Inaugural Fraunhofer – Delaware Technology Summit

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Energy and Life Sciences – Solutions for Sustainability

University of Delaware
Clayton Hall
March 5/6, 2013

Inaugural Fraunhofer – Delaware Technology Summit

SESSION B.1: SUSTAINABLE ENERGY CONCEPTS

Plenary Talk
"Challenges and Solutions for a Renewable Energy Economy"

– Christopher Hebling
Division Director, Energy Technology
Institute for Solar Energy Systems, ISE
Fraunhofer Gesellschaft

Challenges and Solutions for a Renewable Energy Economy

Christopher Hebling, PhD

Inaugural Fraunhofer-Delaware Technology Summit

Energy and Life Sciences – Solutions for Sustainability

March 5 and 6, 2013, University of Delaware, Newark

Fraunhofer Institut for Solar Energy Systems ISE
Freiburg, Germany

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Challenges and Solutions for a Renewable Energy Economy

Or:

‚White man keeps warm by running for wood'

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Fraunhofer-Institute for Solar Energy Systems ISE

Largest Solar Energy Research Institute in Europe

About 1300 members of staff (incl. students)

10% basic financing
90% contract research
50% industry, 40% public
76.5 M€ budget (2012)
> 10% p.a. growth rate

Areas of business:

- Energy-Efficient Buildings
- Photovoltaics *(Si, CPV, OPV)*
- Solar Thermal *(ST, CST)*
- Energy Storage Systems
- Hydrogen Technology
- Emission-free Mobility

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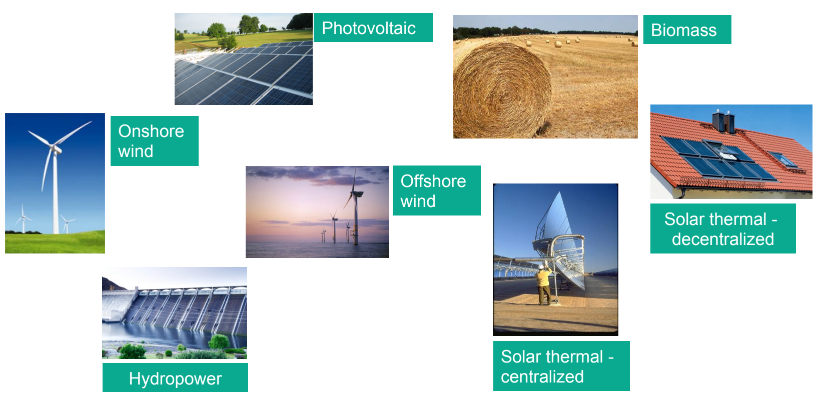
Why Renewable Energies



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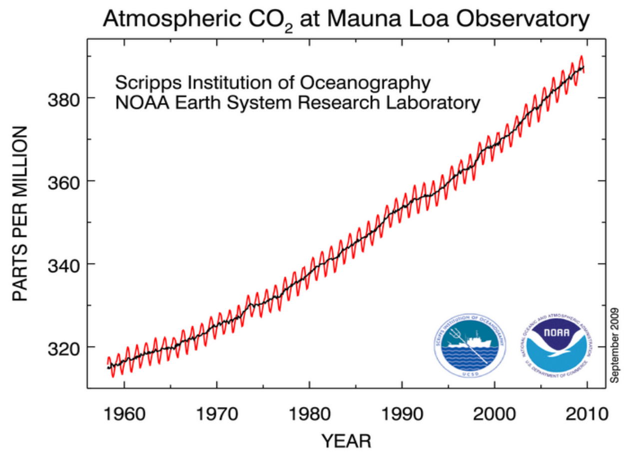
CO_2-Concentration in the Atmosphere

Before Industrialization:
280 ppm CO_2

2012:
> 400 ppm CO_2

Same trend in other climate gases



Source: CDIAC, http://cdiac.esd.ornl.gov

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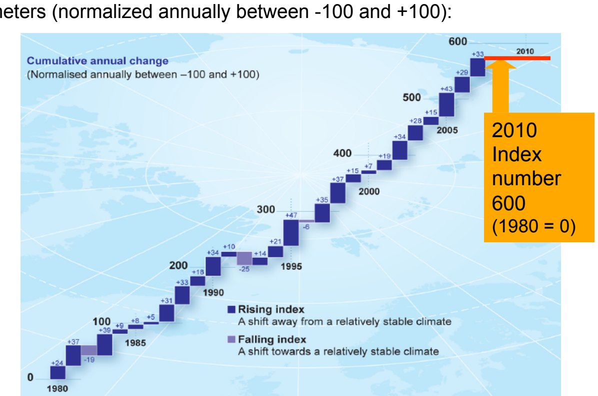
Climate Change Index – Cumulated Annual Change International Geosphere Biosphere Program IGBP

