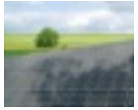


From Societal Challenge to Nano Science

Chemergy:

solar PV and solar fuels

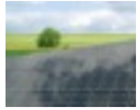
to generate and store

sustainable energy

using nano-technologies

at photon and molecular level

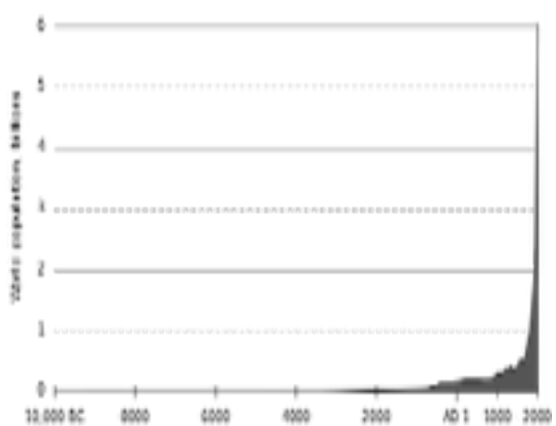
Prof Dr Ir Egbert-Jan Sol
TNO, directeur High-Tech Systems en Materialen
Radboud University Nijmegen, Institute for Science, Innovation & Society

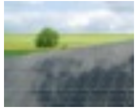


Kardashev's Type 1,2 and 3 Civilisations

- Nikolai Kardashev, 1964: extra-terrestrial civilisations – measure energy use
  - Type 1: planetary civilisation consume sunlight on their planet (10^{16} Watt)
  - Type 2: stellar civilisation consume all energy emitted by its sun/star (10^{26} Watt)
  - Type 3: galactic civilisation consume the energy of billion stars (10^{36} Watt)
  - To put 1000 kg from earth at Mars cost 1-10 Terra Watt (10^{12}-10^{13} Watt)

- How useful? (type 0 & type 4 are of latter date)
  - Type 4 extragalactic – dark energy
    (galaxies energy is only 4% of all energy)
  - Type 3 civilisation the Empire of Star Wars
  - Type 2 roughly Star Trek's United Federations of Planets
  - Type 1 next slide
  - Type 0 at 10^{6} Watt is Earth with 1 M humans in historic time
  - Type 0,7-0,8 Earth today - via horse power, via coal and oil to 10-100 Terra Watt
    = 10^{13}-10^{14} Watt is today energy use from fossil fuel - i.e. dead plants





Kardashev’s warning for approaching Type 1

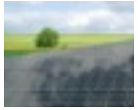
- Nikolai Kardashev, 1964: extra-terrestrial civilisations – measure energy use

- We evolve from a Type 0 tribal civilisation to a Type 1 global society/civilisation
  - English, Internet, UN, middle class, sports/culture, CO_2, ozone, travel/tourism
  - Our energy use will continue to grow and we need to grab/consume all sunlight

- Kardashev’s warning is on excessive use of energy without adequate disposal of heat making the planet of a Type 1 civilisation unsuitable for biology of its dominant life-form and their food sources

- Note: See also Michio Kaku (Type 4 dark energy), Carl Sagan, .. (wikipedia)

- John D Barrow: Type X-minus civilisation is able to manipulate objects of size:
- Type 1: meters, Type 2: Biotech, Type 3: molecules, Type 4: atoms, Type 5: quantum



Chemergy – just like photosynthesis as in nature
Moore's law: from mainframe to tablet in 40 years
Solar learning curve: from power plant to home box

Surplus Electricity

↓

Electrolyze water:

$2H_2O \rightarrow 2H_2 + O_2$

↓

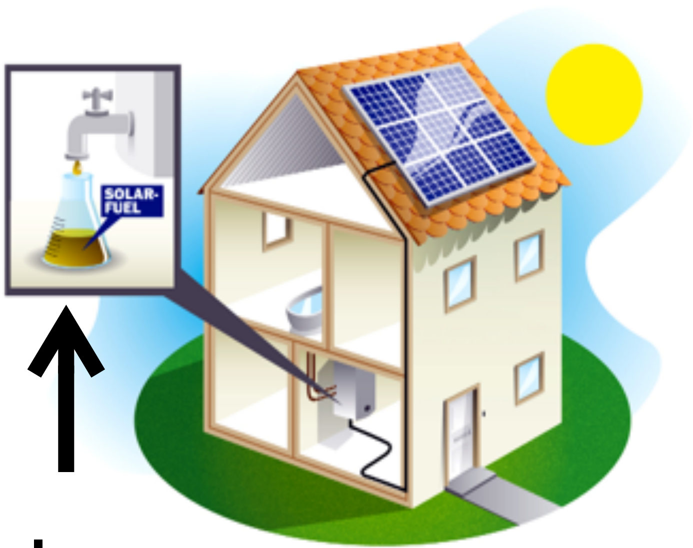
$CO_2 + 3H_2 \rightarrow H_2O + CH_3OH$

↑

Surplus CO_2

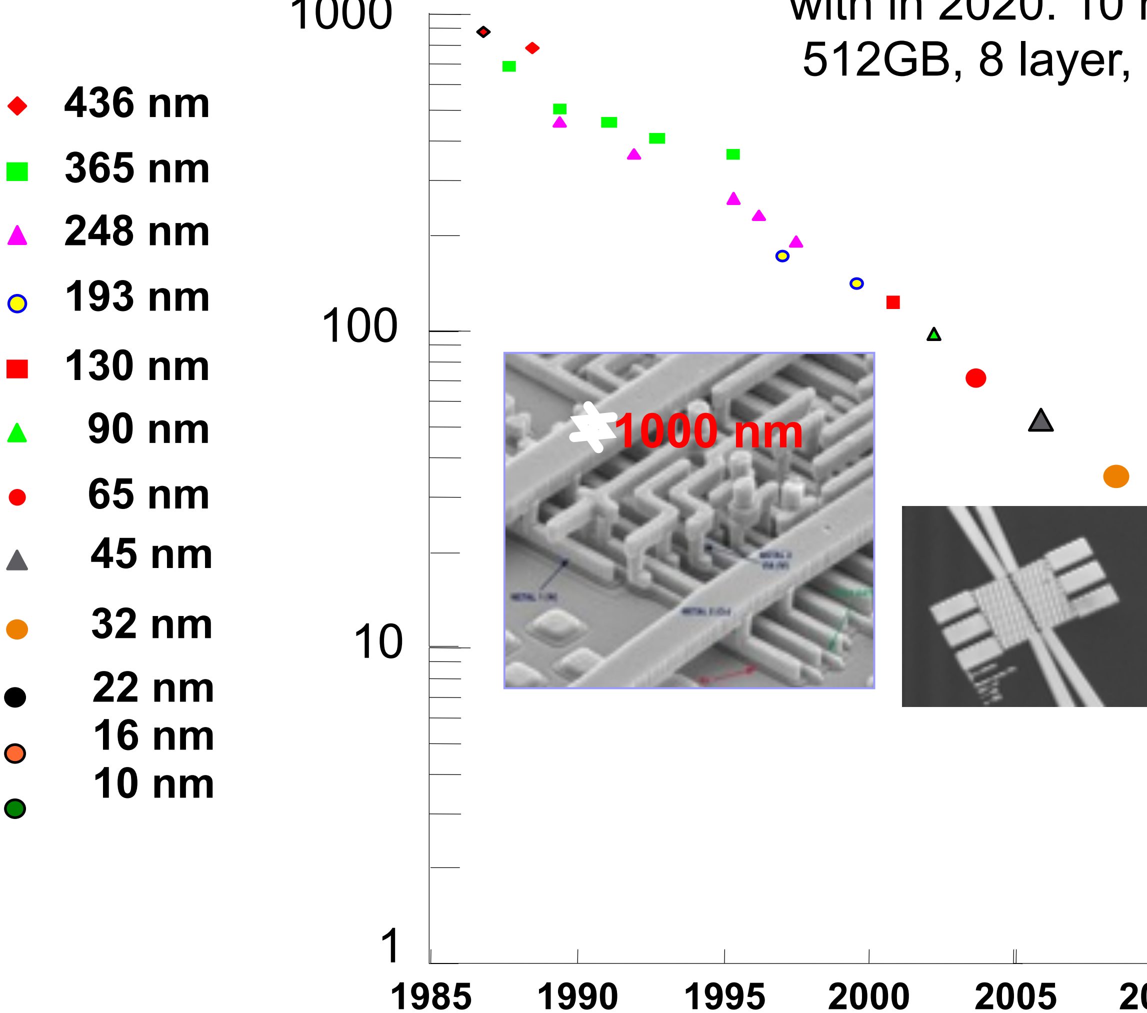
Methanol

↑

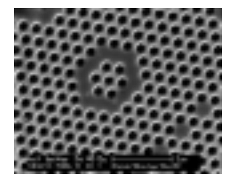


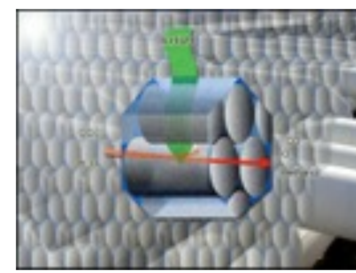
Nano-Tech

From micro-electronics in 1970
to nano-electronics in 2000
with in 2020: 10 nm, 450 mm, EUV, in 3D chip with 512GB, 8 layer, 1000 TSV and 50Gb/s optic. chan.

