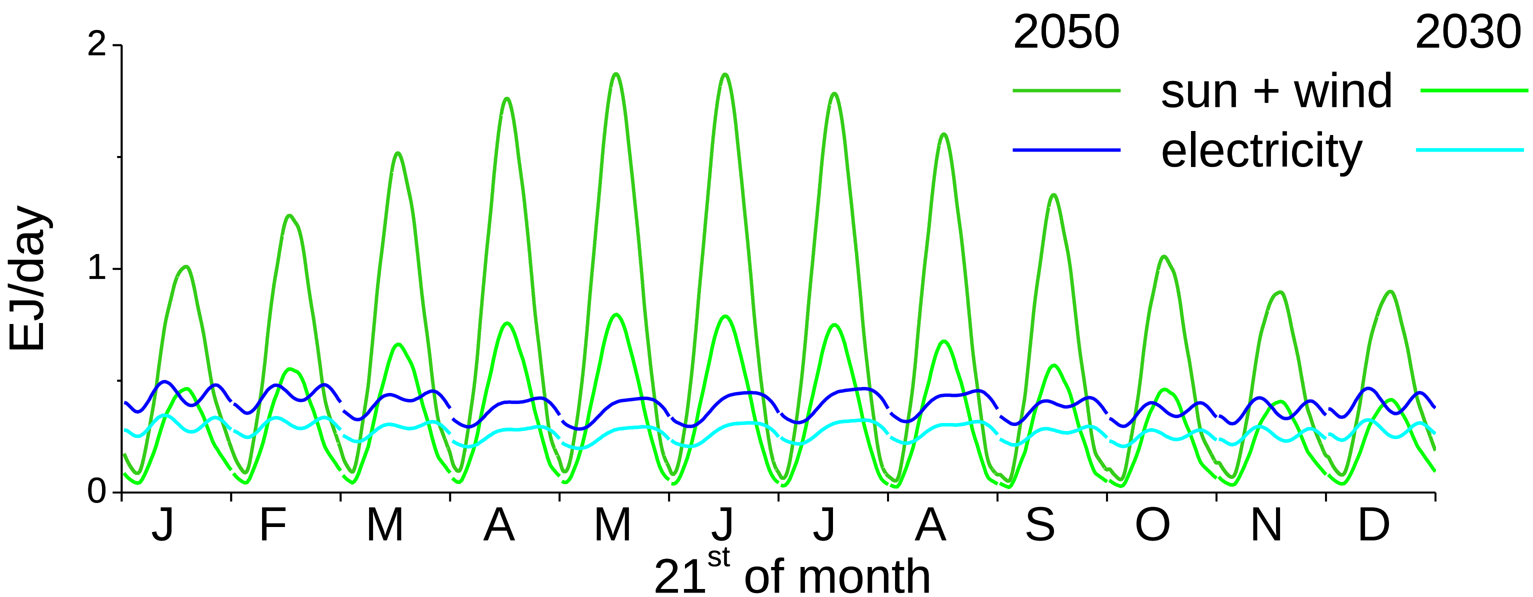
Varying output of renewables on an extended grid

