From Sand und Sun to Electricity and Hydrogen

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The Big Misunderstanding …

$CH_4 + H_2O \longrightarrow 3\,H_2 + CO$

$2\,C_nH_{2n+2} + n\,O_2 \longrightarrow (2n+2)\,H_2 + 2n\,CO$

$3\,C + O_2 + H_2O \longrightarrow H_2 + 3\,CO$

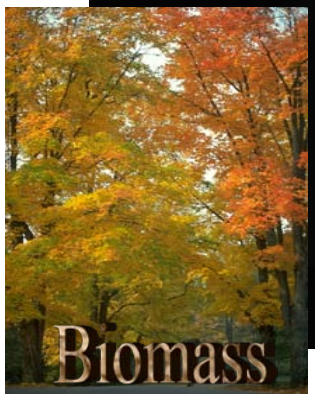
… Hydrogen is a green energy carrier

$CO + H_2O \longrightarrow CO_2 + H_2$

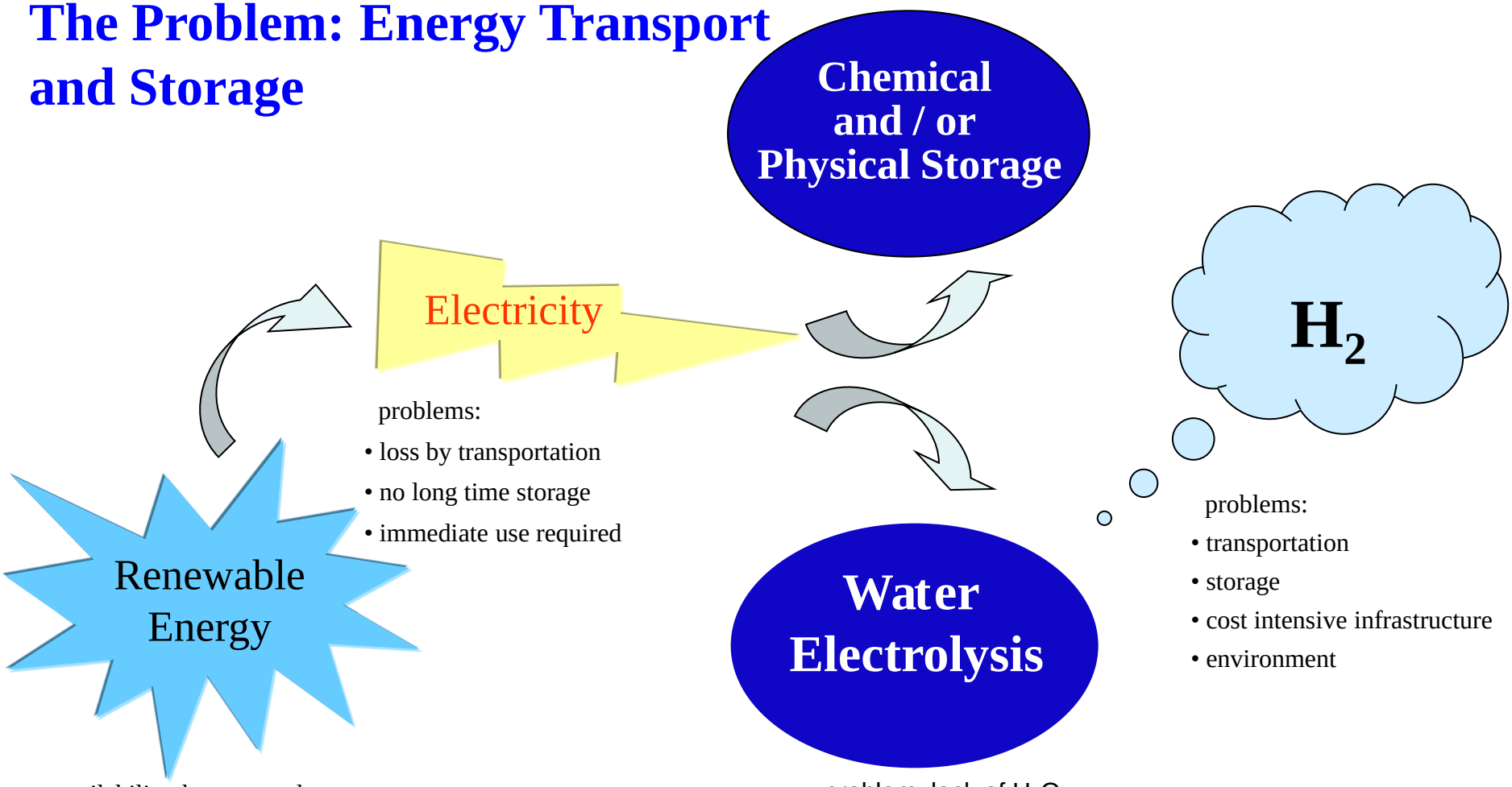
The more hydrogen produced, the more CO_2 is released!

The same is true for electricity produced from fossil fuels!

Proposed Solution



The Problem: Energy Transport and Storage



Statement of the Energy Departement, Washington DC, *July 2002*:
… we are looking for „revolutionary“ new energy production schemes, being convinced that „incremental“ progress and all of the conventional approaches to fuel cells, photovoltaics, fossil fuels etc., aren t going to be sufficient for the future. Simply, our need is a secondary energy carrier, which is transportable without hazards.