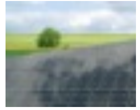


nano-photonics:
Manipulating photons
Si-Photonics 2000-2030
optic computing





nano-cats:
3D nano structures
for chemergy processes



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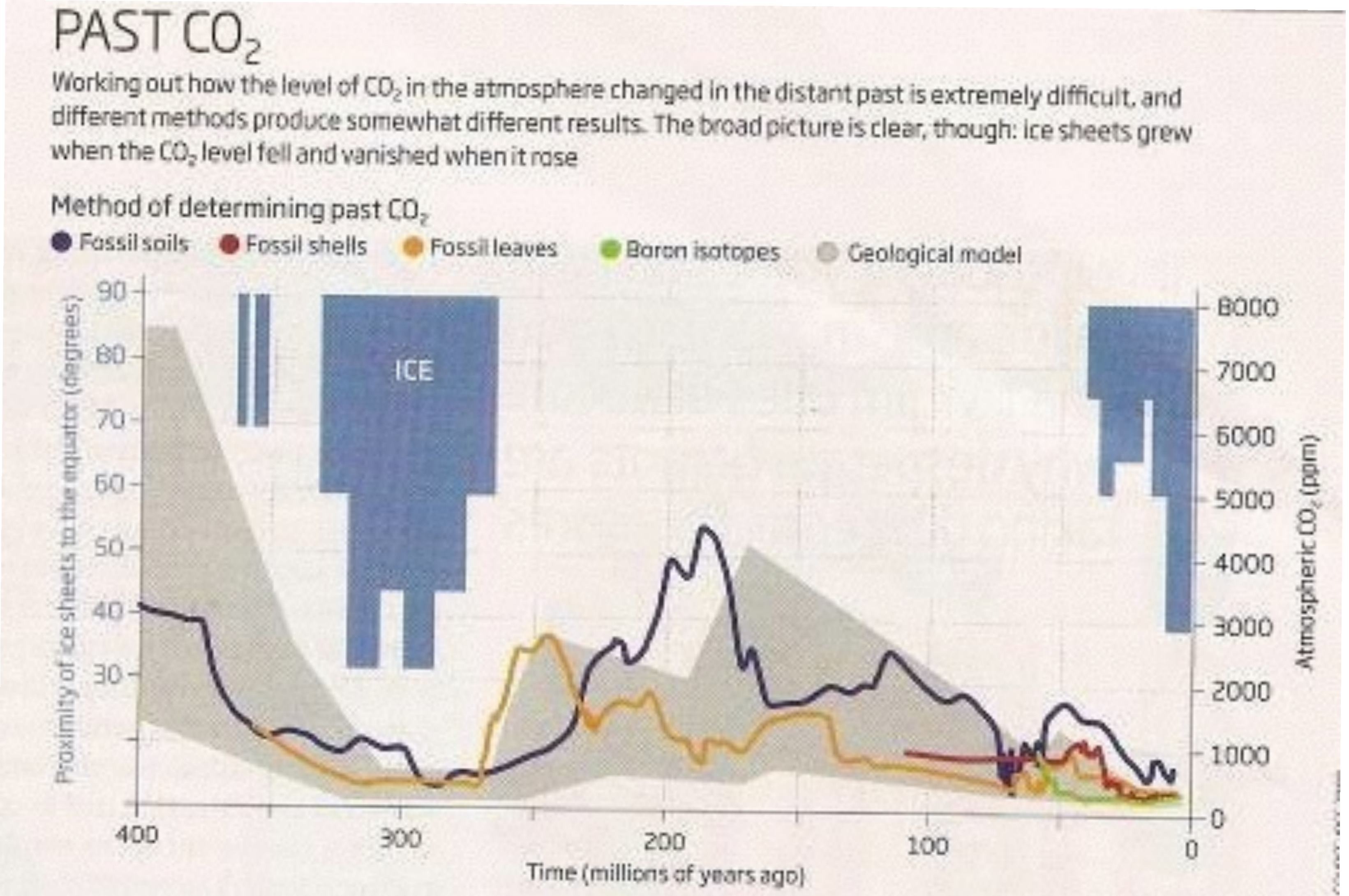
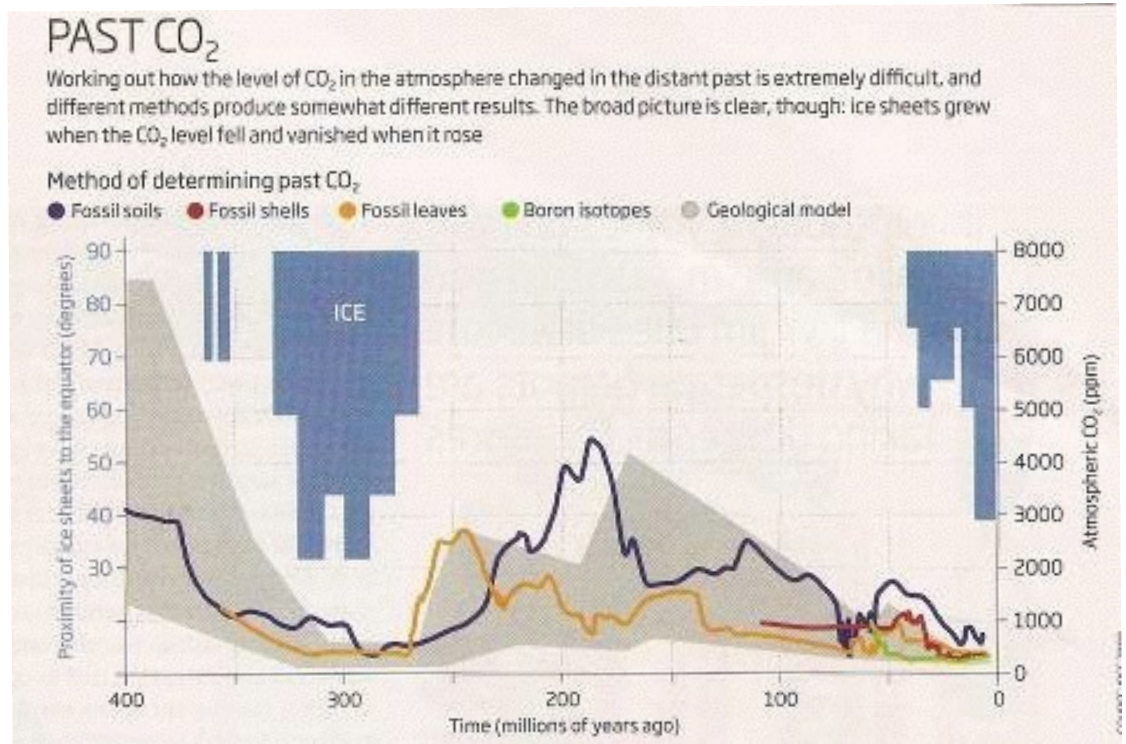
Earth Climate: 300-0 M years



Earth Climate: 300-0 M years

10 degree (0-90) sheet ice from equator and atmospheric CO2 (1000 ppm) versus (horizontal) 400-0 million years (New Scientist, 26 jun 2010) ⟶

