

# Progress towards all-renewable power supplies

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*The Burning Answer*

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[www.burninganswers.com](http://www.burninganswers.com)

<http://pegasusbooks.com/books/the-burning-answer-hardcover>

# The Burning Answer

## Part I: *Popular Science*

History of the semiconductor revolution and how it led to the solar revolution

## Part II: *Environmental Politics*

Progress towards all-renewable electricity and gas supplies varies markedly between countries

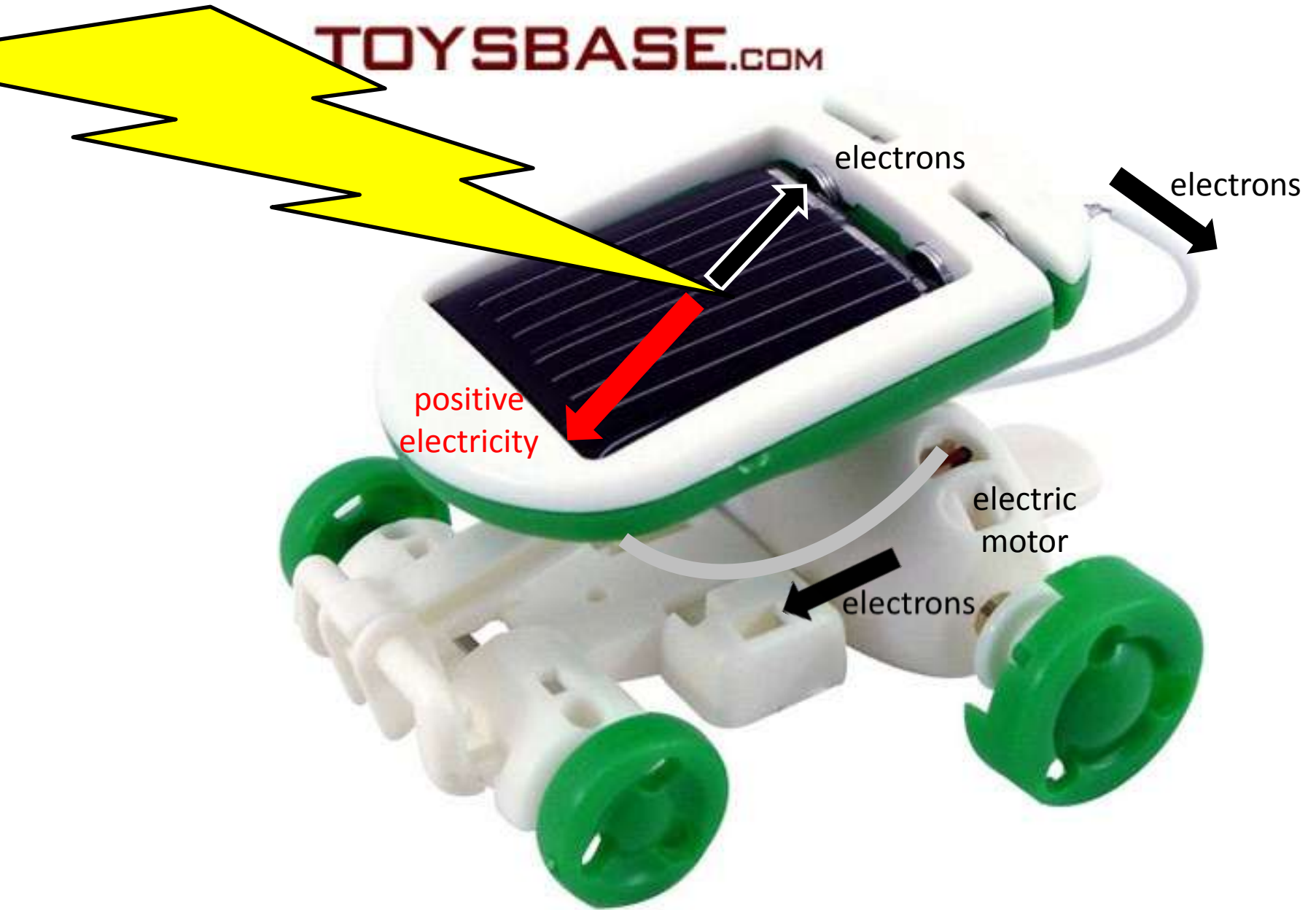
## Part III: *Futurology*

Could we convert sunlight and atmospheric carbon dioxide on our rooftops into solar fuel?