2050

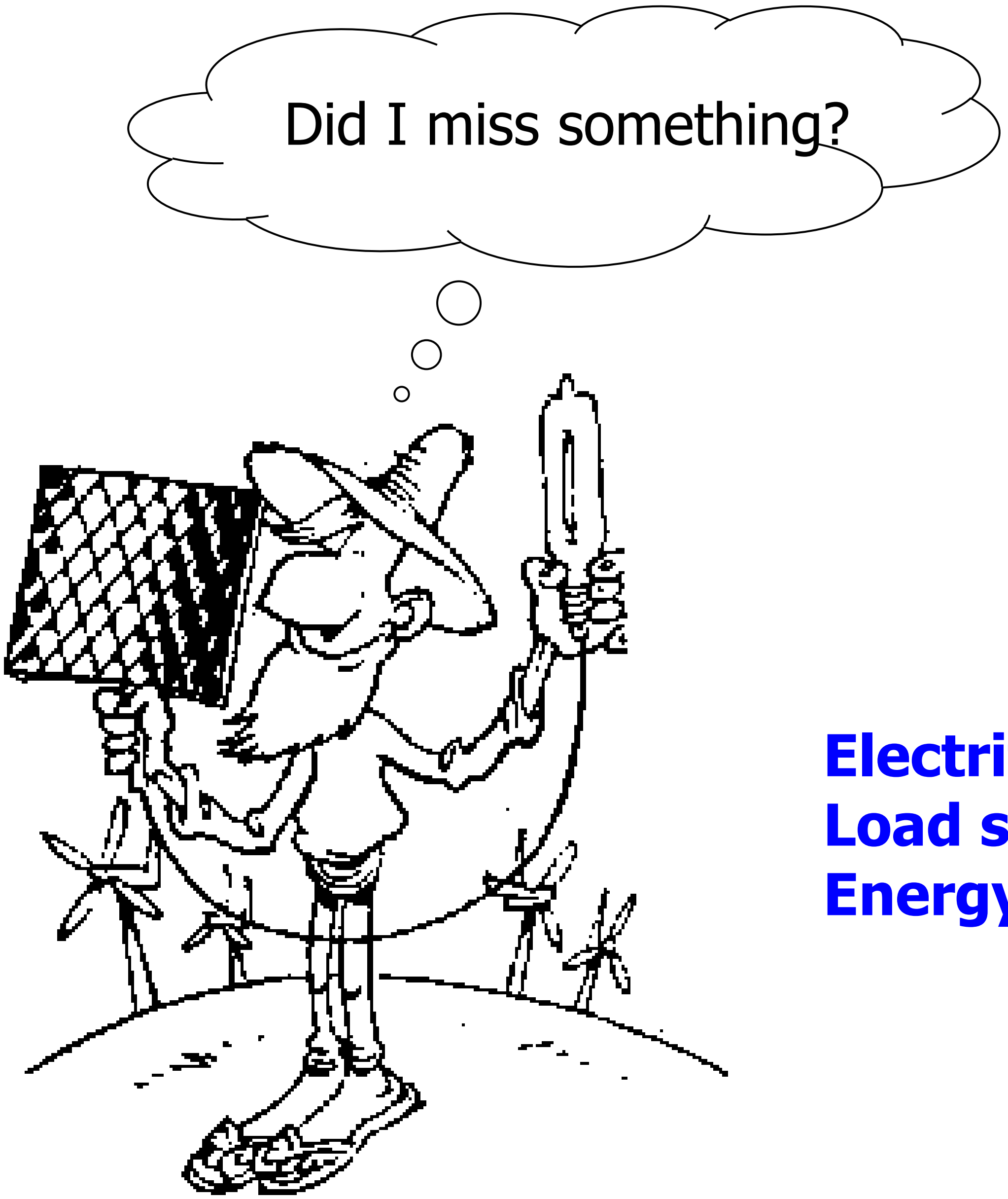




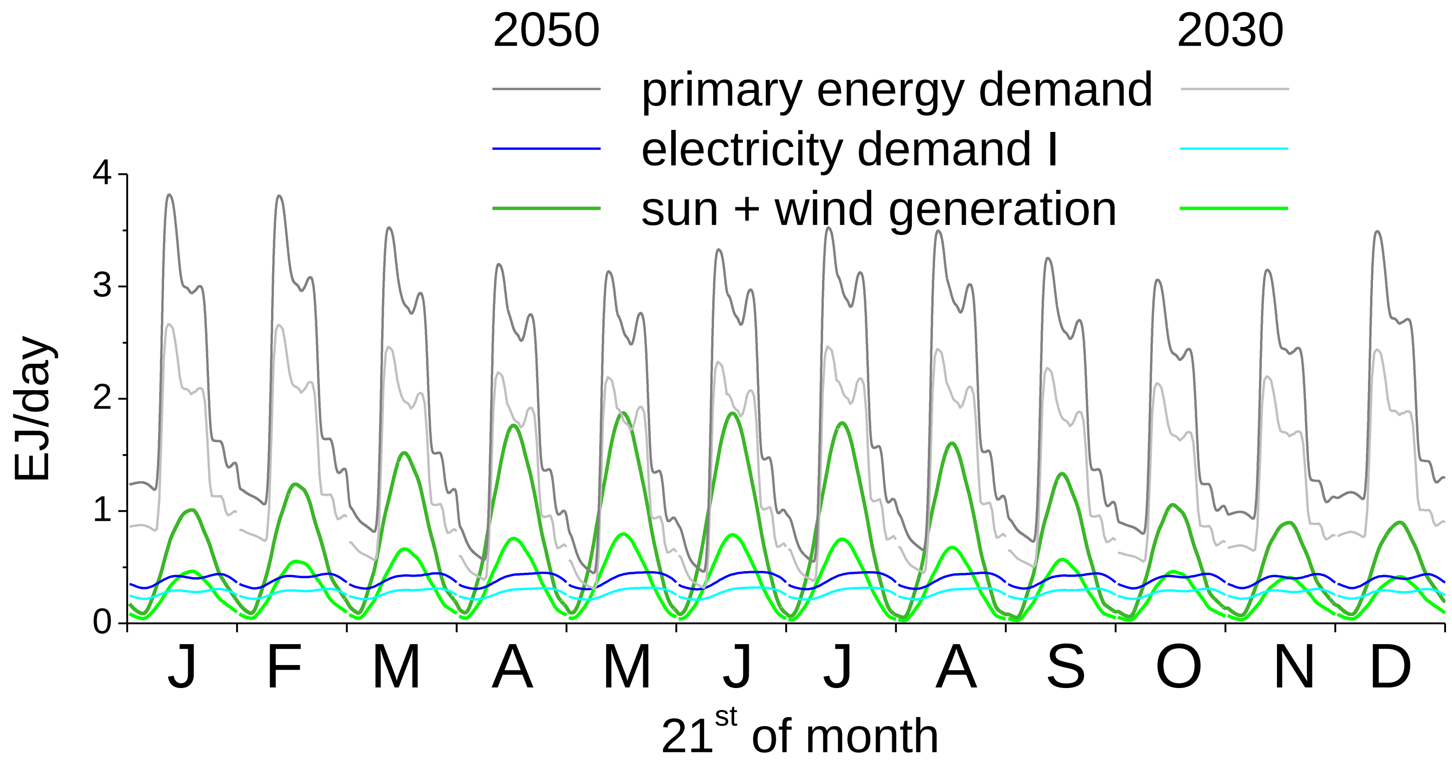
Future sun + wind compared to electricity use