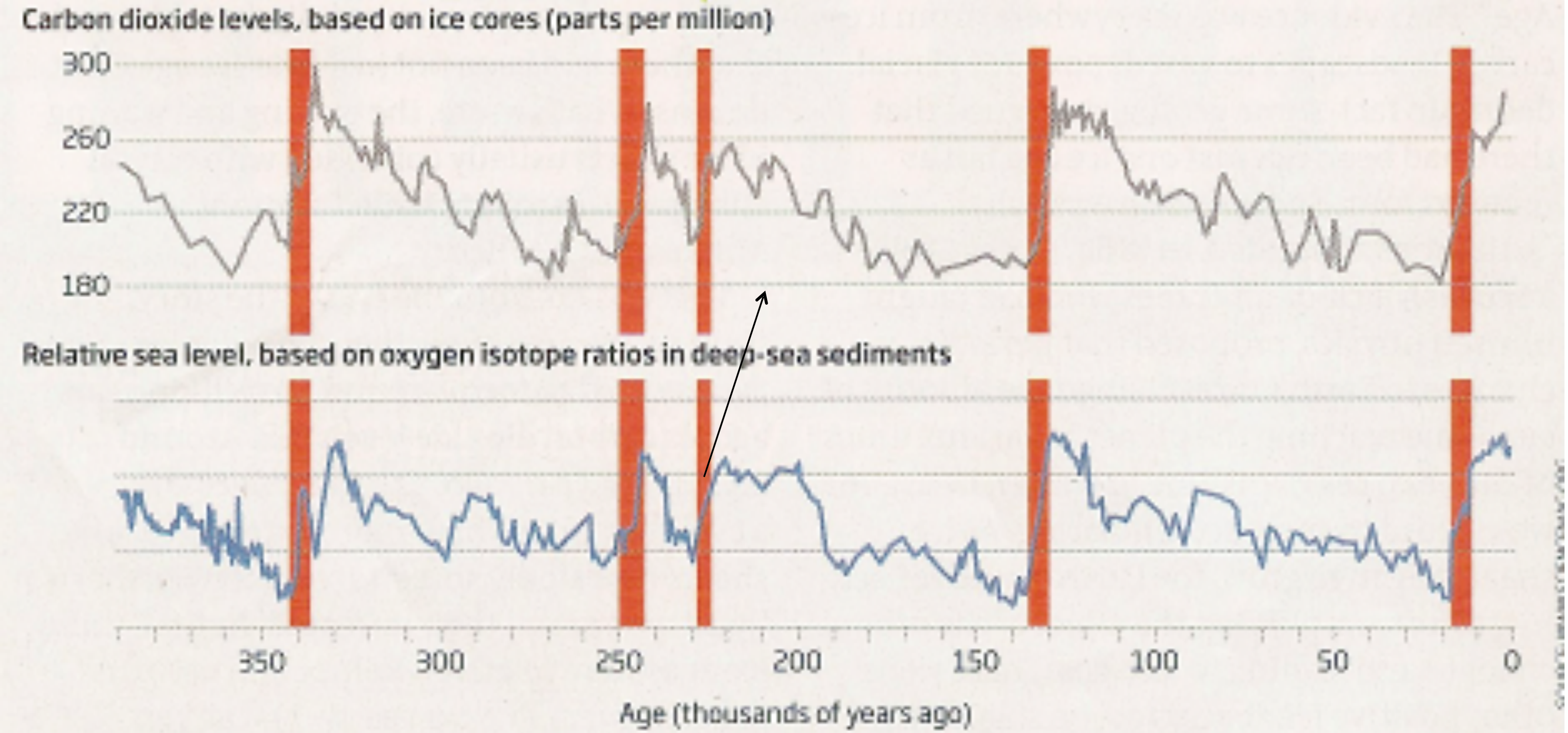


- Sun-type star heat increases by 40% over 10 Billion years, we are half way
- First Billion years on earth, CO_2 created a warm blanket when sun was still cold

- The super ice age 300 M year ago: huge period of ice ages with low CO_2 and sea level -120 m below today and **at warm periods 75 meter above today**

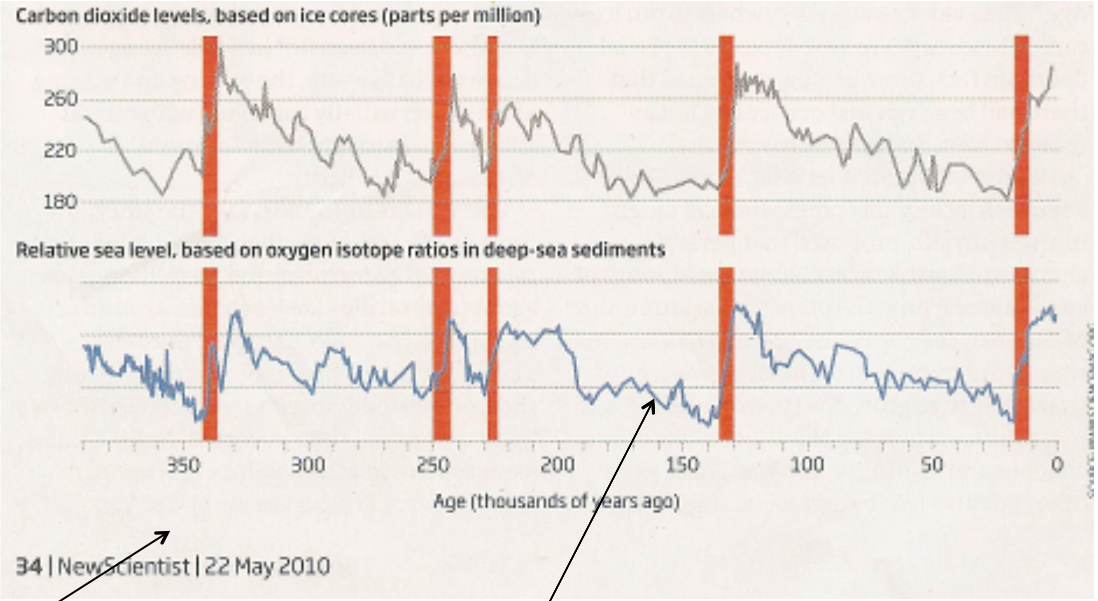
- Antarctica and Greenland 15% of world area (Wikipedia) with 1500 m thick land ice, if melted 65 m sea level rise