# Quantum Theory is Child's Play

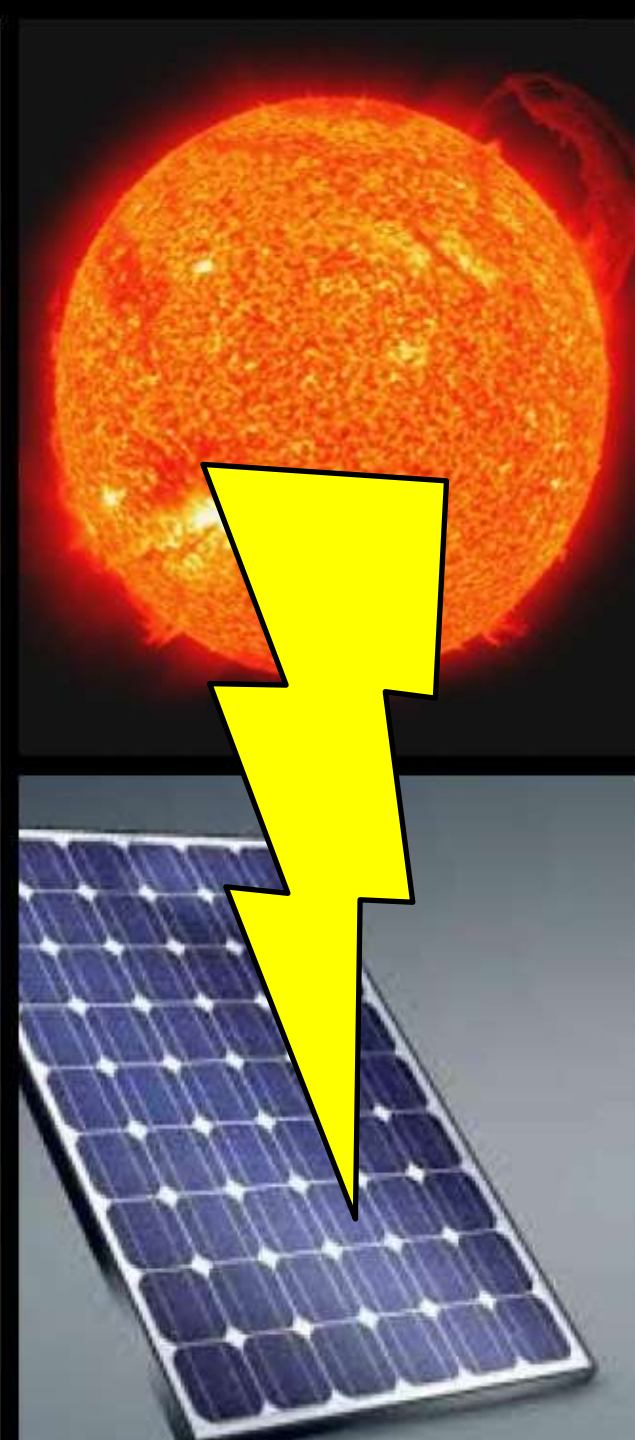
How a solar  
cell works







Sunlight is made up of lots of tiny bits of energy called **photons**. All visible photons in sunlight have enough energy to raise an electron up to the empty band of atoms in a silicon solar cell