The Index combines various parameters (normalized annually between -100 and +100):

- CO_2-concentration in the atmosphere (280 to >400 ppm)
- Mean temperatur on the earth (Increase >0.8^{0}C)
- Height of Sealevel (increase of 10 inch since 1880)
- Ice coverage, summer min. in the arctic (ice coverage -50% since 1970)



Source: International Geosphere-Biosphere Programme (IGBP)

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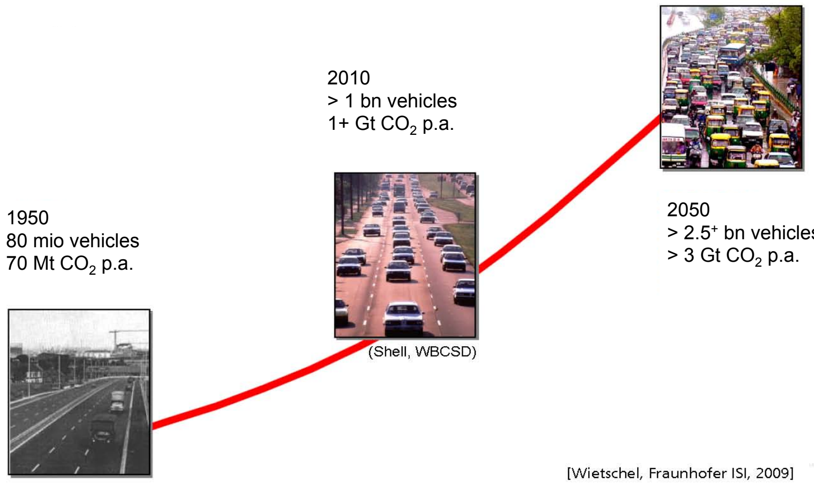
Emergence of Vehicles



[Wietschel, Fraunhofer ISI, 2009]

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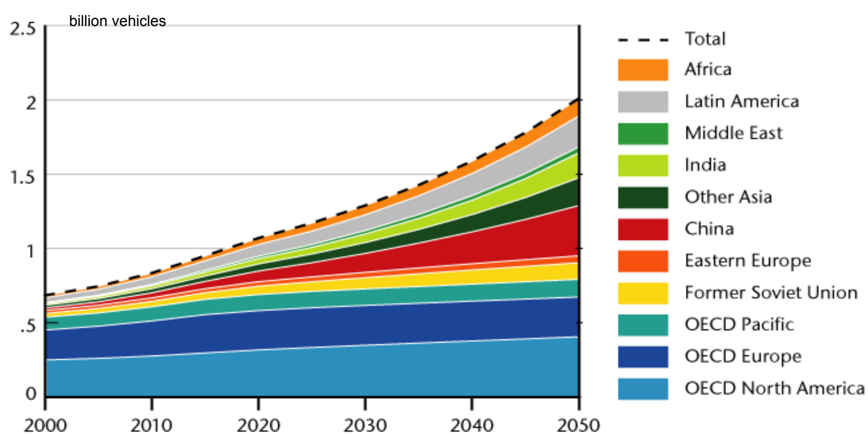
Regional Growth



Source: Sustainable Mobility Project Calculations

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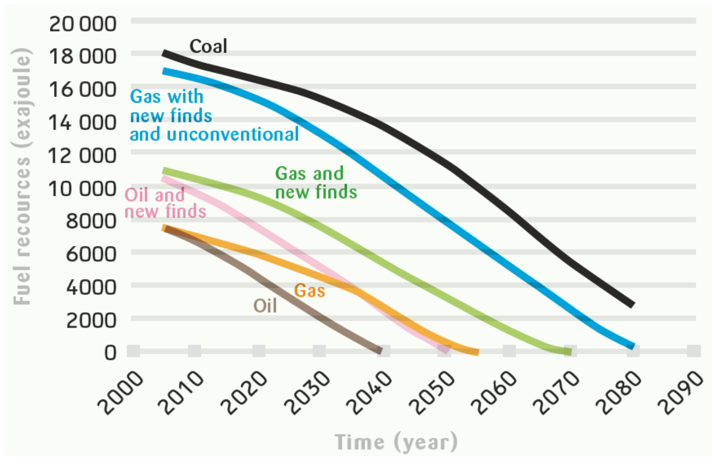
Estimated Resources of Fossile Energy Carriers



Source : book - Smart power generation 2011 – jacob klimstra & Markus Hotakainen

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Renewable Energy Studies

STANFORD UNIVERSITY

Review of solutions to global warming, air pollution, and energy security.