Earth Climate: 300.000 years



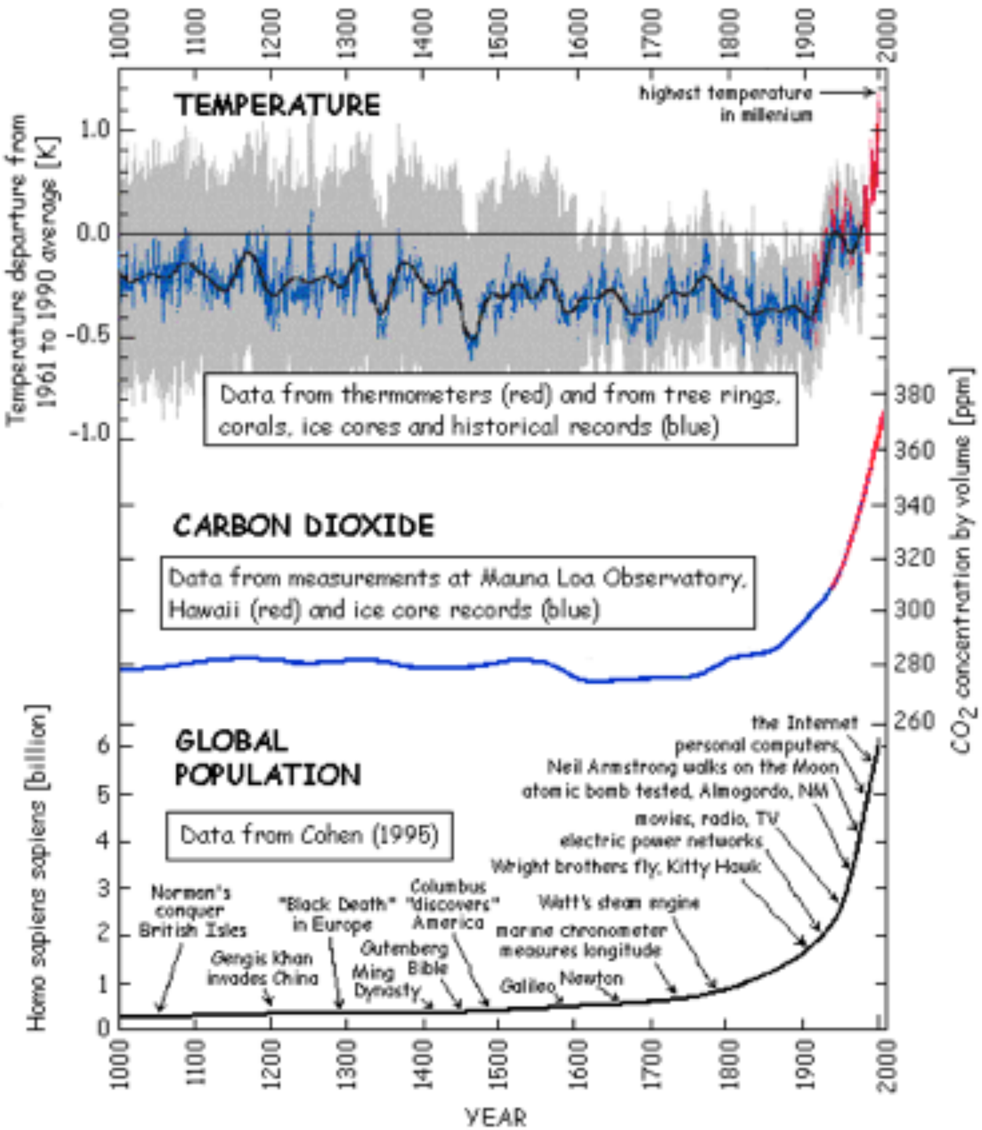
34 | NewScientist | 22 May 2010

Earth Climate: 300.000 years



- Earth:
  - 4.5 B year old
- First humans:
  - Lucy: 4 M year
  - more signs 1 M
  - Homo Heidelberg: 300.000 year
- Ice age around 140.000 ago: 6 m rise in less then 100 years and a transition in 5000 years from max ice to no/normal ice
- Back to Miocene (20My ago): 40 m sea rise and 6 oC warmer (New Scientist (22 may 2010, p36) with the good new: no ice ages any more)
- Note: CO2 levels between 180 en 300 ppm, today 400 ppm

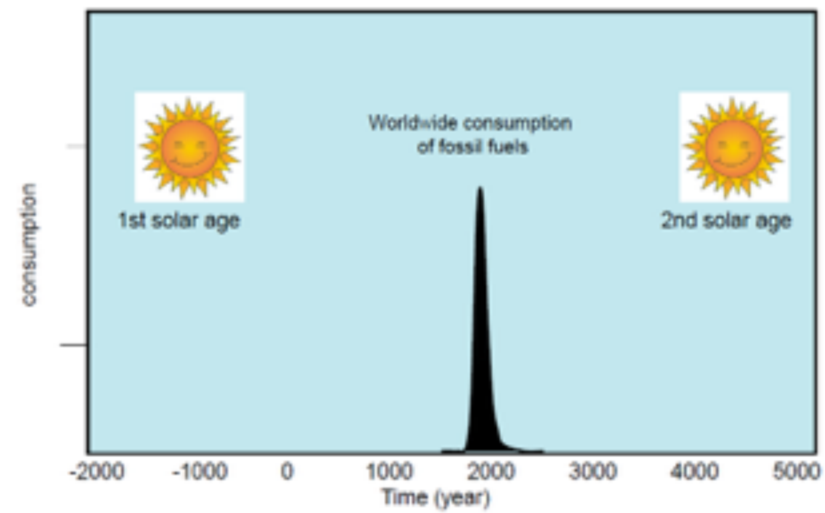
Egbert-Jan.Sol@TNO.nl

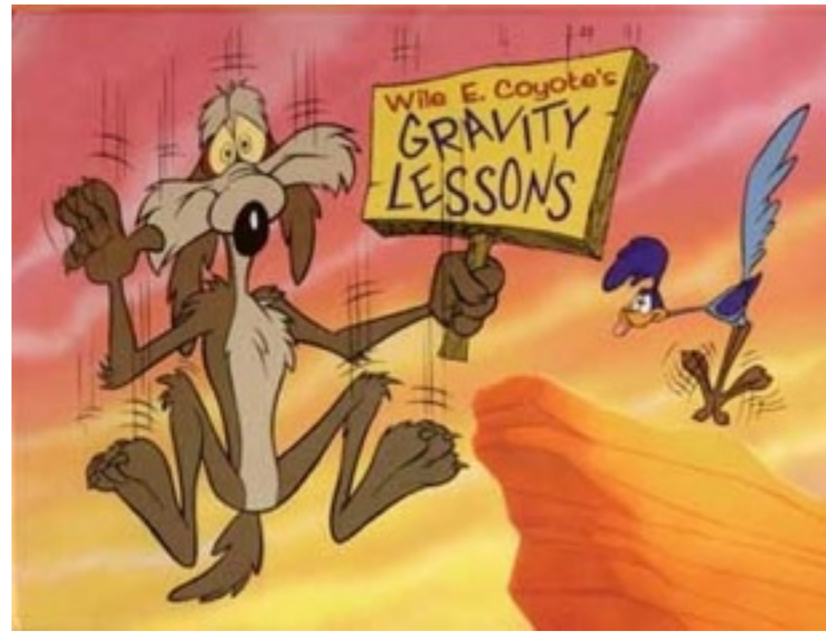
Earth Climate:

4.500.000.000 year old
300.000.000 (super ice age)
300.000 (humans)
3.000 years

and one conclusion:
2^{nd} solar age



Politician turn facts (CO2 level) into opinions (nothing wrong) and from opinions (free market) they make facts (do nothing)



in other words, in their eyes

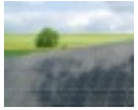
“we can beat gravity”

Scientists & engineers work with

numbers, laws of physics,

calculations and learned lessons of previous experiences.

But our energy use is so large you hardly can imagine it.
125 kWh/d/p = 4 kg oil, 8 kg gas, 4 kg coal => 30 kg CO_2 x 16 M in Nl

TNO innovation for life

Some facts on solar PV (PhotoVoltaic) panels

Energy = Joule = Watt x sec = kWh (compare it with distance (km))

Power = Watt, in solar W_p (Watt-peak) (similar to speed = m/s or km/h)

Solar radiation in NL is 1000 W_{peak}/m^2 , then PV at 20% efficiency gives 200 W_p/m^2

1 W_p power (Watt-peak) solar PV generates ≈ **1 kWh energy per year**

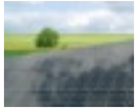
Price for a solar panel is today 1-2 €/W_p and cost 200 - 400 €/m^2

Your roof 20 m^2, then you get 4000 kWh/y solar PV for 4000-8000 €.