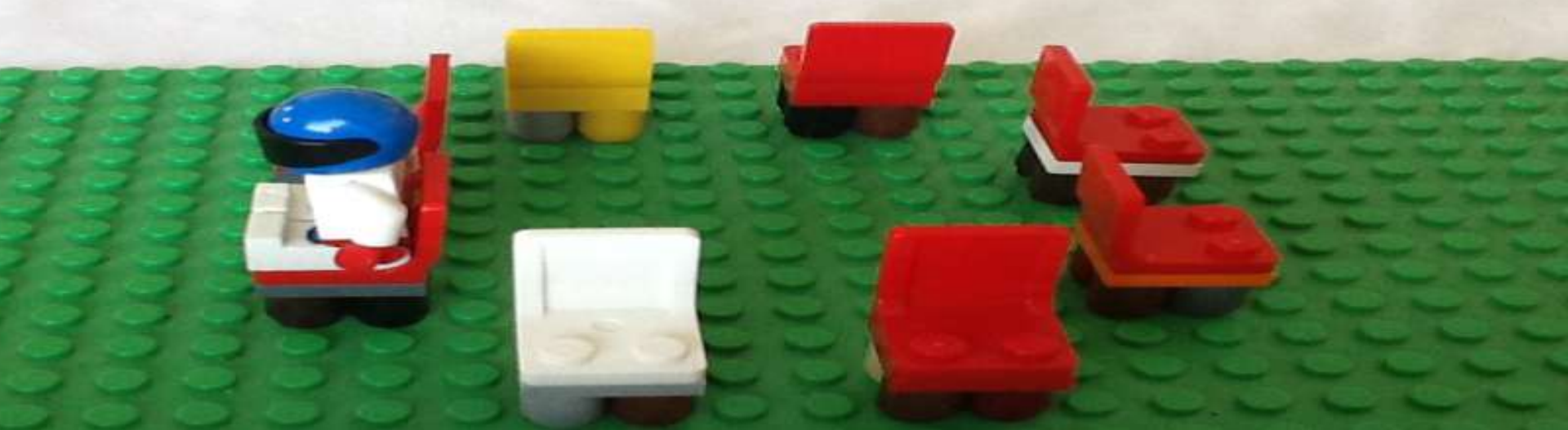




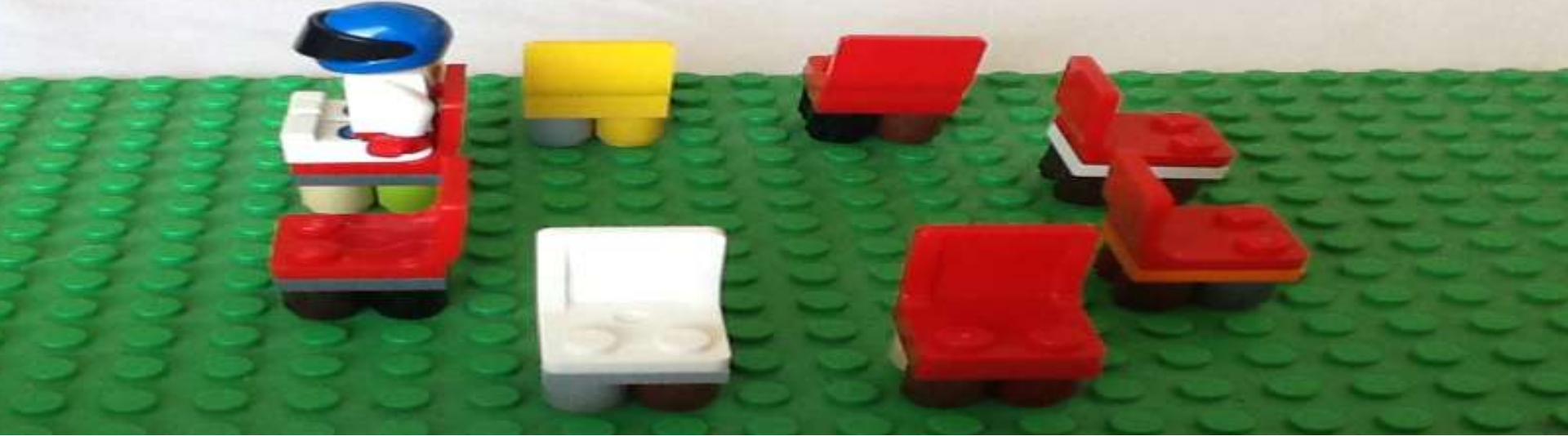












# Christy, Olan, Jude & Eliot



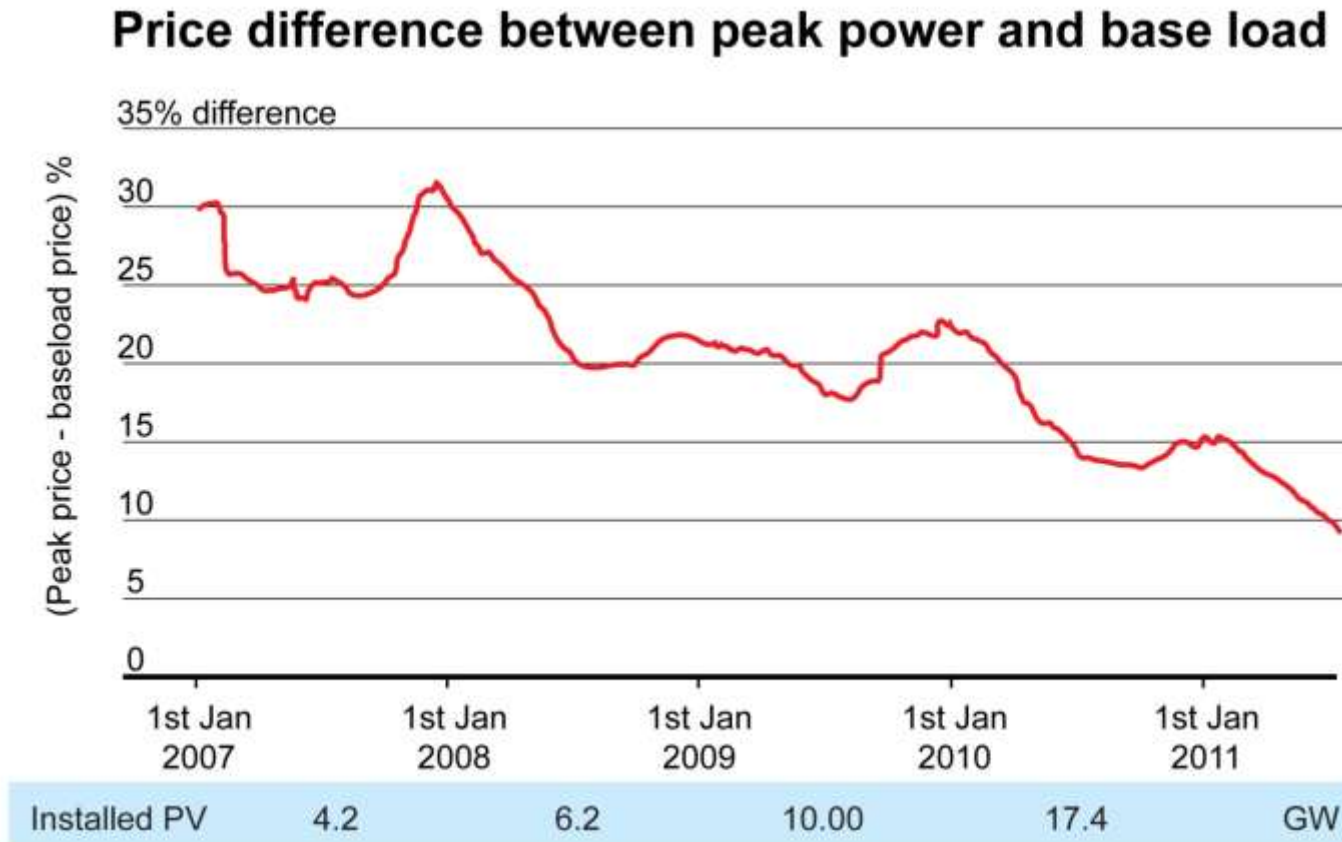
# The Burning Answer

## Part II: *Environmental Politics*

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# The Mystery of the Falling Cost of Wholesale Electricity in Germany

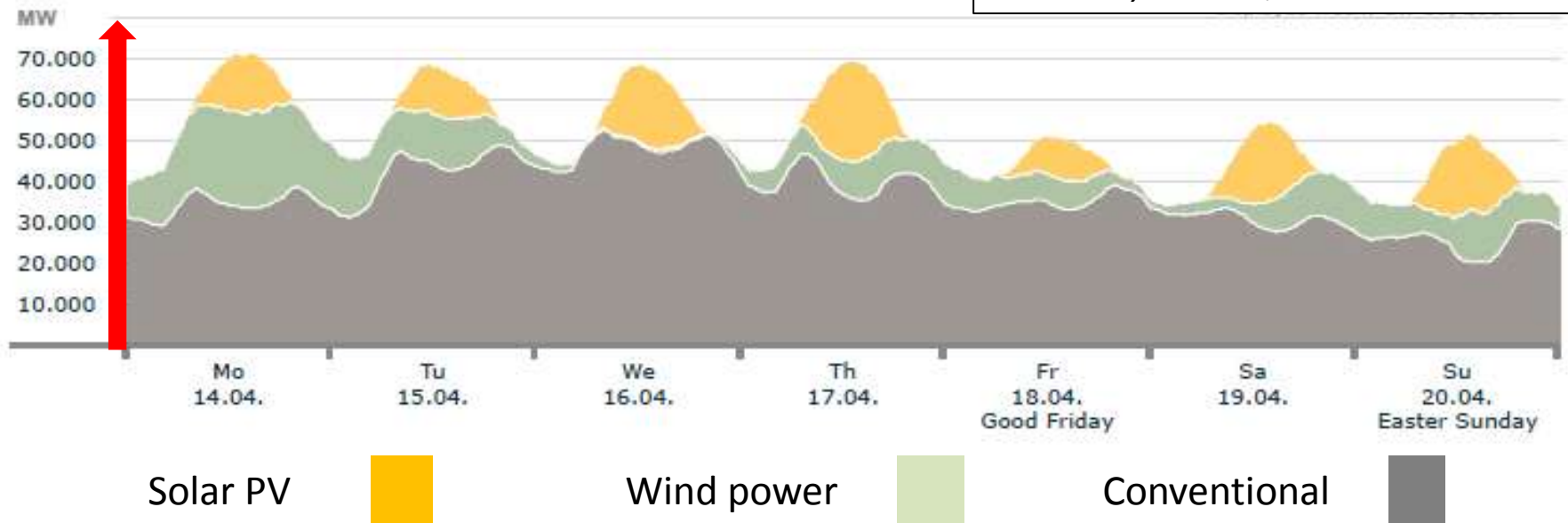


How has PV reduced wholesale electricity price when in 2011 only 3% of German electrical energy from PV?