Statement of J. Hambrecht, Chief Executive of BASF, *The Economist, Nov. 4th, 2006*: “Our fantasy is that in the future solar energy will be stored and put to work chemically, much as it is in plants through photosynthesis“.

How to Overcome the Limitation of Fossil Resources, the CO_2-Problem, Global Warming … and of Political Risks

Excess of

Renewable Energy

transportation by a carrier

The **ENERGY PROBLEM** is a problem of

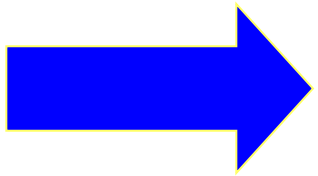
=> **ENERGY STORAGE** and of

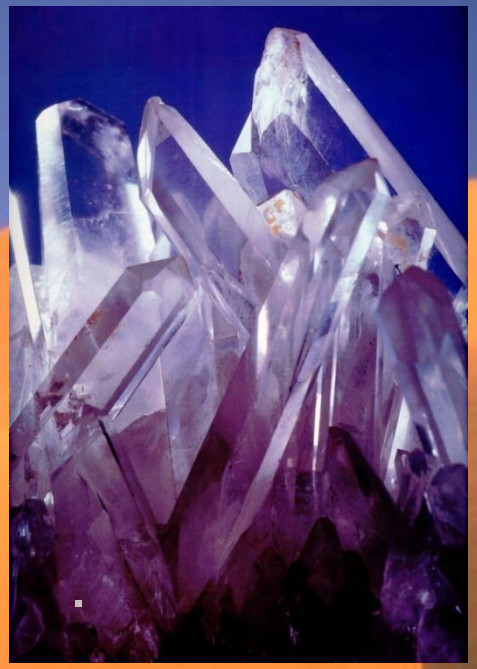
=> **ENERGY TRANSPORTATION**
and thus requires an efficient