M. Jacobson; Energy Environ. Sci., 2009, 2, 148-173

European Climate Foundation

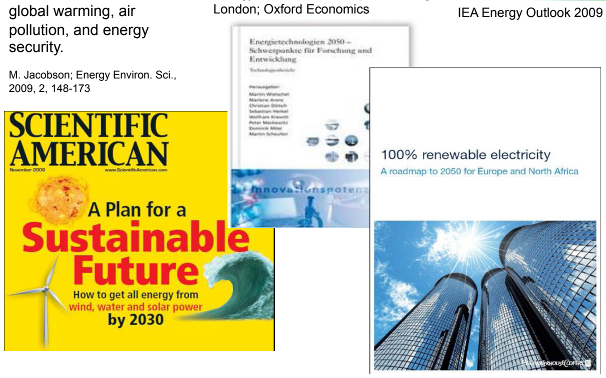
McKinsey & Company; KEMA; The Energy Futures Lab at Imperial College London; Oxford Economics

International Energy Agency

IEA Energy Outlook 2009

EREC

RE-thinking 2050
A 100% Renewable Energy Vision for the European Union, European Renewable Energy Council EREC, April 2010



PRICEWATERHOUSECOOPERS

POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

International Institute for Applied Systems Analysis
www.iiasa.ac.at

ECF European Climate Forum

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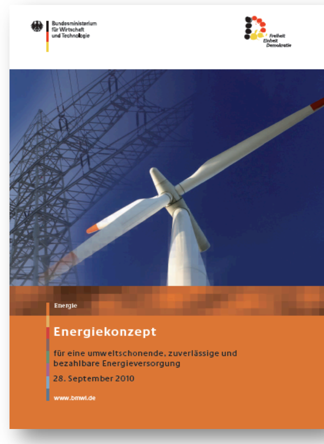
The Energy Concept of the German Government

- Guideline for the transition of the energy systems, in order to reach the 2050 targets
- A transition towards the era of renewable energy is feasable both technically and in terms of investments
- Target: Decarbonization of both the energy system and the mobility sector



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German Government: Targets for the Energy Supply Until 2050

Targetes for the year	2020	2030	
Reduction green house gases	- 40%	- 55%	
Reduction primary energy consumption		- 20%	- 50%
Reduction electricity consumption	- 10 %		
Proportion renewables on energy cons.		18 %	60%
Proportion renewables on electricity cons.		35%	80%

=> Fundamental and fast change of energy system is necessary

Source: Energiekonzept 2050, Bundesregierung, Sept 2010

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Cornerstones for a transition of the energy systems

- Refurbishing of the building stock
  Doubling the refurbishing rate

- Massive increase of all renewable energies
  Photovoltaics, Solar thermal, wind, hydro, geo thermal, biomass

- Fast development of the electric grid
  Transmission and distribution grid

- Development of large scale energy storage systems
  Electricity, hydrogen, methane, biogas, solar thermal storage systems

- Mobility integral part of energy system
  Electric mobility by means of batteries and hydrogen/fuel cells

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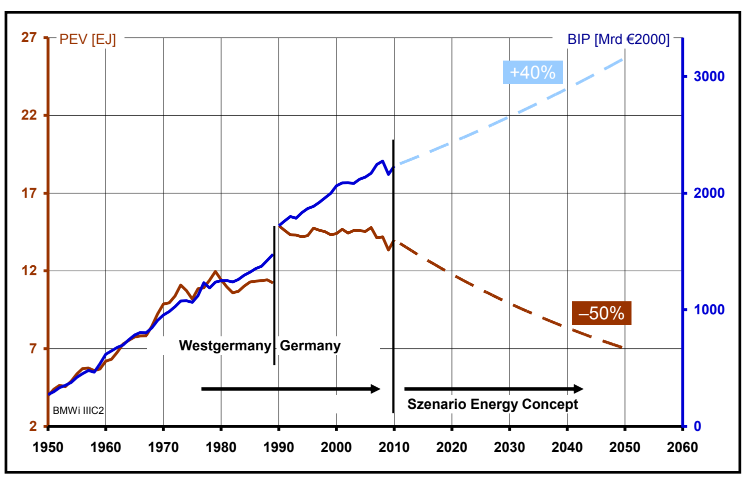
Gross Domestic Product GDP and Energy Consumption in Germany