# Sun power is responsible for 20% wholesale price fall

Electrical Power Demand of Germany (GW)

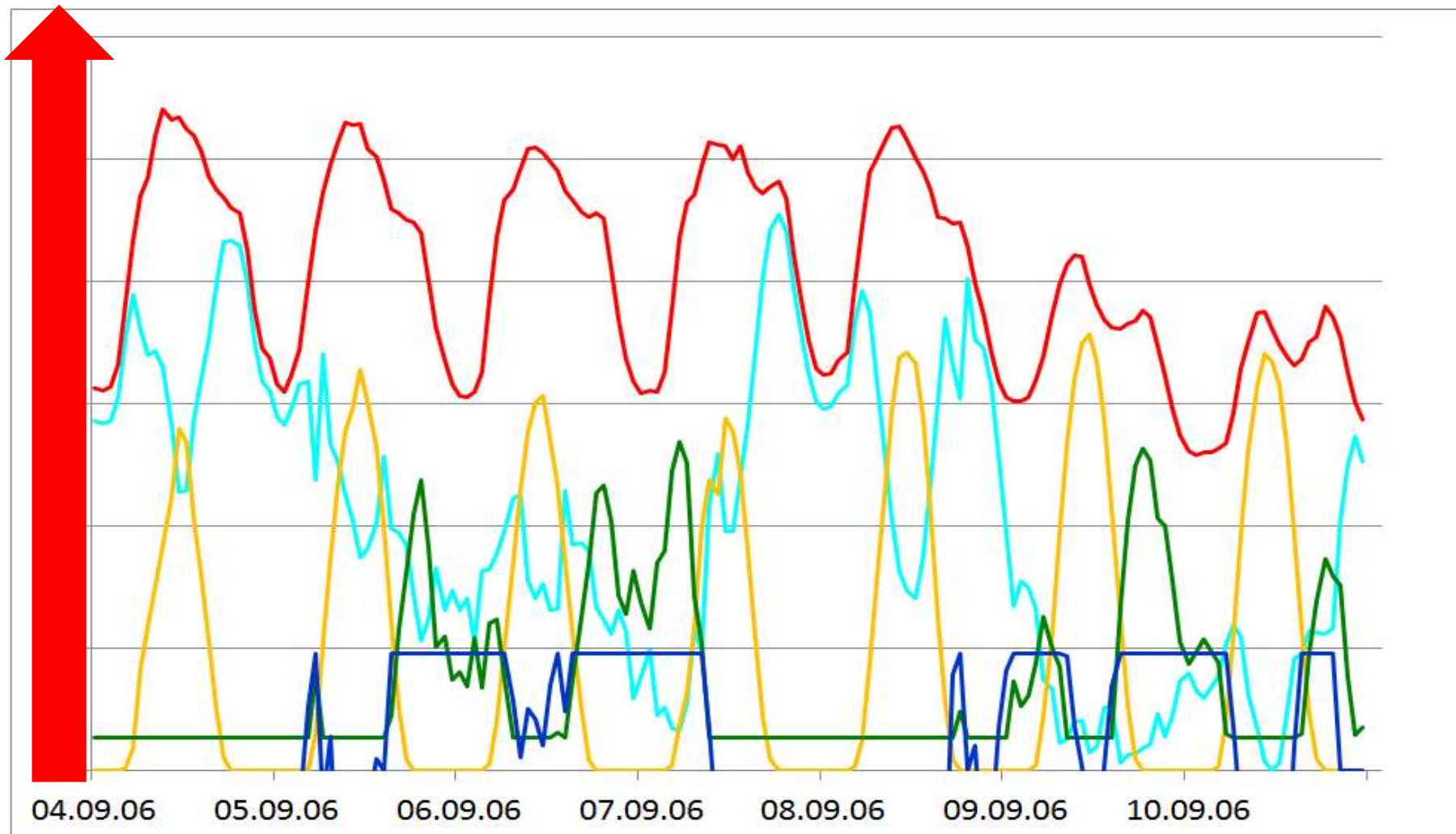
*"Electricity production from solar and wind in Germany in 2014", Fraunhofer ISE*



- PV power supplied 36% of demand on Thursday noon and gold shape of power supply matches peak demand
- PV energy (gold area) is small (only 3% in 2011)
- Local wind variability smoothed on country-wide scale
- Grid OK > 40% PV & > 30% wind power & complementary