Renewable peak power becomes large compared to peak use

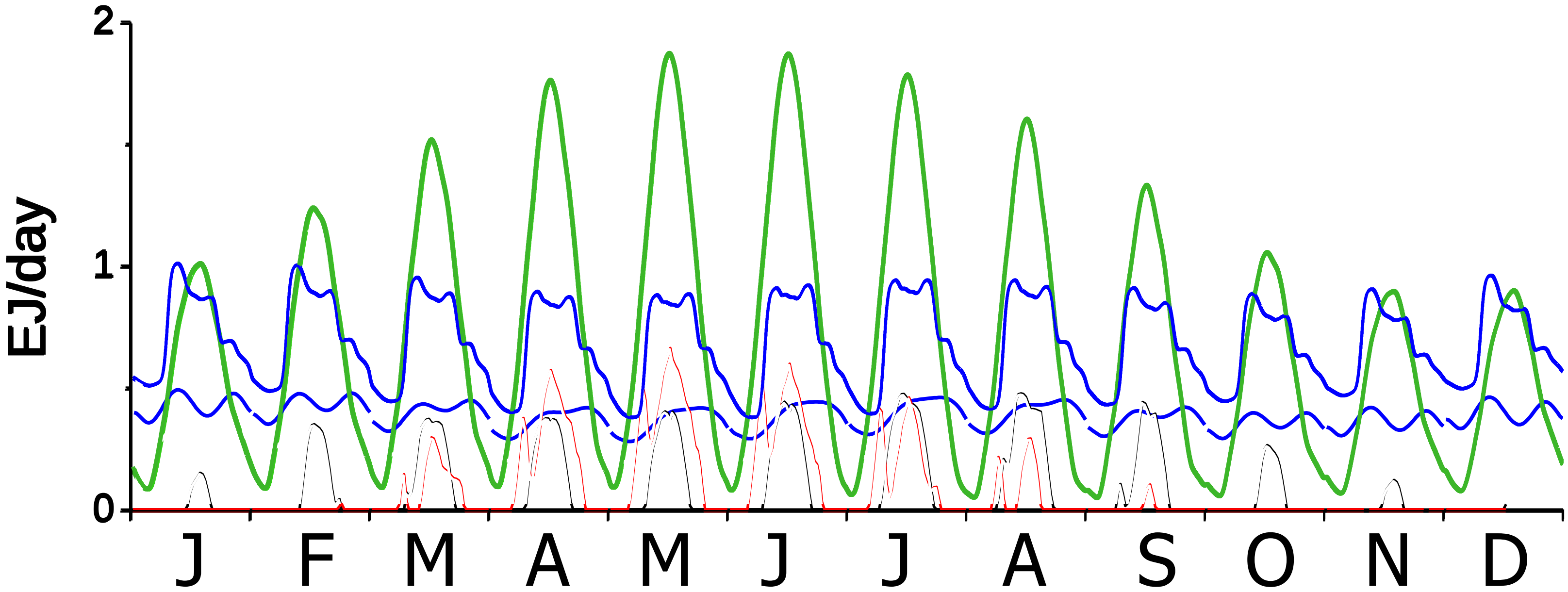


Electrification
Load shifting
Energy storage!