=> **ENERGY CARRIER**

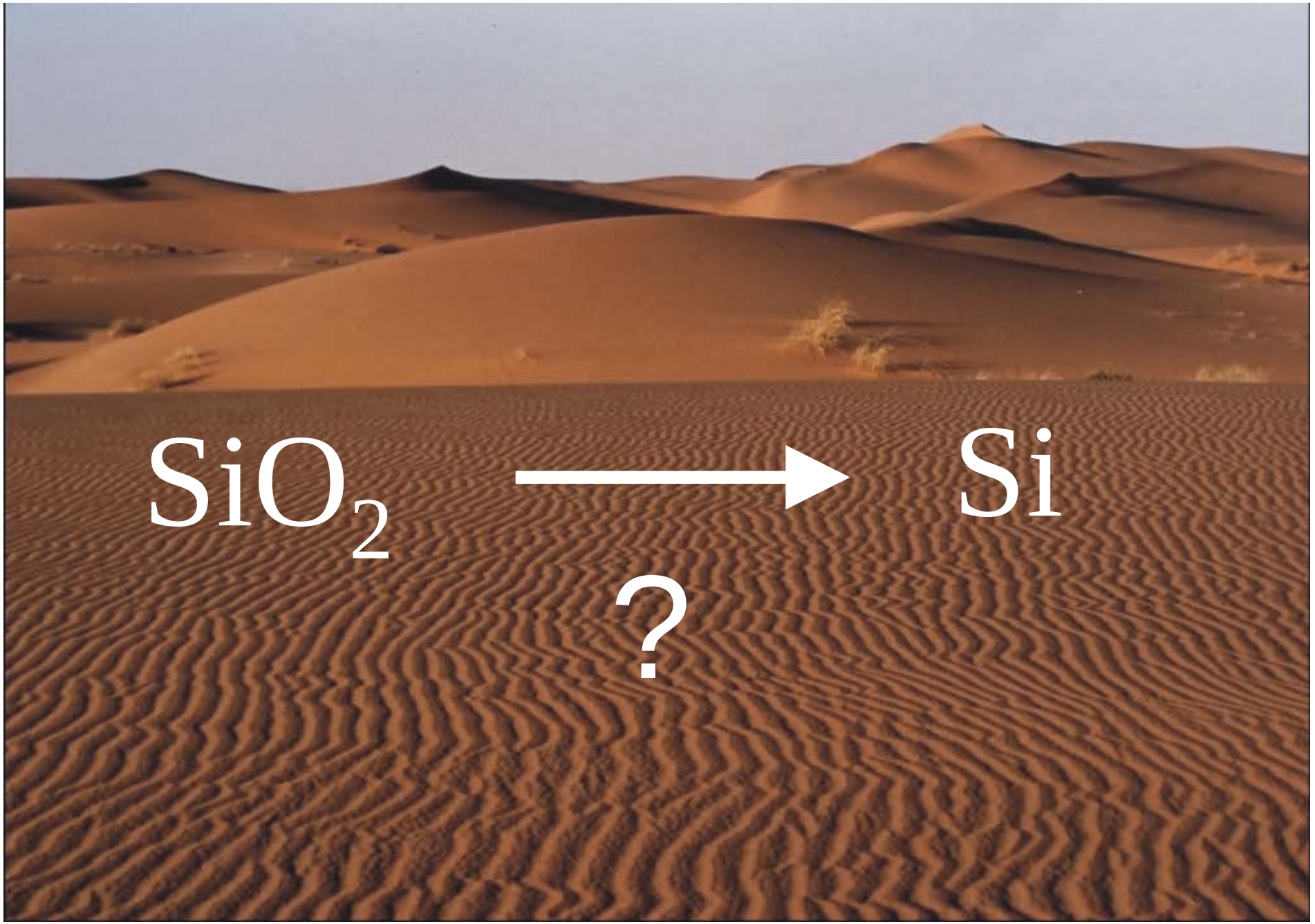
Need of Energy

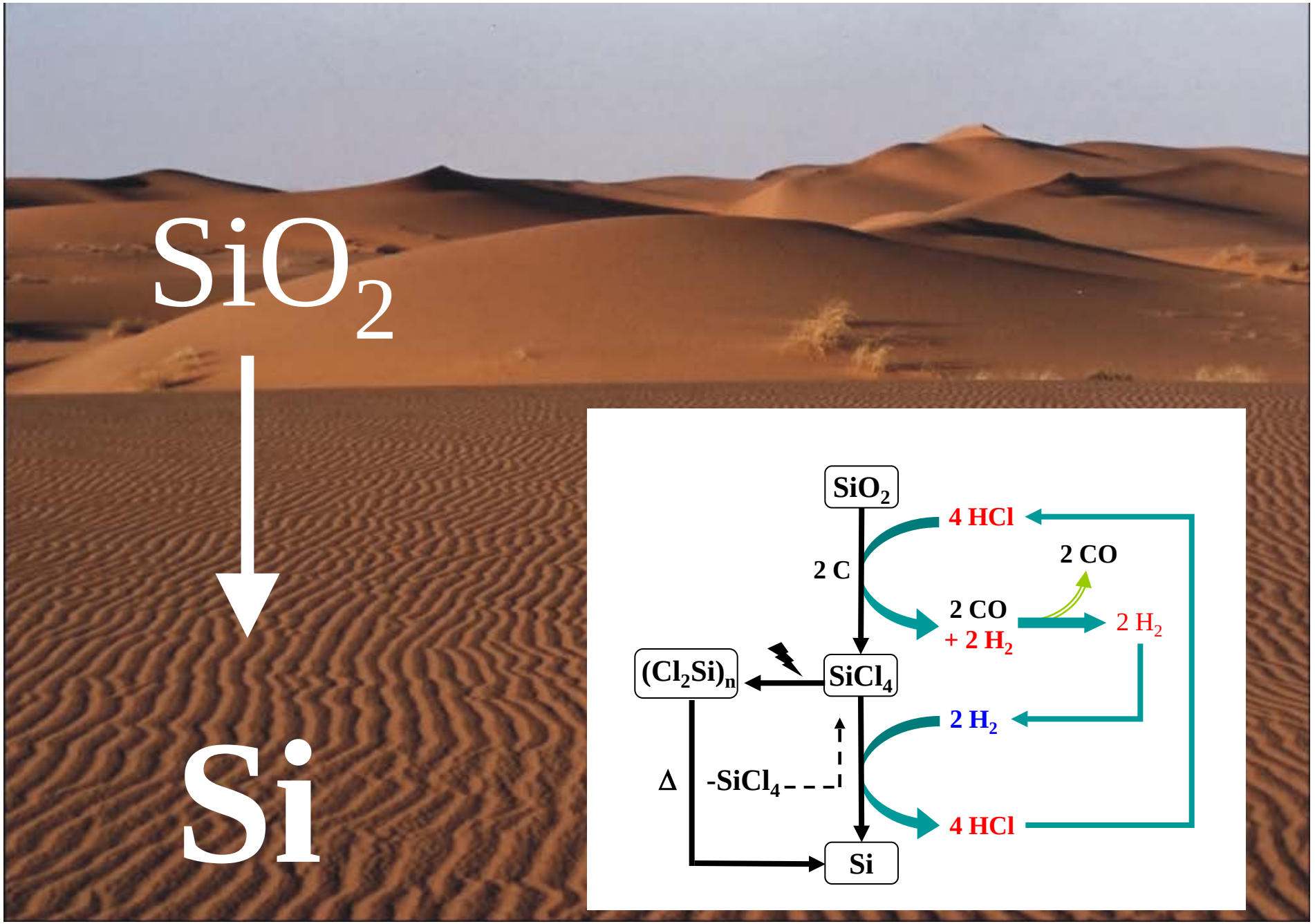
Background and Motivation



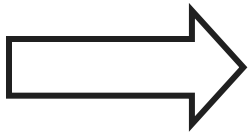


Abundance of SiO_2 in Nature

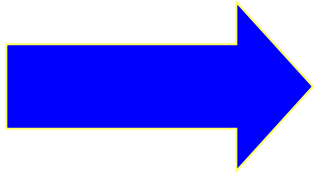

SiO_2
Si
?