# Kombikraftwerk (KKW) in Germany

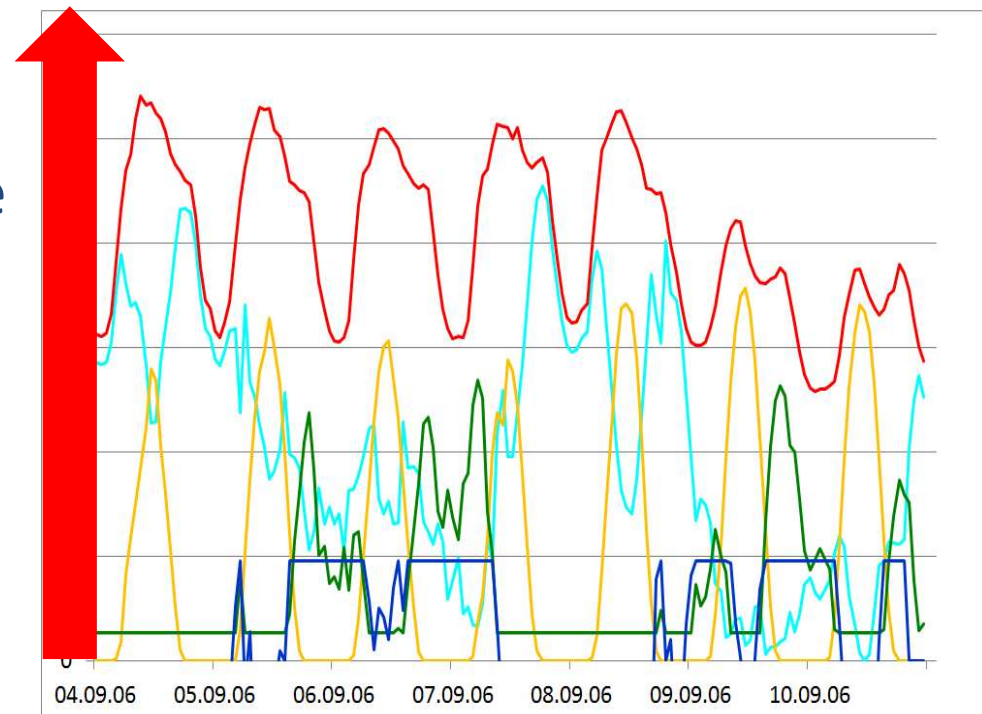
Scaled German electrical power demand



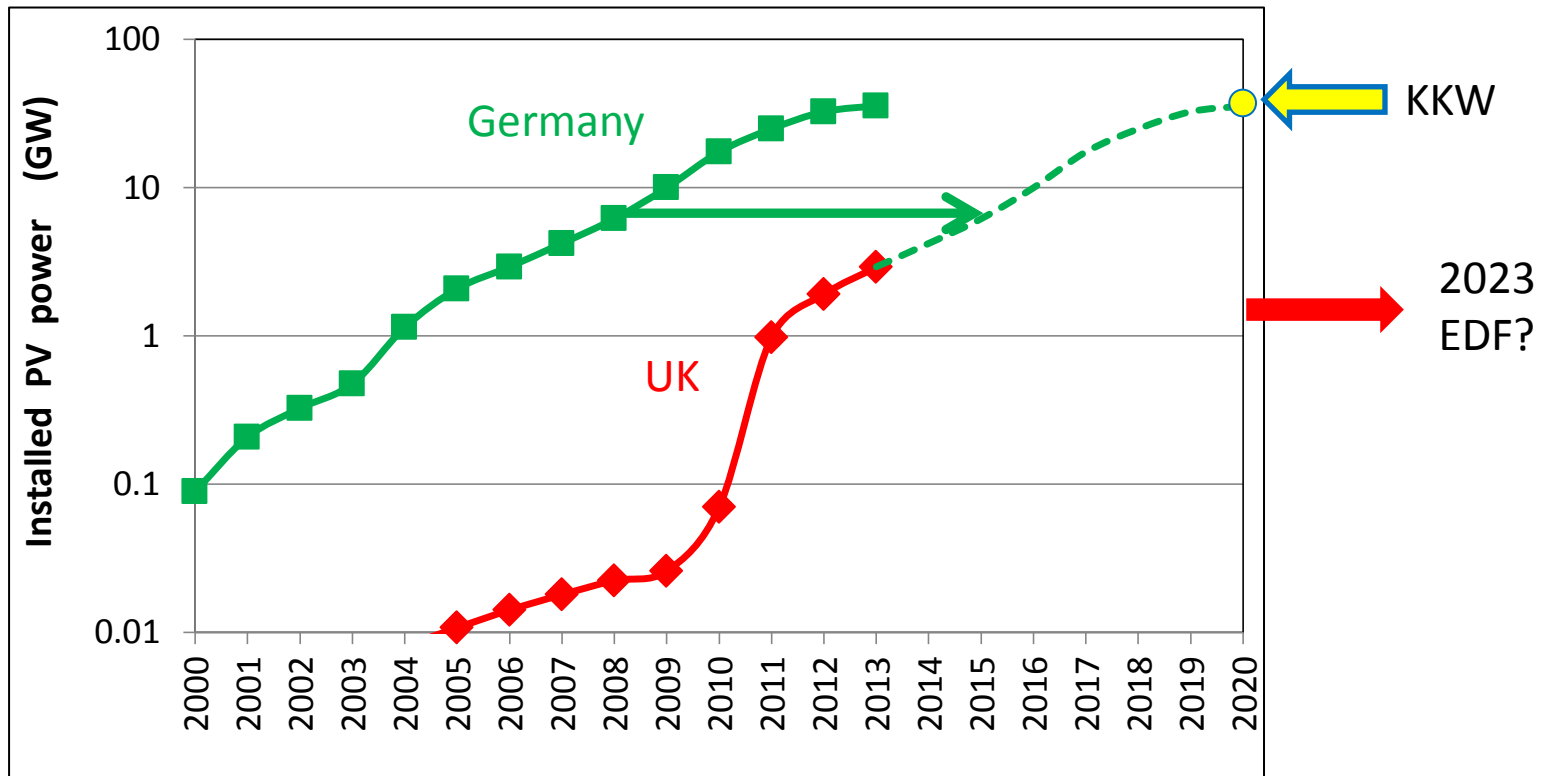


# KKW: combined power plant

- Kombikraftwerk all-renewable project started in 2006
- Over 2006 it matched 1/10,000 of actual German electric power demand with real-time output of PV, wind & biogas generators
- PV and wind together can supply 78% German power demand
- Only 17% back-up power by biogas electricity required
- Only 5% back-up from storage was necessary
- Note the marked wind/biogas variation over local regions - smoothed out nationwide in 2014 demand-supply slide