2050
2030
primary energy demand
electricity demand I
sun + wind generation
EJ/day
0
1
2
3
4
J
F
M
A
M
J
J
A
S
O
N
D
21st of month

What to do with too much electricity?

- use electricity for more applications (EV, heating,…)
- match supply & demand by long/short term storage



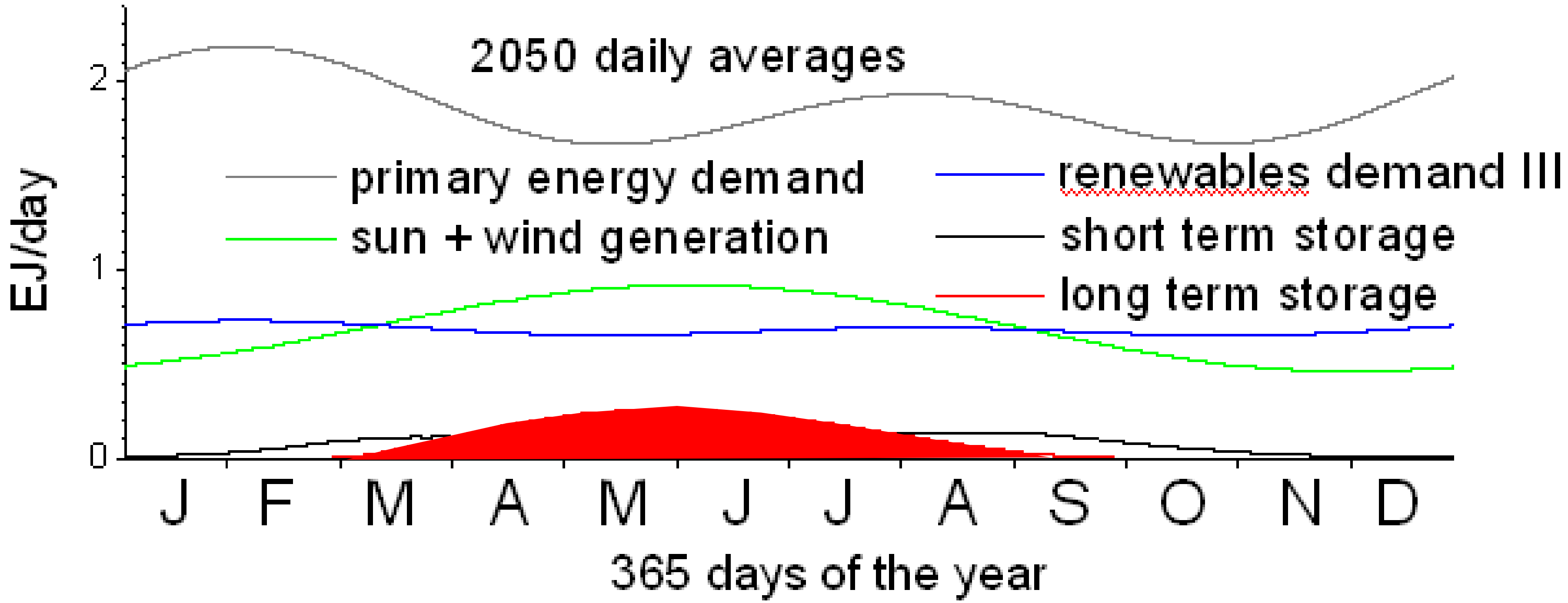
2050:

Short term: 0.2 EJ

NL ~ 44 kWh/house

TUDelft

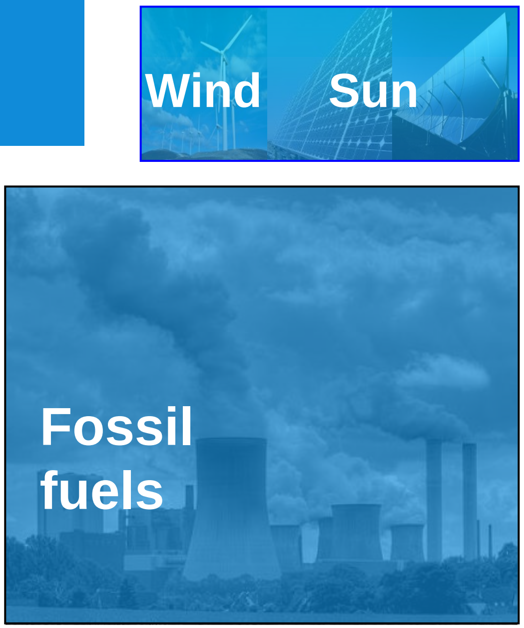
Daily averages…

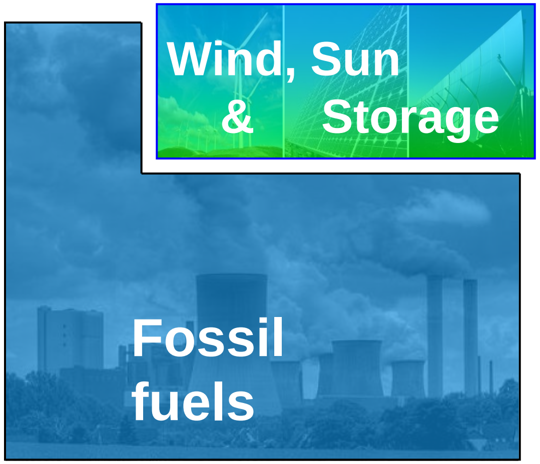


2050:
Short term: 0.2 EJ
NL ~ 44 kWh/house

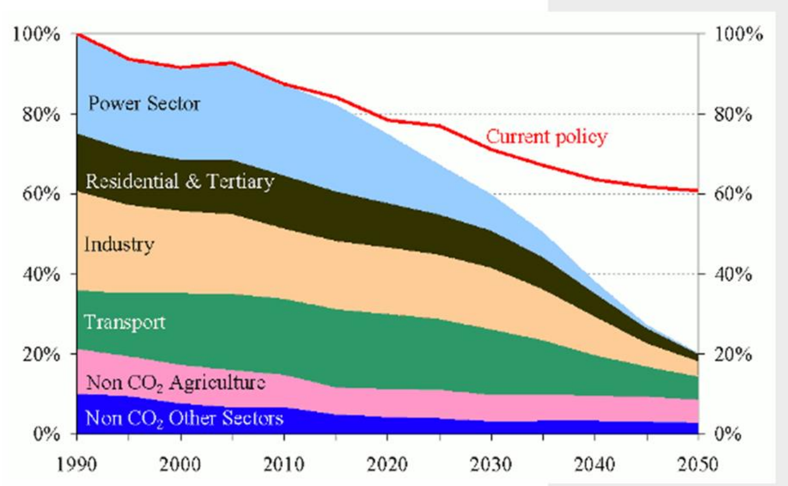
2030:
10 EJ =
2800TWh

2050:
29 EJ =
8000TWh





Note EU Roadmap:
-80% CO_2 in 2050



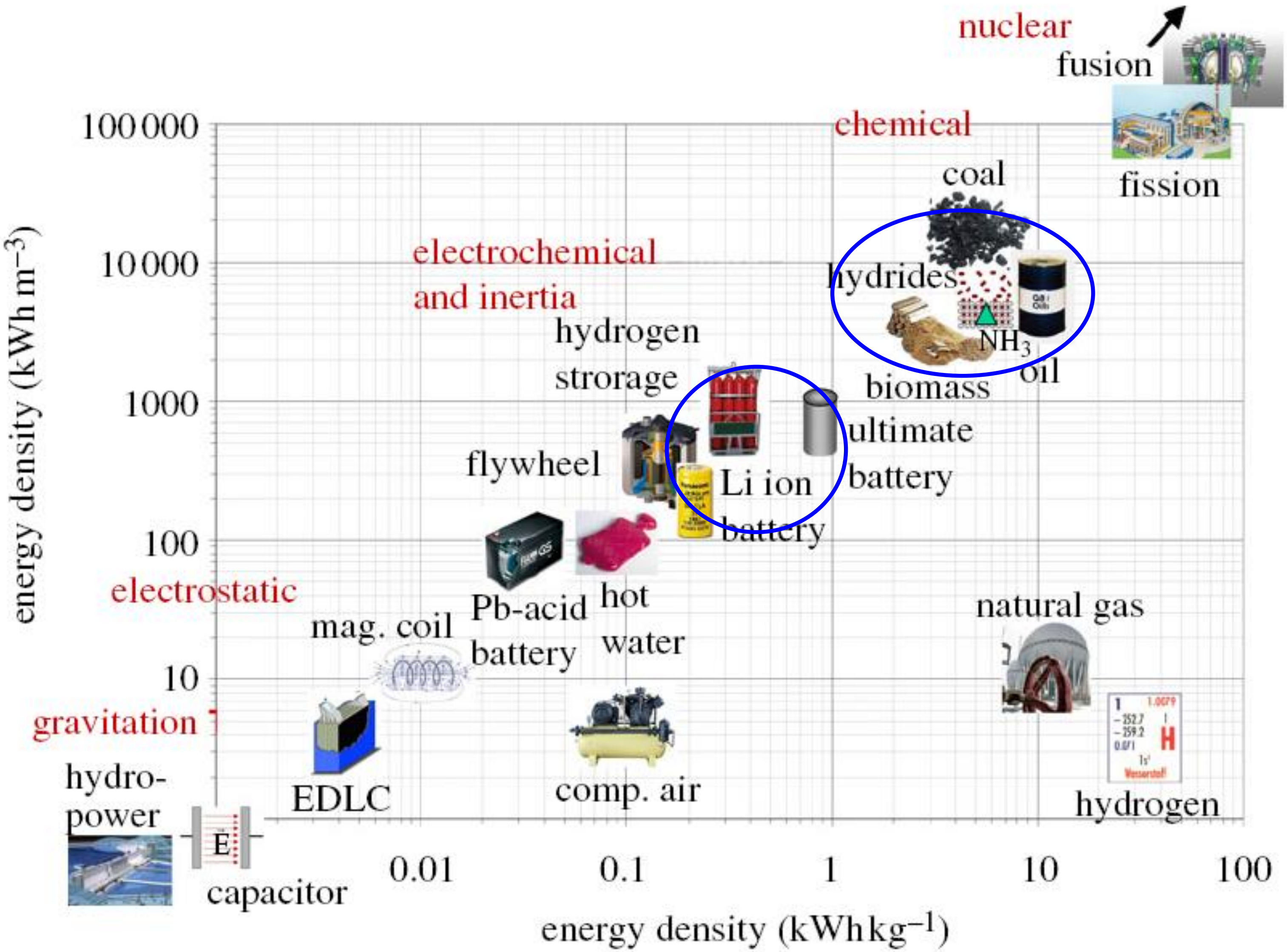
Price effects in Germany during the day:

- Reducing daily price for renewables
- Reducing daily price for fossile power
- High investments in parallel infrastructure

→ Deteriorating earnings at higher cost (for all)

Large scale energy storage is required for economic renewable energy implementation

Energy densities of storage technologies



Solutions for large EJ scale energy storage?

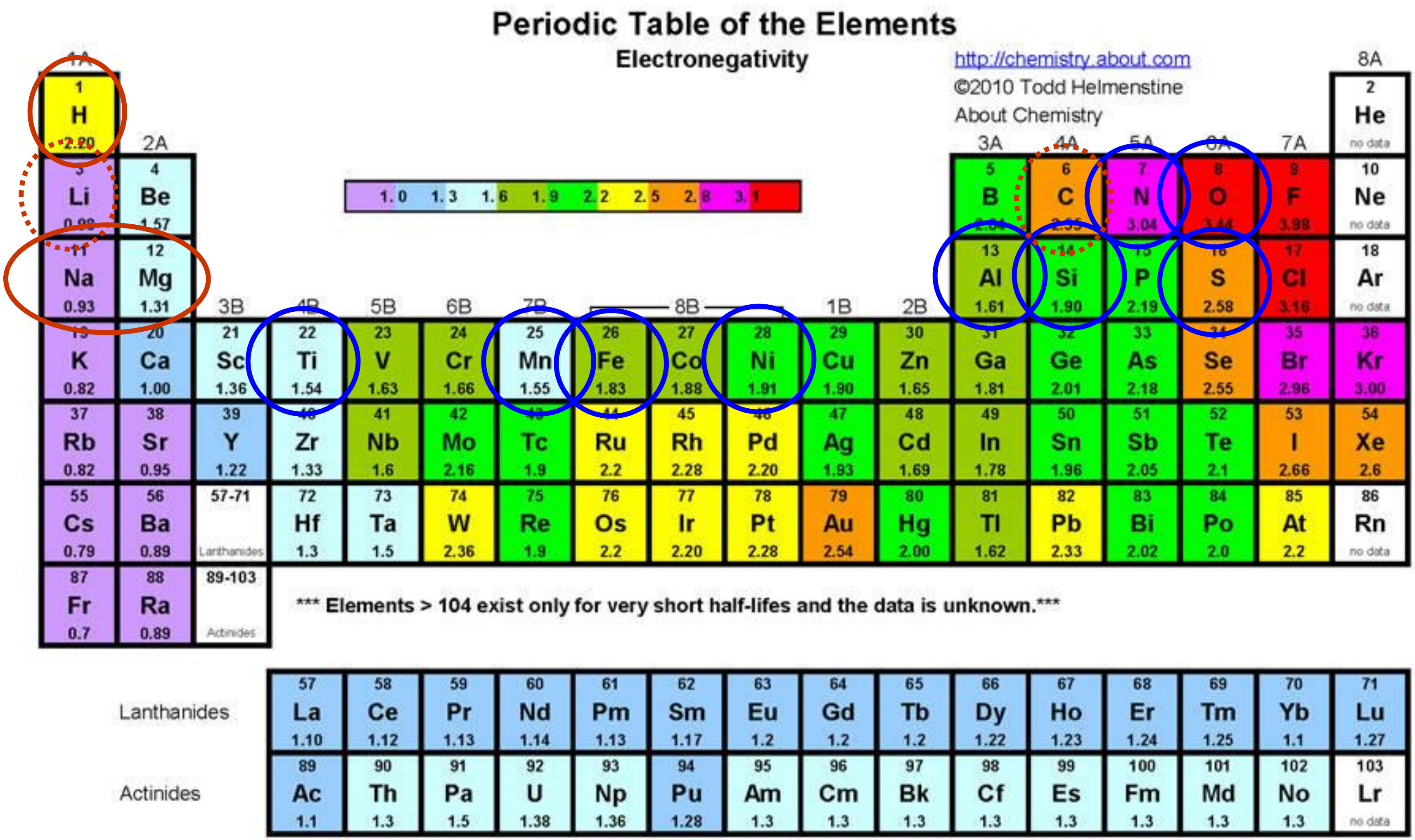
	capacity EJ scale	efficiency $e^- \rightarrow e^-$	Long term	Short term
Hydropower	- -	++ $_{0.8^2}$	-	++
Compressed air	- -	+ $_{0.75^2}$	-	++
Batteries	-	++ $_{0.85^2}$	- -	++
Hydrogen under-ground storage	+	-/-- $_{0.65^2 x 0.85^2}$	++	+
NH_3 (*l*)	++	- - $_{0.3x0.65}$	++	+
$C_nH_mO_p$	++	--- CO_2 from air?	++	+