SiO_2
Si
SiO_2
4 HCl
2 C
2 CO
2 CO
+ 2 H_2
2 H_2
$(Cl_2Si)_n$
$SiCl_4$
2 H_2
Δ
-$SiCl_4$
4 HCl
Si

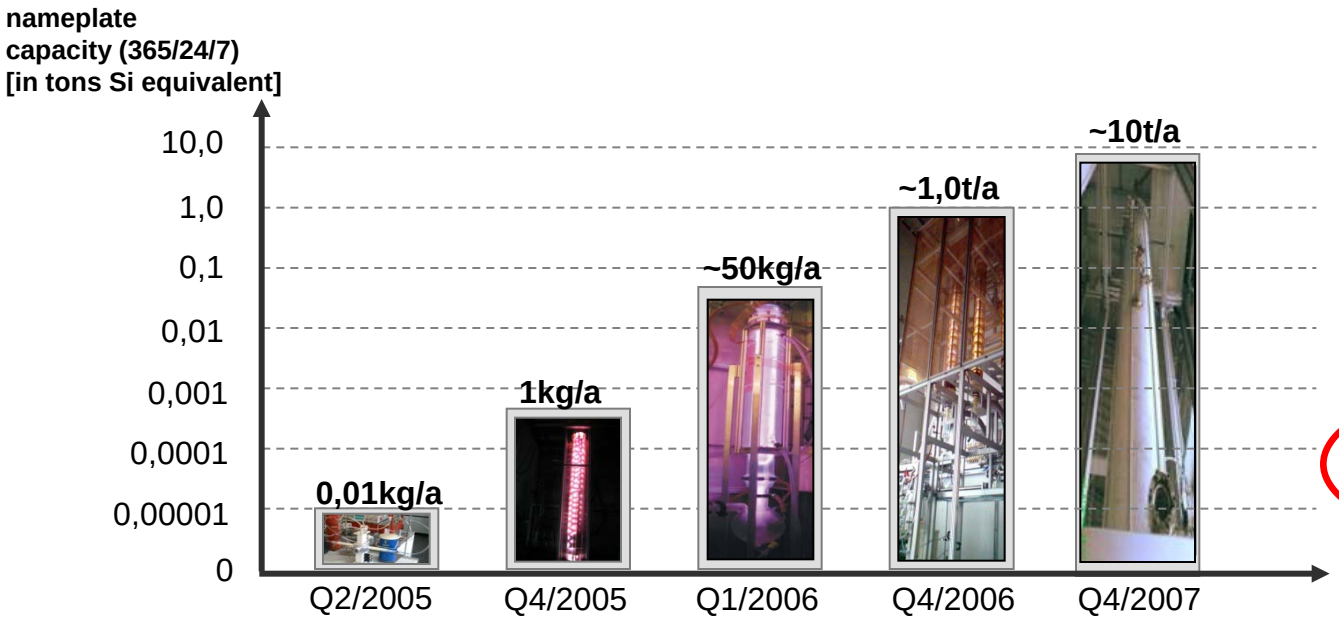
Upscaling and Technology

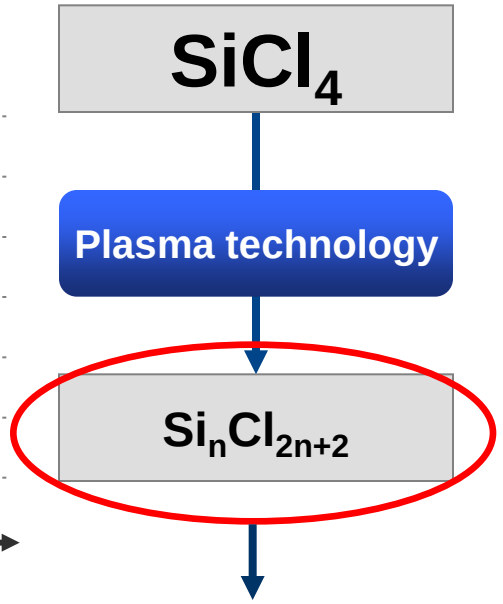


Perspectives



SPAWNT Production / Research





Pyrolysis

- **Solar Silicon**

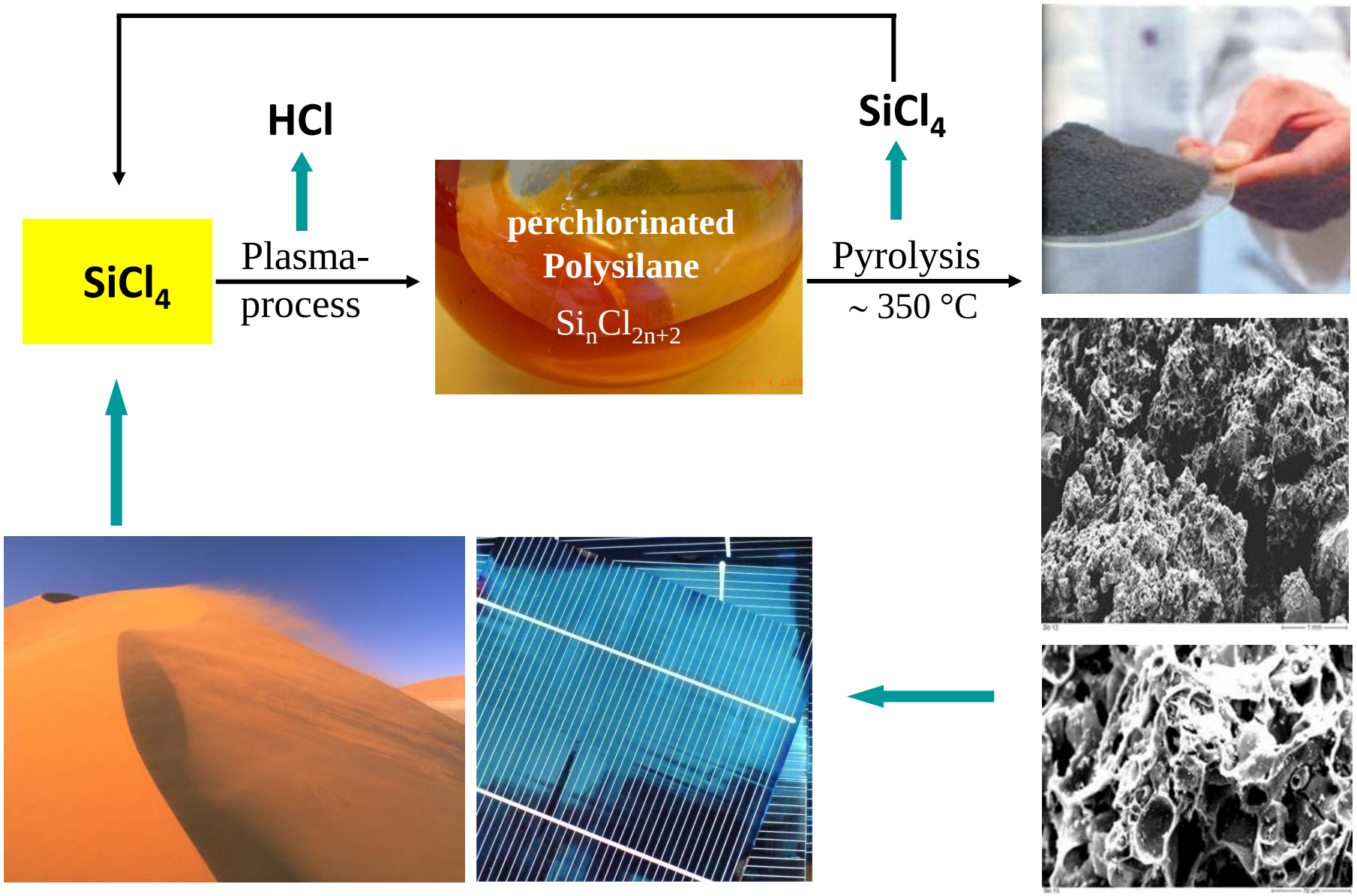
Derivatization

- **Coatings** (SiC, Si_3N_4, SiO_x)
- **Silicide layers**
- **Doped Si + Si/Ge layers**

Hydrogenation

- **PV thin films**
- **Printable electronics**
- **Hydrogen carriers**

From Sand to Photovoltaic Grade Silicon



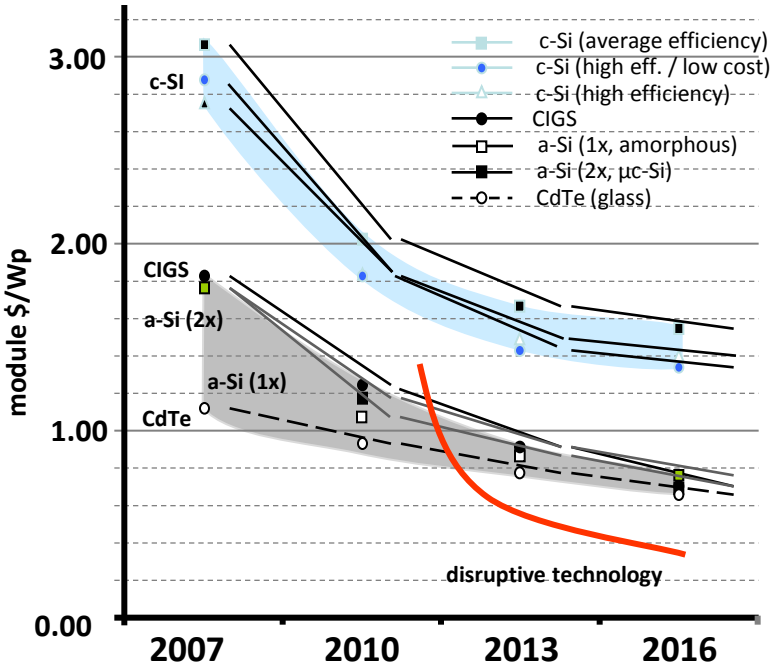
… Today: Beneixama (Spain – 20 MWp)

area: 500.000 m^2, ca. 100.000 modules for > 12.000 house holds
produce ca. 3 mio liters of Diesel-äquivalents / year

output: > 30 mio kWh/year save > 30.000 tonnes CO_2 / year

From Sand to PV – Thin Films and "Printable Electronics"

$SiCl_4$ → Plasma-Process → perchlorinated polysilanes Si_nCl_{2n+2} → Pyrolysis / Chlorination → Si_nCl_{2n+2} (n = 2 – 6)

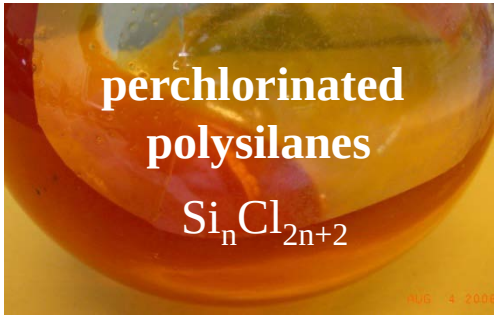


- **c-Si** will remain high cost module, with high efficiency cells able to compete on levelized cost levels
- **a-Si** (micromorph) is now entering production: stronger price digression immanent
- **CIGS** is still struggling to enter mass production
- **CdTe** is and will remain module cost per watt leader, but seems to run into resource constraints on the single digit GW level