8000 € at 25 year at bank (2% interest, 1,2% tax) vs. 25 y x 4000 x 0,20 € = 20.000 €.

but solar PV is peaky (6h/d peak at 20 m^2 at 200 W = 24kWh/d)

but your average use per household is 3600 kWh/y, or 10 kWh/d, so you need buffering



Storage is needed, use old e-car batteries (at 80%)

For 20 h (24 – 6 h sun) you need 18/24 of 10 kWh ≈ 7,5 kWh storage needed

Lead battery (car) 35 Wh per kg ≈ 7500 Wh/35 Wh/kg ≈ 200 kg

Lithium-ion 150 Wh per kg ≈ 50 kg but expensive 10 kWh at 4000 Euro

Electrical car: 10 kWh gives you 50 km

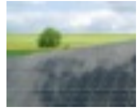
Tesla S (new car model): 60 kWh version has 400 kg batteries at 50.000 $

10 kWh = 5 hour charging x 2 kW = 5 h x 2000 W = 5 h x 220 V x 10 A

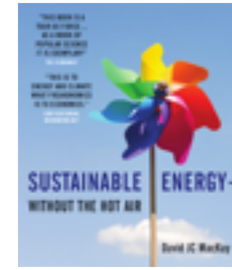
And other 10 kWh solar panels requires another 18 m^2 on your roof

(use 3 year old, least performing car battery at home of 8 kWh storage,

And keep your car at home during sun shine, or buy a second car for the other day)



MacKay: Sustainable Energy without hot air



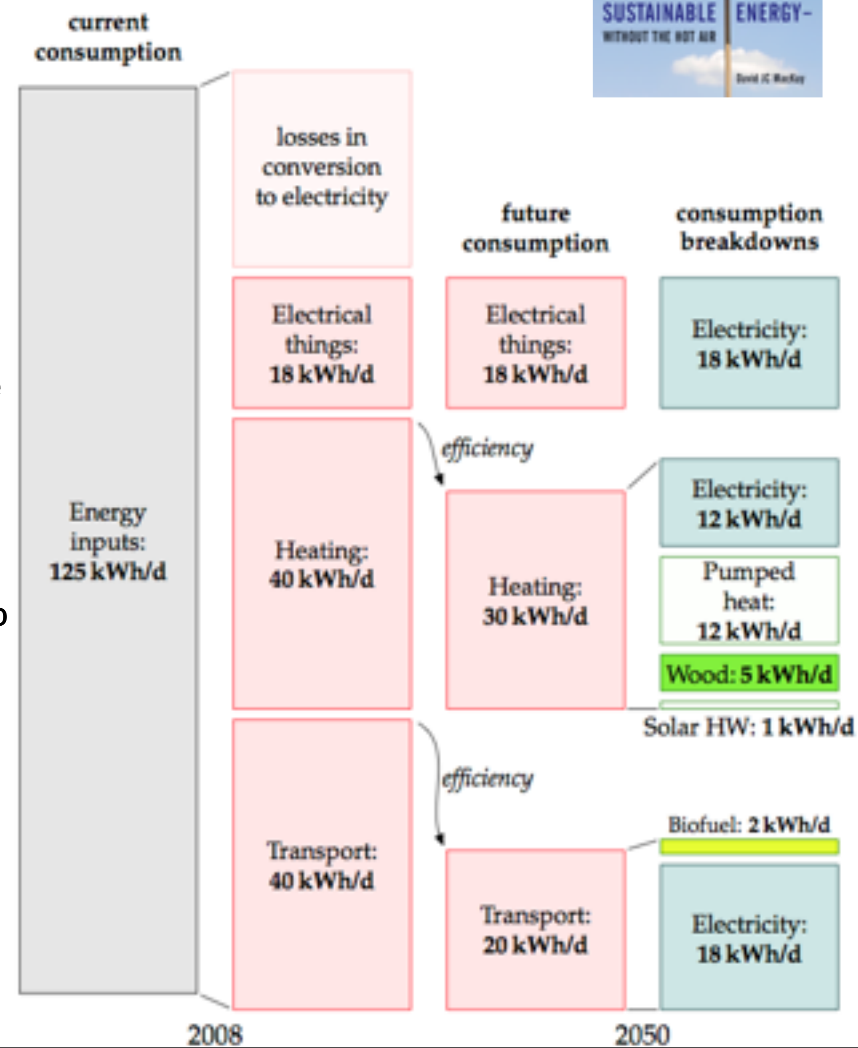
www.withouthotair.com
to download book in PDF

Ambition full sustainable in 2050:

Electrical energy use per person
≈ 50 kWh/d/p, or 100 kWh/d/house

100 kWh/d/p in 2050, then you
need 200 m^2 PV / house at 20%
or say 100 m^2 PV / house at 40%

If storage at 10 kWh/d/home took
already 200 kg lead batteries,
100 kWh/d is not realistic, or with
Lithium-ion (10 x 50kg) too costly



So far that was a lot of info, but possible

You don’t have 100 or 200 m^2 on your roof, only 20 m^2 shadow free max.

You can have some batteries for 10 kWh storage for a 24h cycle,
but not for 100 kWh for a 24h cycle and the whole year cycle.

8 Million household that require 80-180 m^2 (1/200 -20 m^2 on own roof) =
8 M x 80-180 m^2 = 640-1440 km^2 40-20% efficiency panels in NL
NL is 37-40.000 km^2 large, so 2-4% of landscape will be covered
mostly 1-2 hectare of the 50 hectare per each farmer.
(note: today NL has 150 km^2 horticulture under glass)

let’s say we need 640 km^2 solar PV, impressive, but doable by 2050

MacKay: Sustainable Energy without hot air

MacKay: www.withouthotair.com
to download book in PDF

Electrical energy use per house
≈ 100 kWh/d/house by 2050

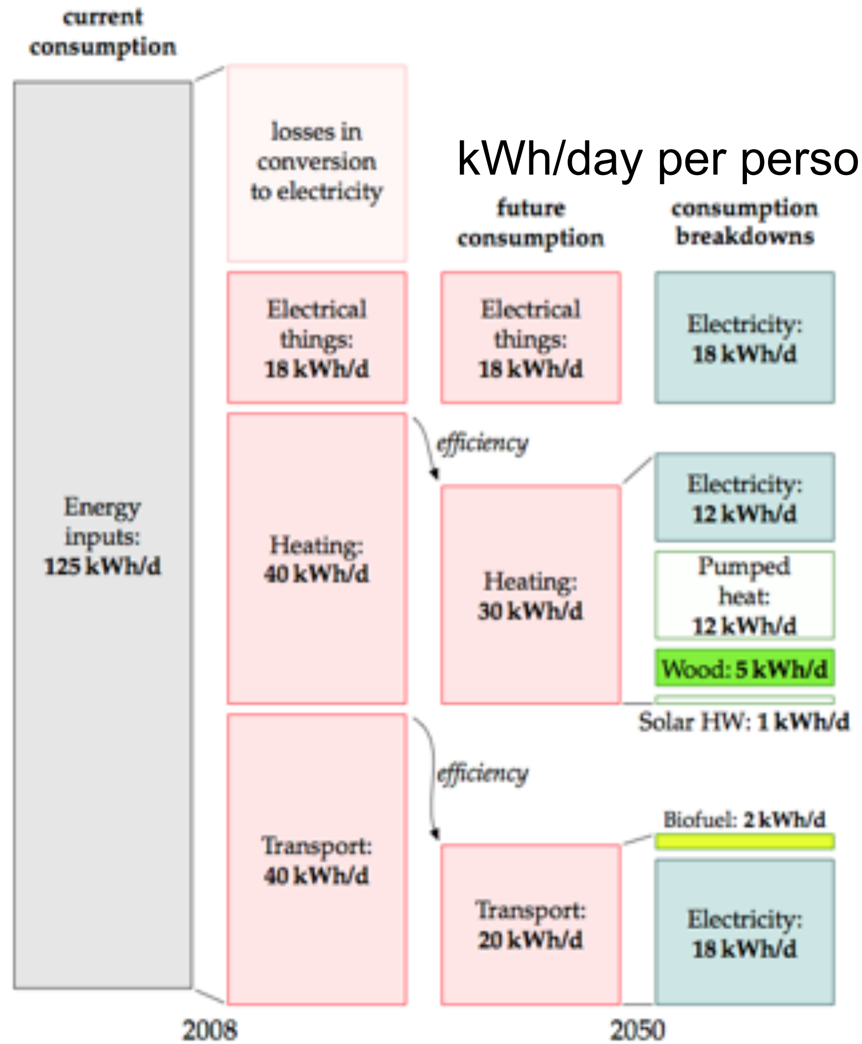
Today house: 10 kWh/d/2p, doable with 20 m² and 4000+ €.

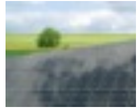
100 kWh/d/h in 2050, then you need 200 m² PV / house at 20% and at a cost of 40.000 €

To store today 10 kWh/d/house takes already 200 kg lead batteries, then 100 kWh/d need 2000 kg at costs approaching 40.000 € / 3 year

Challenge: Sustainable with PV

Yes, by 2050 but ..