# PV Power in Germany & UK

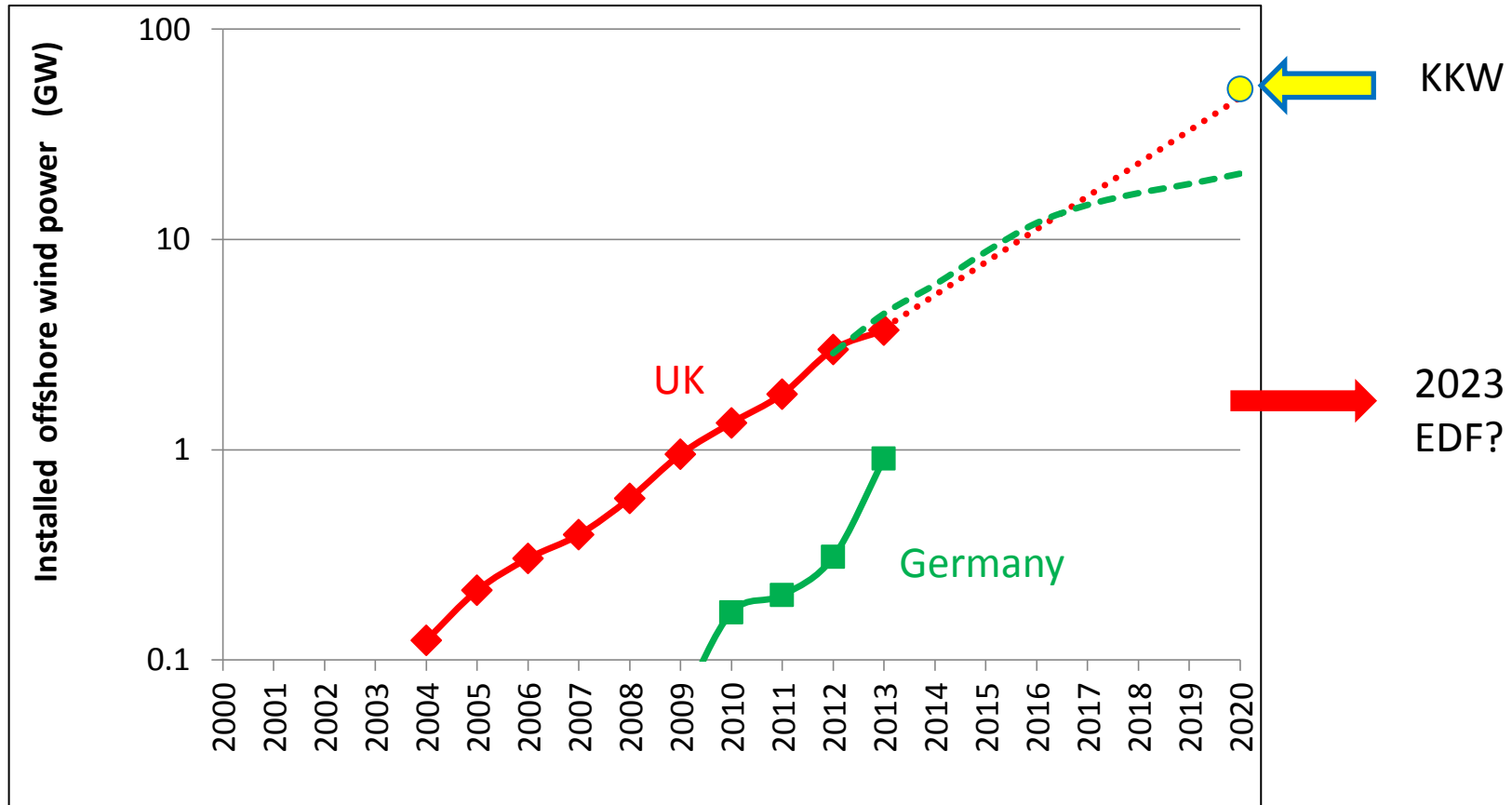


If UK follows German trend will hit all-renewable target (KKW) in 2020

PV power could be 22 times larger than Hinkley Point C in 2023 (EDF)

Government cuts to solar farm subsidy will slow expansion

# Offshore Wind Power Germany & UK



Despite being large scale in a difficult environment, off-shore wind power has increased exponentially like much smaller scale PV

If offshore wind maintains its 10-year trend, like PV it could hit its KKW target by 2020 and have 30 times EDF nuclear , 3 years earlier



# All-renewable gas supplies

- Anaerobic Digestion (AD) of waste not competitive with land use for growing food crops
- Farm animal waste, crop waste and food waste decay to biomethane for electric or gas grids
- Very low (or negative) carbon footprint: avoids the greenhouse gas emissions were waste left to rot



# Progress in Europe to all-renewable gas grids

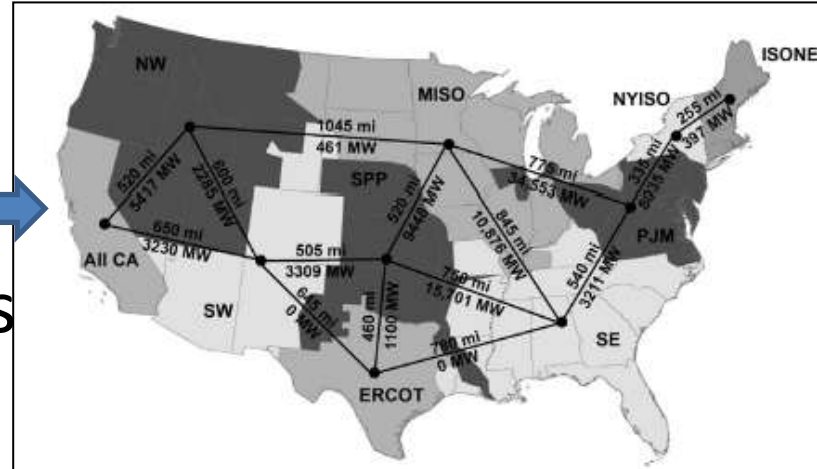
- UK first UK system connected to gas grid in 2012. By 2014 there were 28 certified systems
- By 2016 Good Energy and Ecotricity expect to offer biomethane as well as all-renewable electricity
- Germany had 6,800 AD plants in 2010 – US had 150
- Are there enough resources given gas demand for electricity, heating, industry & transport?
- UK government report estimates around half the food crops we grow for humans and cattle is wasted

# Reducing gas demand renewably

- Heating with ground and air-source heat pumps can reduce demand for natural gas
- Sweden leads - generating half its final energy use renewably in 2009 thanks to heat pumps.
- Shallow geothermal energy from under the car park can provide heating, air conditioning and efficient refrigeration for stores and commercial buildings

# All renewable electricity in USA?

- Separate US electricity grids
- I suggest KKW demonstrations be run for a year on each grid with all local renewable feeds
- Mark Jacobson, (Stanford): no access to grid demand
- There are all-renewable electricity suppliers like **Marin County Electricity** but they not allowed to supply everywhere on the California grid



<http://www.mcecleanenergy.org/faq/>



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# Future applications of QuantaSol quantum well (QW) concentrator cells

- 2009 Single-junction + QWs => efficiency **28.3% @ 534x**
- 2010 Triple + QWs middle cell, wafer mean **39.7% @ 500x**
- 2011 2<sup>nd</sup> company to pass qualification with Amonix  
Order for 1MW cells  
Sold to JDSU + 4 of team
- 2012 QW in top cell  
wafer mean **42.5% @ 500x**
- JDSU stopped all CPV R&D



# An electric car powered by sunlight - today

A typical PV system in average UK sunlight will generate electricity to power an electric car for the average domestic mileage in a year

Kevin Sharpe, CEO of the charity Zero Carbon World, gets more mileage from his rooftop near Bath as both he and partner work at home



With 42.5% efficient cells could the excess electricity be stored as a **solar fuel** that would power a **fuel cell** to extend the range of the electric car?