Research, geology?

Storage options for large scales: to be developed (!)

- batteries	- For the short term only (low J/€) - Requires long life, cheap batteries
- H_2	- Requires large scale storage method itself - Can partially be fed in gas-grid (max 10% ~5GW in Germany, limited compared to current 22GW PV record)
- $C_kH_nO_m$	- Synthetic conventional fuels - Requires a carbon source
- NH_3	- Is already produced & stored at large scale, but not from renewables. - In industrial environment only (safety). - Low efficiency
- heat	- Conversion losses may be recovered as heat, CHP

Preferably abundant elements!



Acknowledgements

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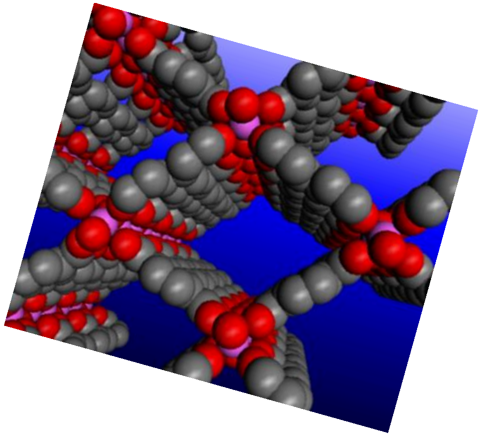
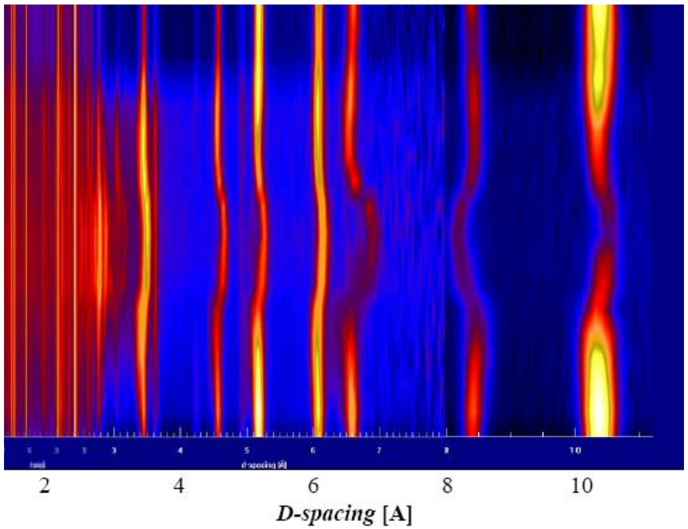
- **U Nijmegen:** Ernst Van Eck, Arno Kentgens
- **ILL (Grenoble, France):** Mark Johnson
  Mohamed Zbiri
- **ANSTO (Menay, Australia):** Don Kearley
- **And others**