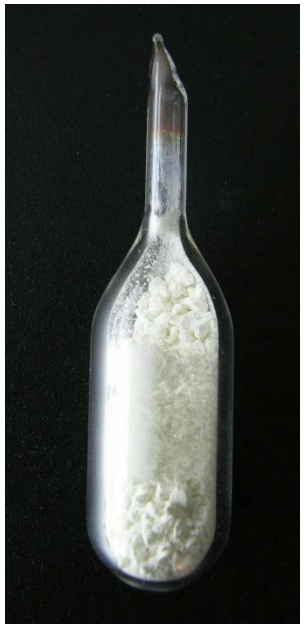
Si_nH_{2n+2} (n = 2 – 6)

From Sand to “Synthetic Silicon Oil“

$SiCl_4$ → Plasma-Process →

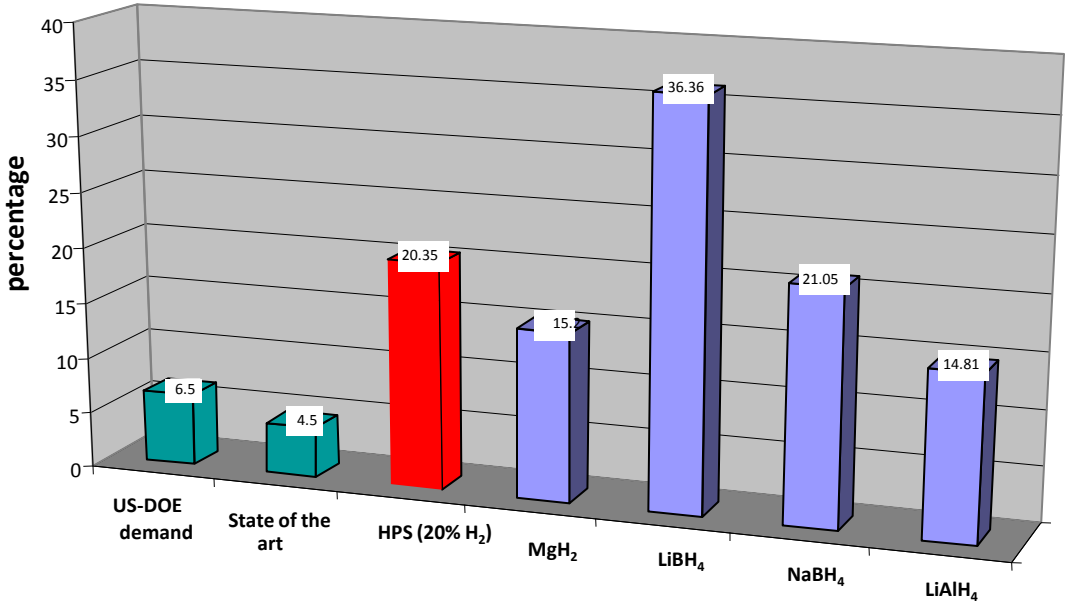


→ $LiAlH_4$ →



DOE – Targets:

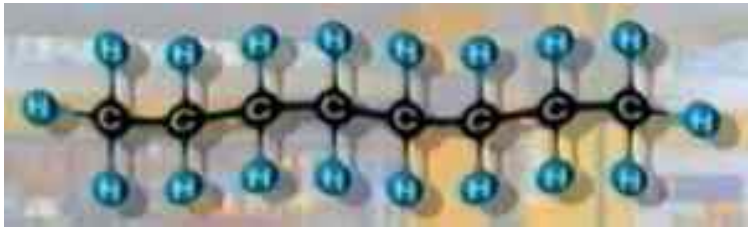
weight of tank	max 46 kg/100 kWh
volume of tank	max 48 l/100 kWh
hydrogen storage capacity	min 6.5 wt. %



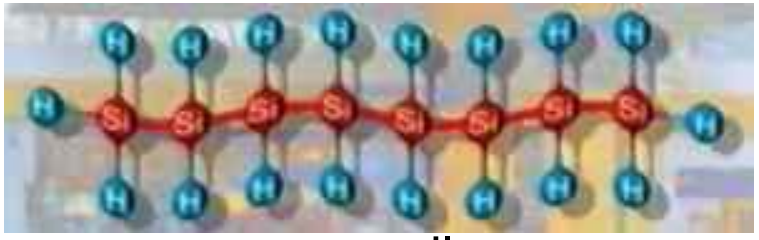
solid

H-Polysilanes (HPS)