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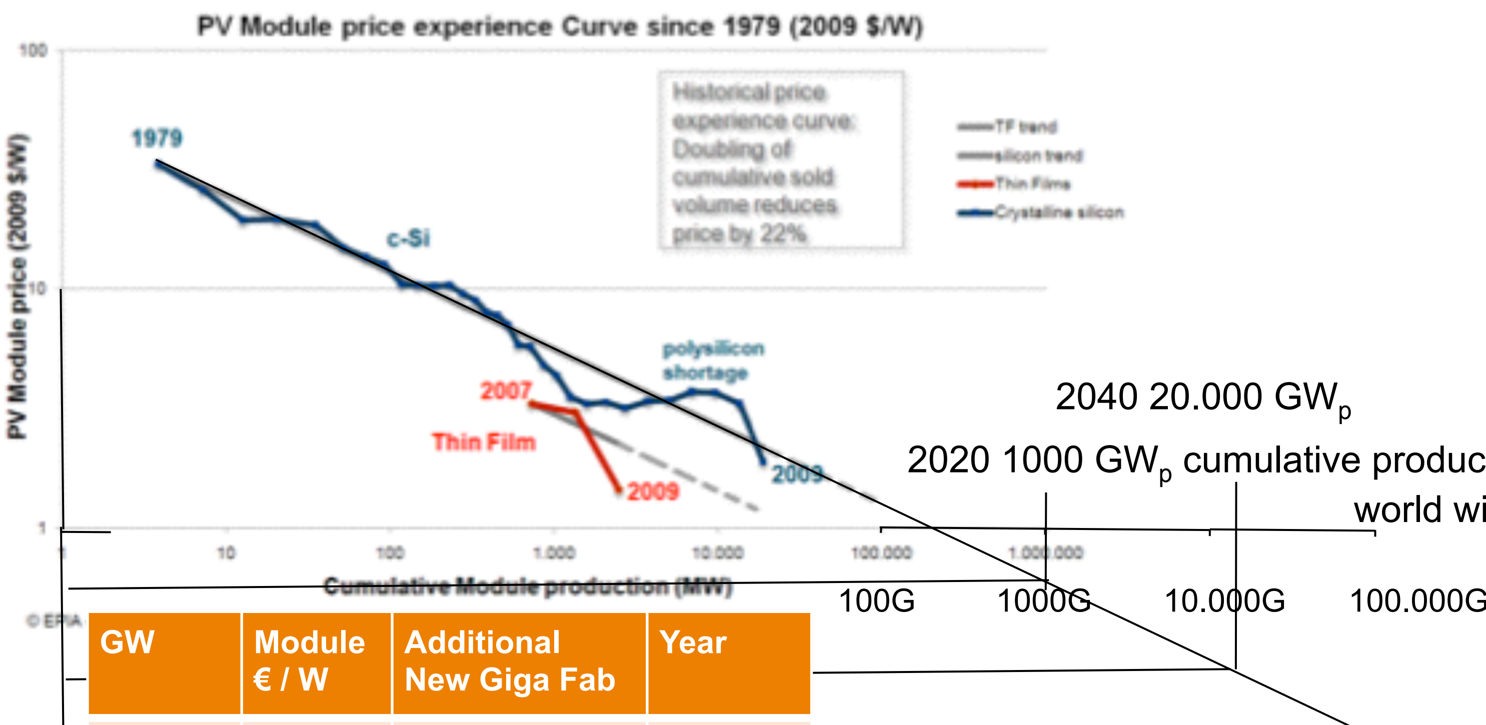
Solar PV Module learning curve (after EPIA 2009)

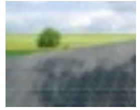


2040 20.000 GW_p

2020 1000 GW_p cumulative produced world wide

GW	Module € / W	Additional New Giga Fab	Year
20	2	➔	2010
250	1	➔+15	2015
1000	0,60	➔+47	2020
4000		➔+71	2025
8000	0,30	➔+96	2030
24000	0,20	➔+146	2040

2040: 20 m2 at 40% efficiency and 0,2 €/W_p costs 1600 € and gives you 8000 kWh/y



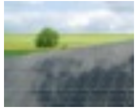
Solar basic scenario in GW_p

Solar	NL	Germany	EU/Europe	World EPIA 6	World IEA 2010
People &space	16M and 41k km	80M and 350k km	≈400M/750 4M km		≈8B 150 M km
2010	<1	14		35	40 GW
2020	4-10	52	125-375	350-700	200 GW
2030	10-30		275-650	1000-1850	
2040				(2000-3000)	1800 GW
2050	30-80			(3000-4500)	3000 GW

Netherlands 60 GW_p in 2050 100% sustainable electricity is do-able

Is 3000 GW_p worldwide (in 2050) possible?

(World electricity usage today 10TW=10.000 GW, Solar 2012 1% 100 GW_p)

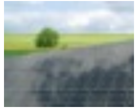


Is it possible to produce 3.000 GW_p in 2050?

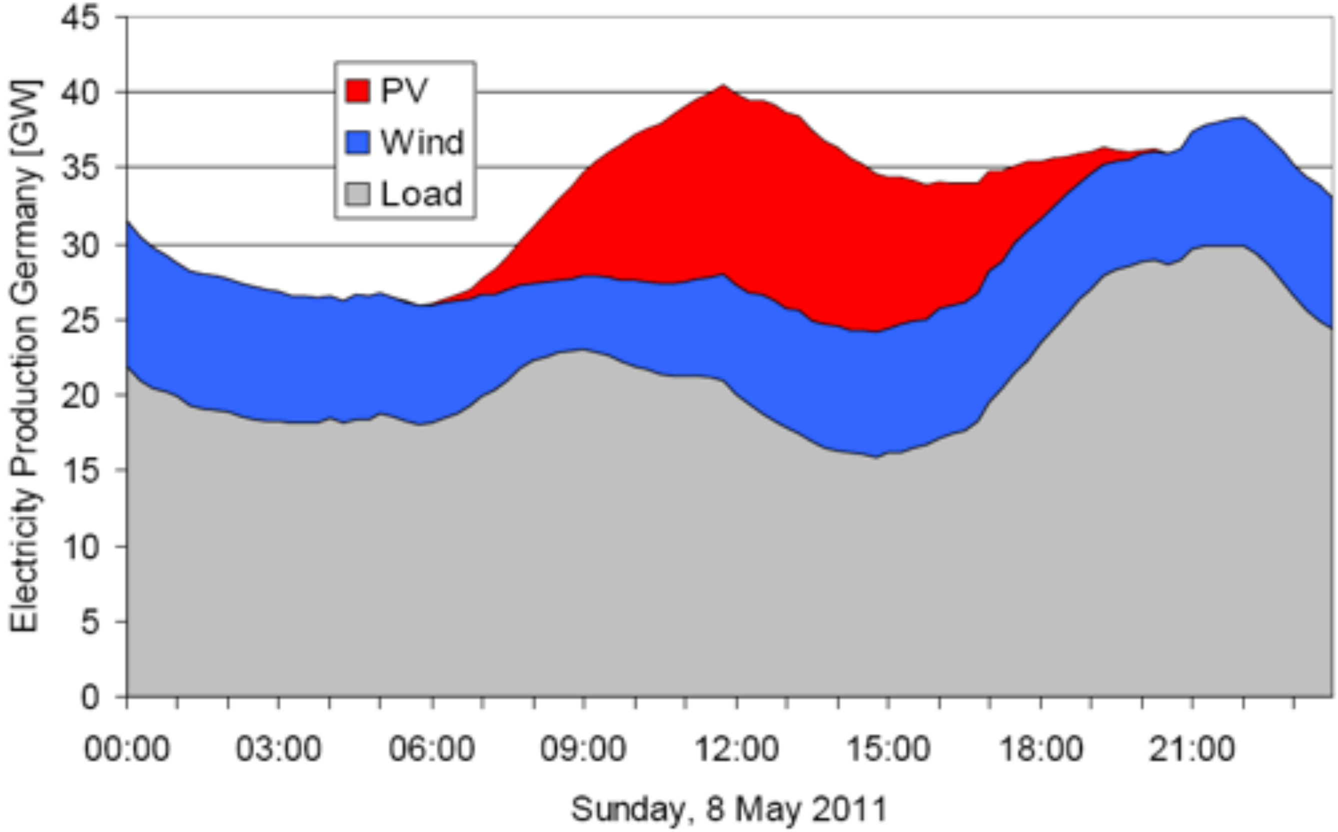
year	GW Cum. Installed panels	Learning Curve € / W	1 GW fabs	New fabs added that year	Sales output all fabs
2010	40	2	20	4	40B
2015	200	1	40	4	40B
2020	500	0,80	60	4	48B
2025	900	0,65	80	4	54B
2030	1400	0,55	100	4	55B
2040	2650	0,50	140	4	70B
2050	4000	0,40	180	4	72B