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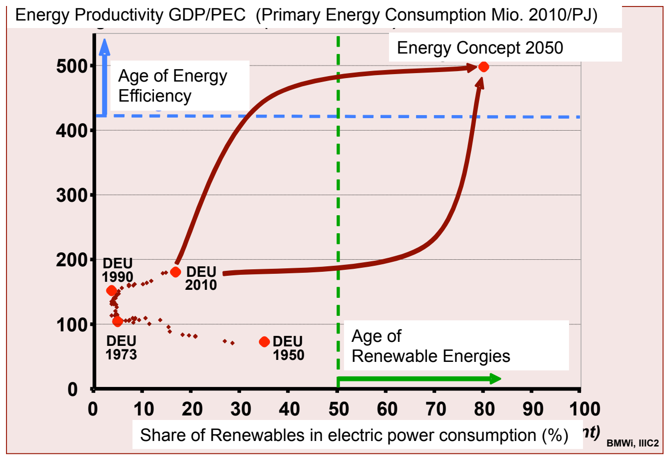
Development of Energy Efficiency and Renewable Energies in Germany



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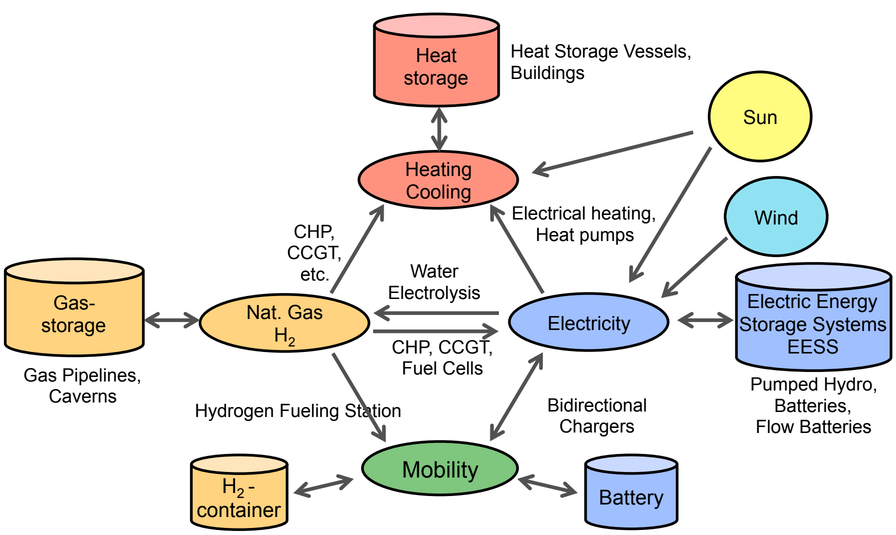
Transition to a Solar Energy Economy



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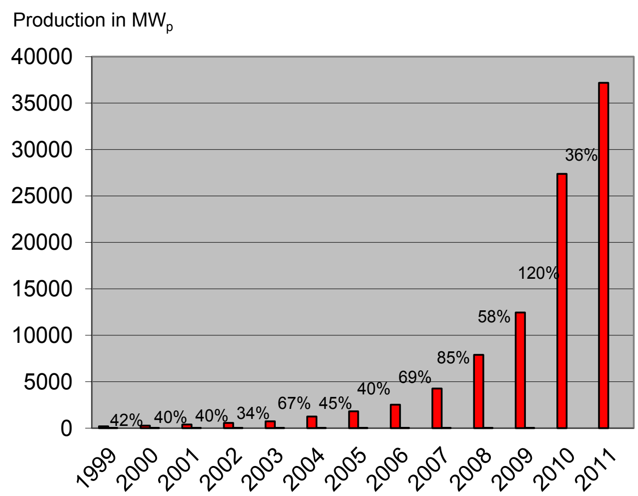
Global Market Growth of Photovoltaics



W_p = maximum power output of a PV module @1000 W/m² illumination (AM1.5)

Source: Photon 2012

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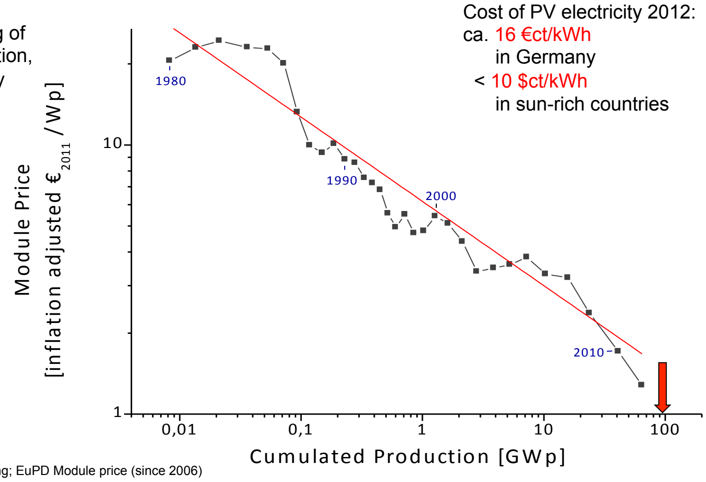
Price Learning Curve (for c-Si PV Technologies)

Learning Rate:
With each doubling of cumulative production, price went down by 20%!