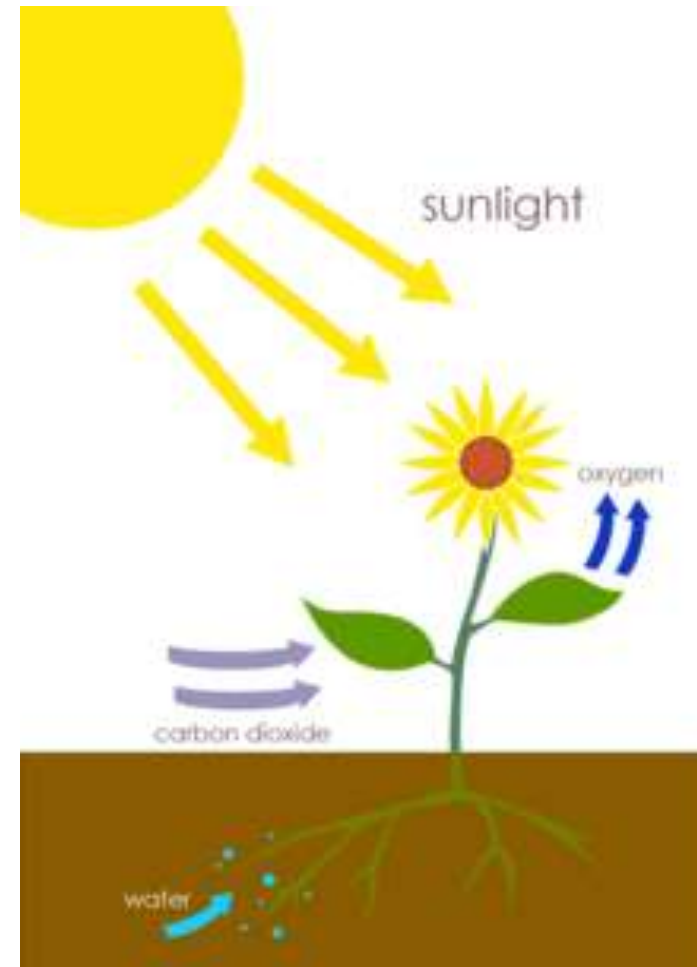
# Can we produce solar fuel from atmospheric carbon dioxide?

The American Physical Society (2011): Direct air capture of carbon dioxide “is not currently an economically viable approach to mitigating climate change”

But CO<sub>2</sub> is captured viably in submarines and space stations

Also nature captures carbon dioxide from the air and use sunlight to turn it into the fuel (carbohydrates) plants need - **photosynthesis**

Nature took over two billion years to develop photosynthesis by chance. An **artificial leaf** can be developed more quickly with the scientific method