In 2010 we added 4 x 1 GW_p new fabs

3000 GW_p (60 GW_p in NL) in 2050 is piece of cake, aim at 2025



Contribution of PV on 8 May 2011 in Germany (Estimation: 13 GW, >30%, PV+Wind: >50%)



Source: Online Information of German TSOs

Prof. Dr.-Ing. Martin Braun
„The Development of Smart Grids - High Penetration of PV into the Grid“
6th General Assembly of the European Photovoltaic Technology Platform
30 June 2011 – European Parliament, Brussels, Belgium

7

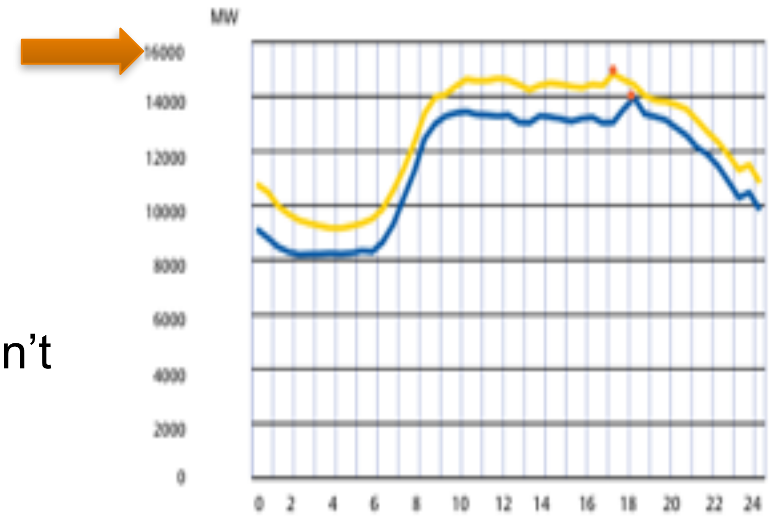
Challenge: how to buffer by 2050 GWh in NL

Electricity: 50 kWh/d/p (MacKay sustainable 2050)

640 km^2 x 400 W$_p$/m^2 (40% eff) generates 256 GW during peak sunshine

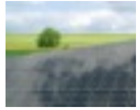
NL peak electricity usage in 2008: **15 GW**

Tennet dec/jan 2007/2008
During peak days



2010 electrical netwerk (15 GW) can't transport 2050 demand of 255 GW.

We need local (solar) generation & storage solutions



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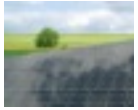


Storage at national scale

Central storage is a no go:

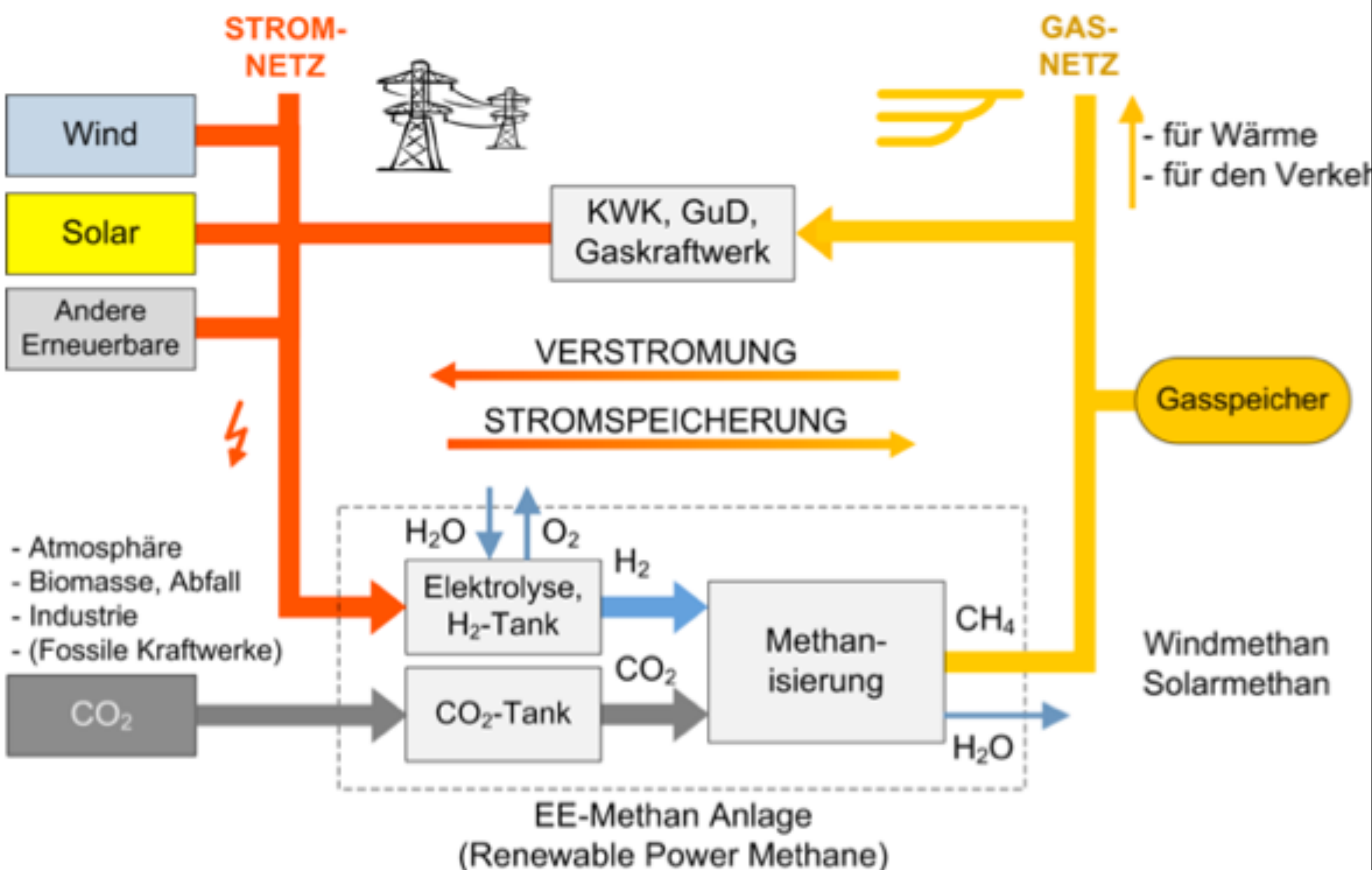
Assume 16 M persons in NL uses 50 kWh/d/p, then NL needs 800 GWh/d.
If sun shines 4 hour/day, we generate 4h/d x 250 GW = 1000 GWh/d
assume we use during those 4 hour 200 GW, then can we store 800 GWh/d
Today world wide pumped hydro capacity is 127 GW (EPRI 2010)

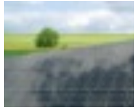
800 GWh hydrostorage: 16.000 Million m^3 over heigth of 10 m.
Markerwaard 400 km^2 needs 40 m depth with IJsselmeer 4 m depth

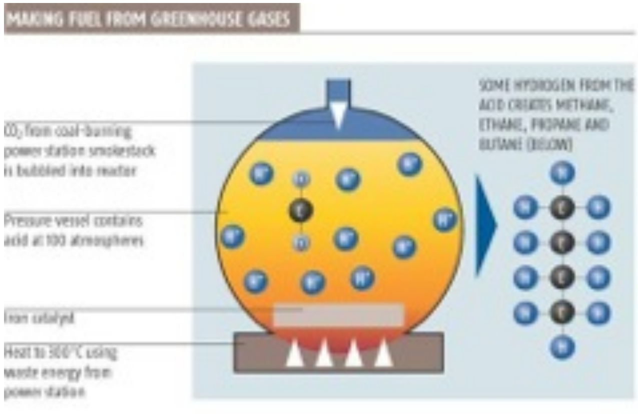
Power density in MJ/kg

Lead Bat. 0,12 (35 Wh/kg) and Li-ion Bat 0,54 (150 Wh/kg)
Methanol 21 (6000 Wh/kg) and Gasoline 43 (12.000 Wh/kg)
Hydrogen 120, but difficult to store (700 bar vs 5 bar camping gaz)