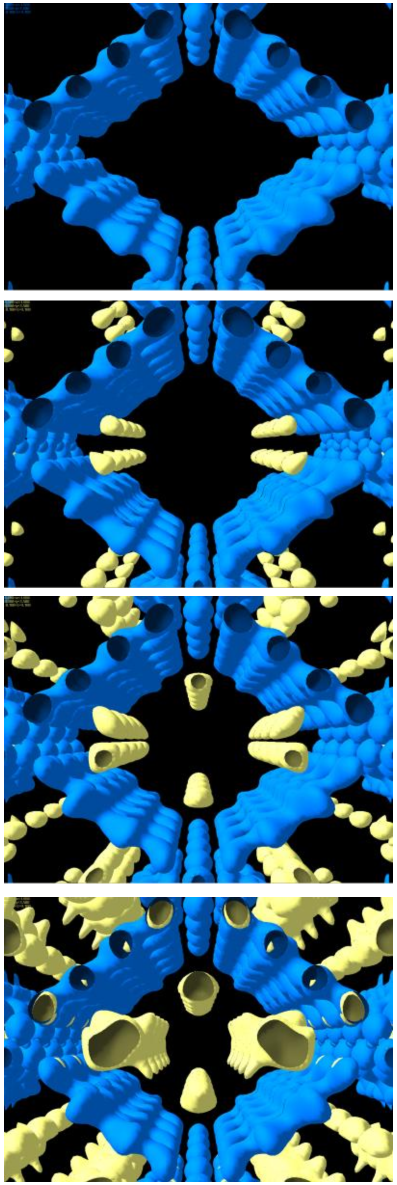
Agentschap NL
Ministerie van Economische Zaken, Landbouw en Innovatie

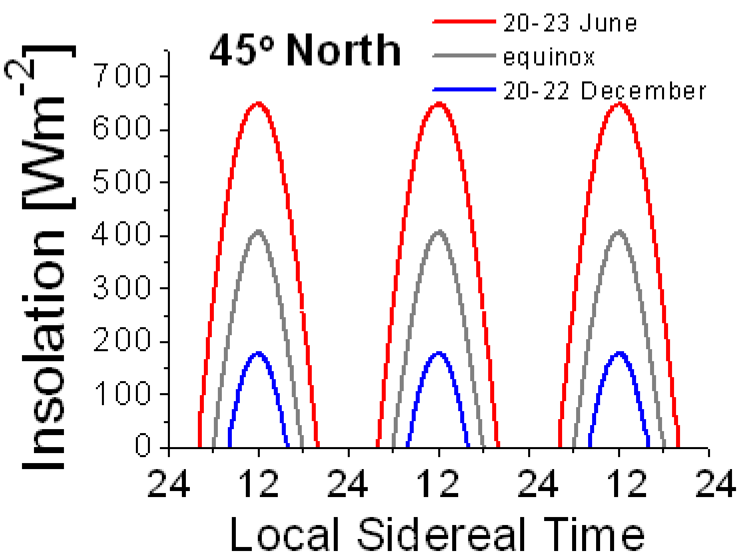


Neutron diffraction measurements

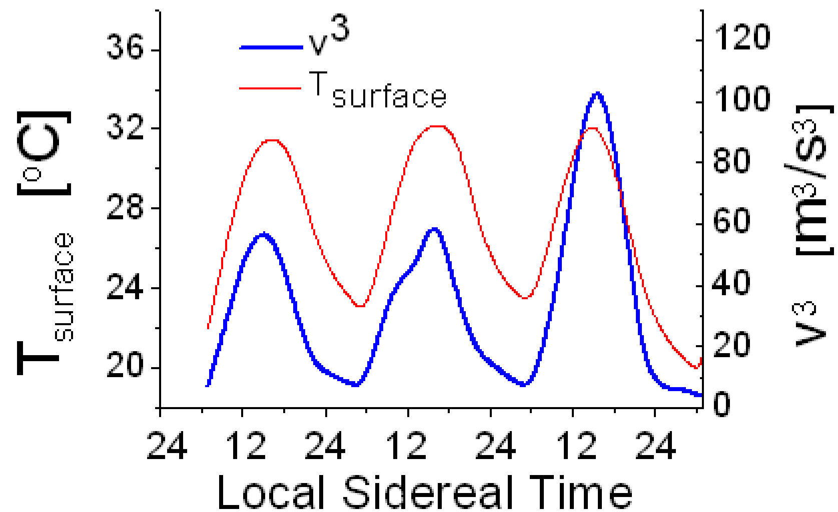


Images of the inside of the material, visualizing the hydrogen





Solar power:
Large variations during the day.
Large difference between seasons



Wind power ~v^3:
Also large variations during the day:
wind is driven by surface temperature
(this becomes visible for very large grid, e.g. 3000x3000km^2)