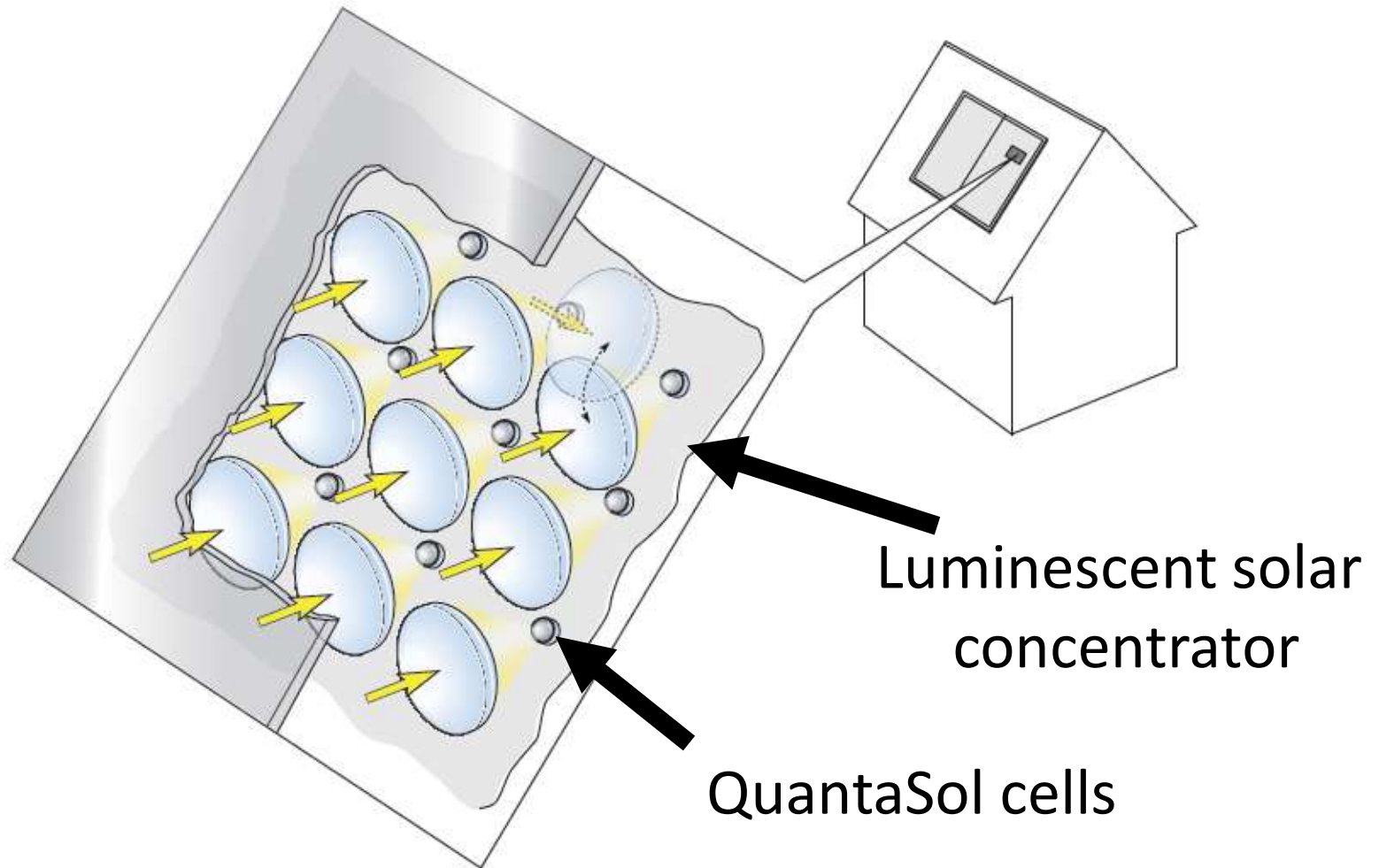




# Parts of the artificial leaf already available

- ETH Zurich have invented a nano-structured gel that absorbs carbon dioxide at ambient, desorbs at 90° C
- QuantaSol cells can be optimised to work at high temperature in concentrated sunlight. If cool with water its temperature can be 90°C and the heat energy used to desorb the CO<sub>2</sub>
- Still need cheap, long-lasting and efficient catalysts to speed up the chemical reaction to produce solar fuel in photo-electrochemical cells.

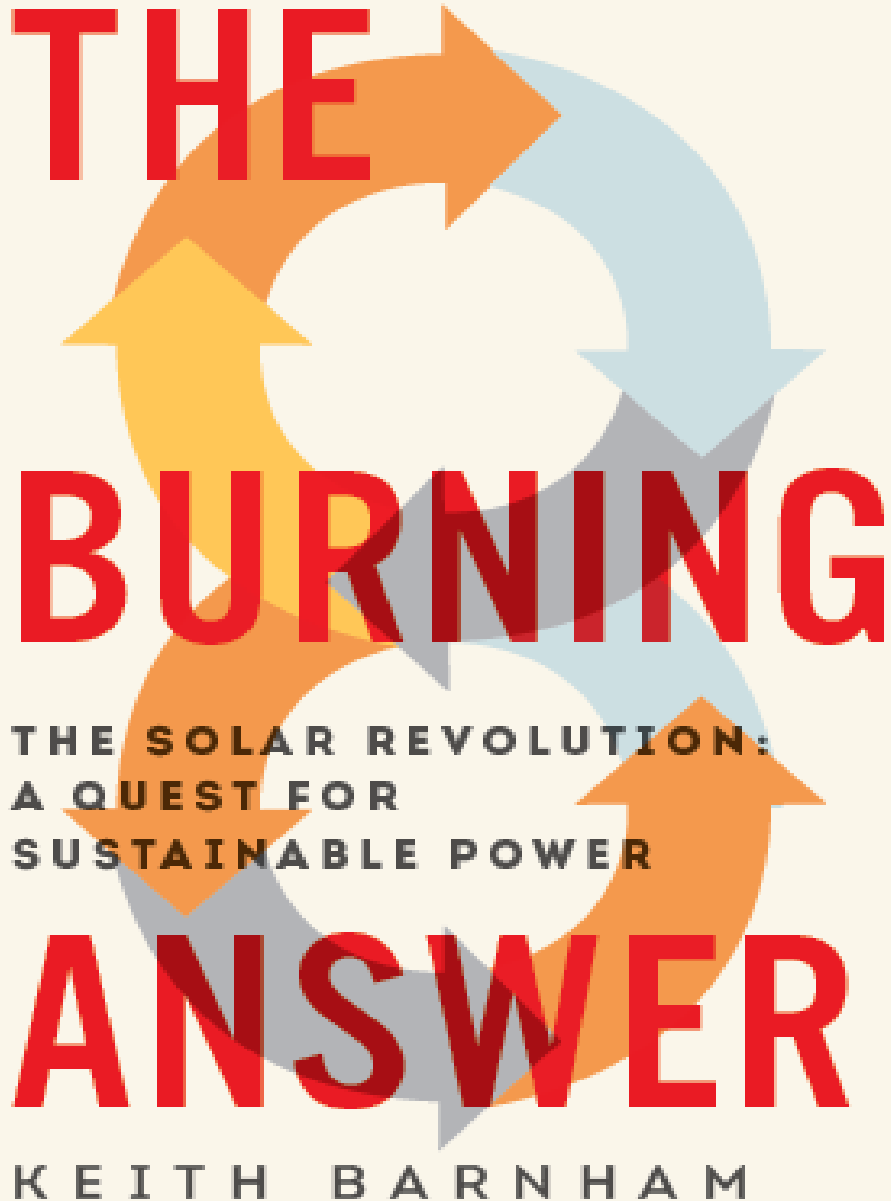
# Rooftop concentrator for PEC cells



# Conclusions

- An all-renewable electricity supply based on PV wind & waste biogas electricity is reliable, reduces wholesale cost & fastest way to reduce global warming
- Suggest NREL make KKW studies in US grid regions & organise all-renewable state competition
- Environmental limit of 50 gm CO<sub>2</sub>/kWh is practical
- Waste heat from the generation of electricity by QuantaSol cells technology can extract CO<sub>2</sub> from air
- In a roof-top system QuantaSol cells and luminescent concentrators can provide the voltages and photon fluxes that the artificial leaf will need.

"A very important book." –Bill McKibben, author of *The End of Nature*



Further information In  
new US edition

Pegasus Books  
New York  
15<sup>th</sup> May 2015

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# What does the scientific literature say?

- 3 peer-reviewed surveys of 274 published life-cycle analyses (LCAs)  
(Energy Policy **36**, 2940 Sovacool, **37**, 5056 Beerten, J.Ind.Ecol., 16, 2940, Warner & Heath)
- Only 6 LCAs independent & cover all 5 LCA stages
- Beerten re-analysis (3,9). Range fuel, decommissioning & waste