German “Methaniserung” (Sterner, 2009)





Chemergy

Sabatier process:

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

needs ruthenium catalyst,

temperature and pressure [Yamasaki, 2002, New Scientist]

get your CO_2 from a point-source and H_2 from electrolyze

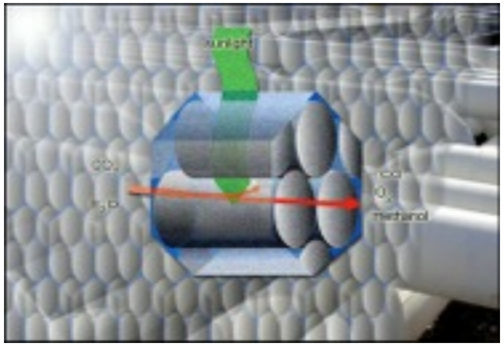
Problem: for (300°C) temp & (60 bar) pressure require economy of scale

Chemergy:= storage of surplus (free) energy & CO_2 into chemistry

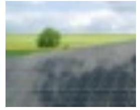
Nanostructured Catalyzers: **mechatomics** with

e.g. 3 nanometer structures

Problem: does not exit



Heinz Frei, 2006, 3-D nanostructure



Chemergy – just like photosynthesis as in nature
Moore's law: from mainframe to tablet in 40 years
Solar learning curve: from power plant to home box

Surplus Electricity

Electrolyze water:

$2H_2O \rightarrow 2H_2 + O_2$

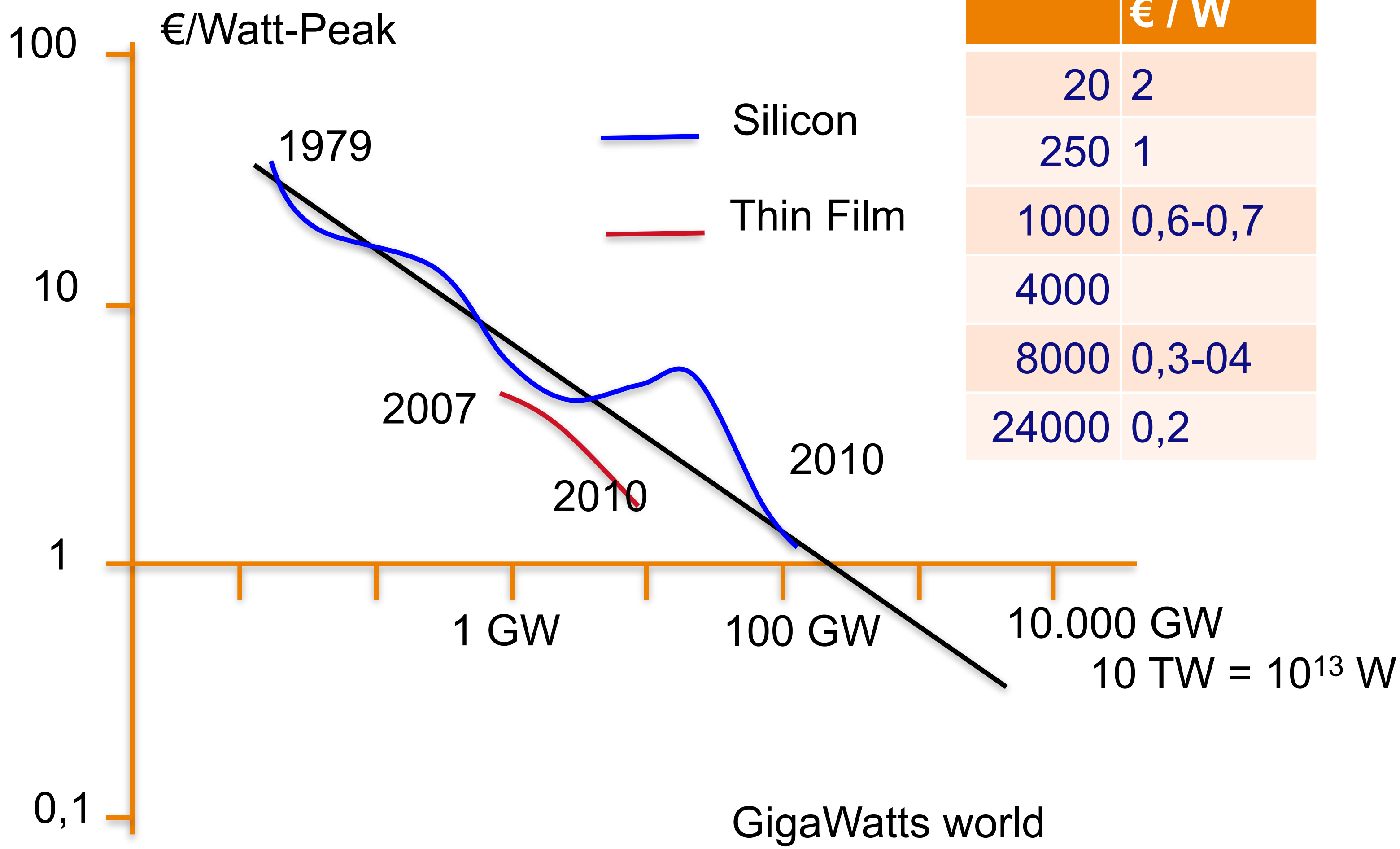
$CO_2 + 3H_2 \rightarrow H_2O + CH_3OH$

Surplus CO_2

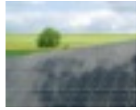
Methanol

800 GWh stored into 133 M kg = 170 M lt methanol
Or at home 100 kWh/day into 16 kg = 20 lt methanol

Learning curve for Solar Modules



GW	Module € / W
20	2
250	1
1000	0,6-0,7
4000	
8000	0,3-04
24000	0,2

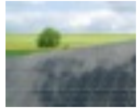


The most optimistic view: solar storage solved

Chemergy (solar storage) scenario:

if every one does a little, we achieve a little, so we need for 4B people 80.000 GW_p not a 3000 in 2050 (800 in 2030)

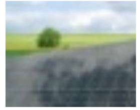
year	GW Cum. Installed panels	Learning Curve € / W	1 GW fabs	New fabs added that year	Sales output all fabs
2010	35	2	13	7	40B
2015	285	1	88	15	50B
2020	1210	0,60	263	47	140B
2025	3320	0,40	544	71	300B
2030	7205	0,28	949	96	280B
2040	22800	0,20	2134	146	400B
(2050)	80000				



Electrical energy sustainable by 2050

Electricity today at home (2p) requires 3650 kWh/y or 10 kWh/d, by 2050 electricity (elec car, heatpump) requires 50 kWh/d/p x 16 M p in NL = 800 GWh per day or 200 GW_p during 4 h sun

Solar	%	NL	Germany	EU/Europe	World
People &space	m	16M and 41.k km	80M and 350k km	≈400M/750 4M/10M km	≈8B & 150M km
2010			14 GW		40 GW
2020	avr		52 GW	200 GW	
2020	10	20 GW	70 GW	400 GW	1.000 GW
2030					
2040	100			8000 GW	24.000 GW
(2050)	100	**200 GW =2,5% NL**			(80.000 GW =0,25 % opp.



Summary statements – solar PV/solar fuels

- Solar PV learning curve goes faster then wind, fusion, biomass,..
- Solar PV with Solar fuels (C_xH_y) as sustainable energy will win

- But growth will stop around 2020-2030 because of lack of storage
- Nature shows how energy storage on earth is done:
  - Store in hydrogencarbons as solar fuels

- We are facing a fundamental challenge to be solved within 10-20 years
  - From 20% to 30-40-50% solar PV efficiencies using (new) nano-tech
  - Technological version of photosynthesis using ? Nano-catalyse

- When solved solar PV+fuels will take over a 1000+ B$/y oil/gas market
- Then chemergy makes a 100% sustainable, CO2 neutral society possible