CO_2-Free Alternative Fuel



octane



octasilane

Hydrogen Generation from HPS

$$Si_{15}H_{32} + 30\ H_2O \rightarrow 15\ SiO_2 + 46\ H_2$$

452 g 540 g 900 g 92 g ~ 3kWh

92g/452g = 20.35% Hydrogen Content

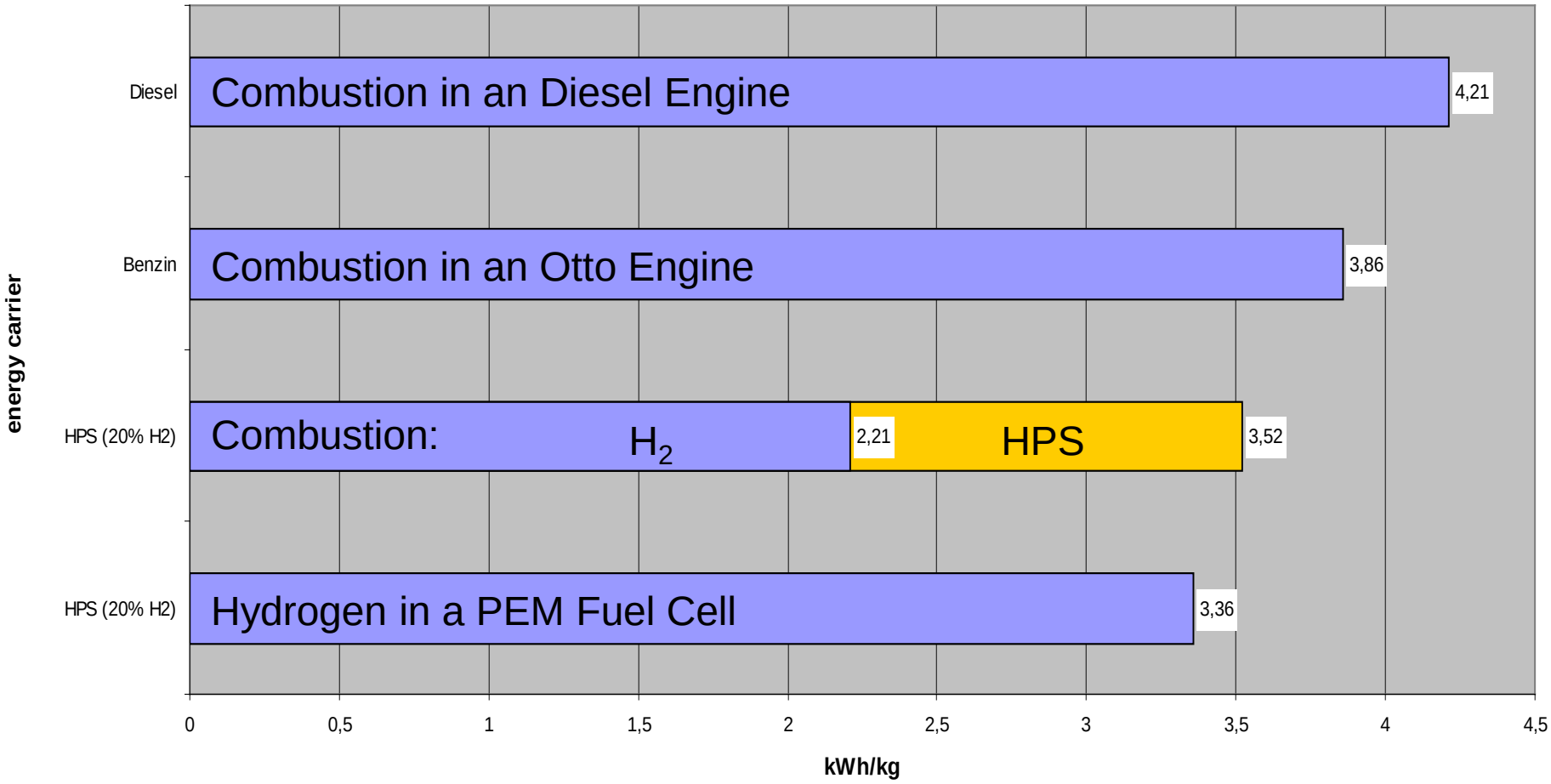
Products from use in PEM fuel cell:

$$46\ H_2 + 23\ O_2 \rightarrow 46\ H_2O$$

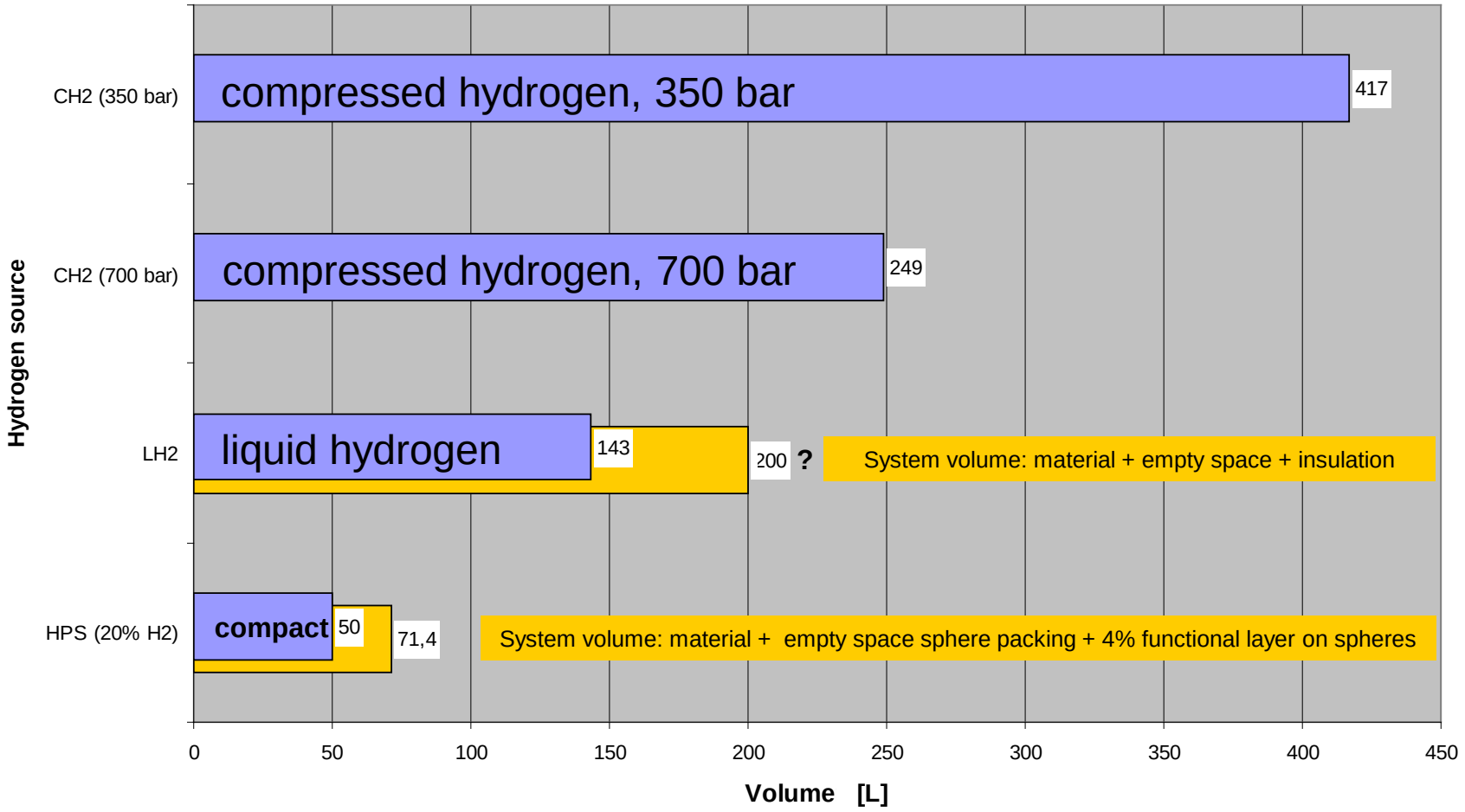
92 g 736 g 828 g

$\Rightarrow$ 900 g SiO_2 + 288 g water are formed

Energy Output per 1 kg of Energy Carrier in Driving Engines



Volume Required for Storage of 10 kg Hydrogen

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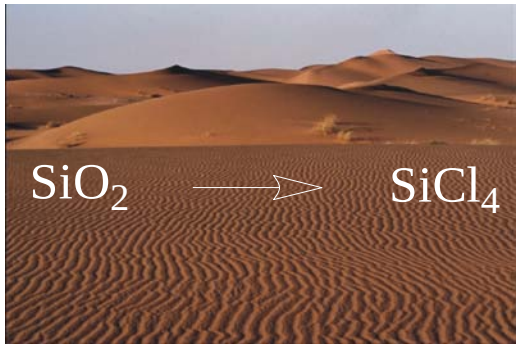
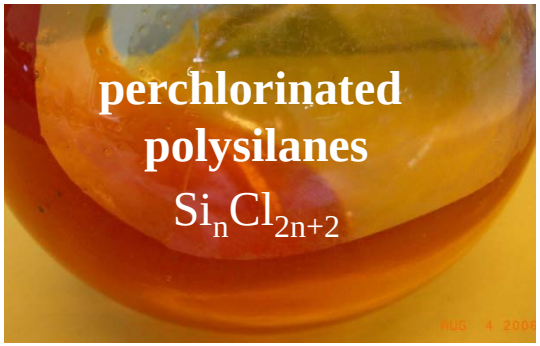
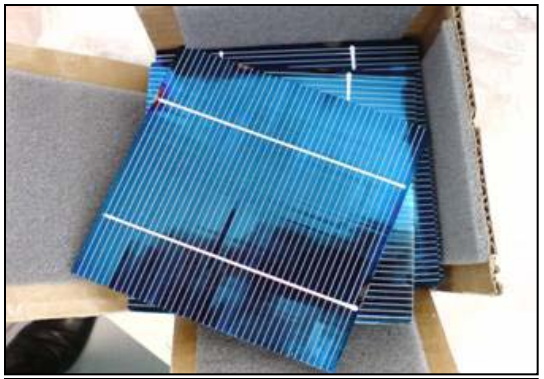
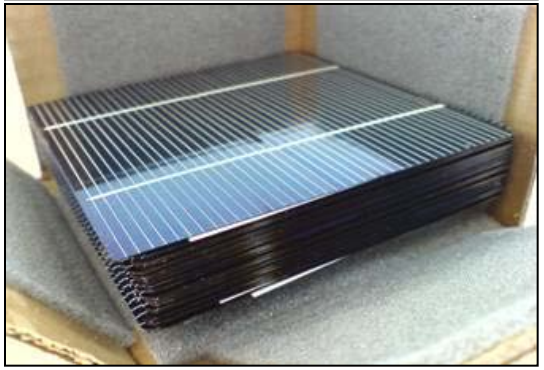
NaOH / H2O
2 mol / L
H2O


SiO_2
$SiCl_4$

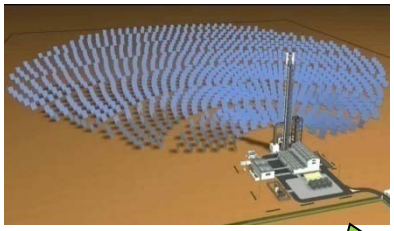

perchlorinated
polysilanes
Si_nCl_{2n+2}


citysolar
technologie





The Vision Becomes True …



Water-Electrolysis

Transport and Storage

Silicon

H_2O

T / ↯

SiX_4

$(X_2Si)_n$

[H]

$(H_2Si)_n$

H_2O

H_2

(X = Cl, F)

SiO_2

Electricity

production of clean water

PEM Fuel Cell

… It‘s Up to Us to Make it Happen