Cost of PV electricity 2012:
ca. 16 €ct/kWh in Germany
< 10 $ct/kWh in sun-rich countries

Source: Navigant Consulting; EuPD Module price (since 2006)

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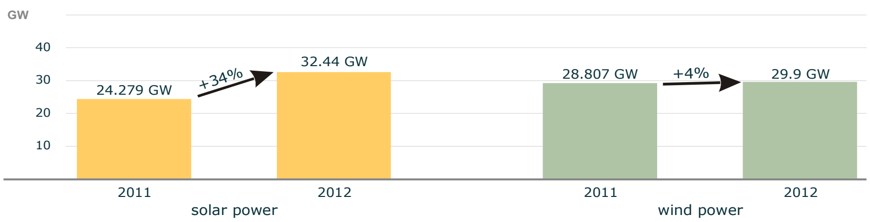
Installed solar and wind power 2011 and 2012

Installed solar and wind power



Graph: B. Burger, Fraunhofer ISE; data: Bundesnetzagentur

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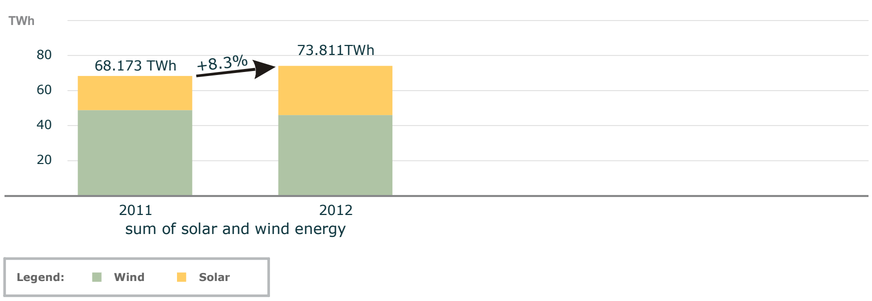
Production solar and wind in 2012

Annual sum of solar und wind production



Graph: B. Burger, Fraunhofer ISE; data: EEX Transparency Platform

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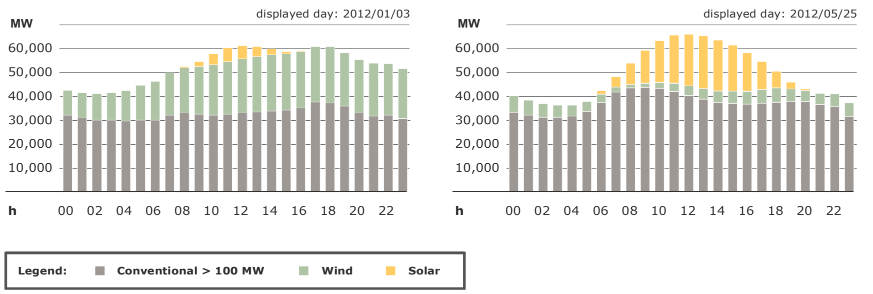
Electricity generation in Germany
Selected days 03.01.2012 and 25.05.2012

Actual production | **Actual production**



Source: B. Burger, Fraunhofer ISE, 2012

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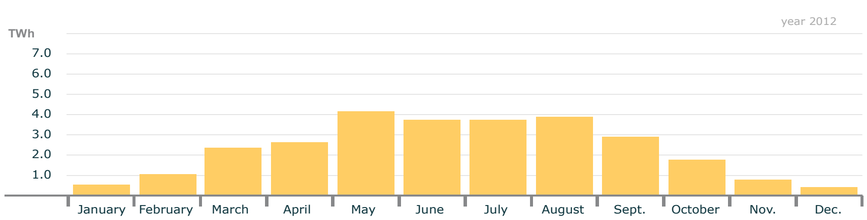
Monthly Solar Production

Monthly Production Solar



- The maximal production of PV was reached in May 2012 with 4.1 TWh
- The minimal production was 0.44 TWh in December 2012

Graph: B. Burger, Fraunhofer ISE; data: EEX Transparency Platform

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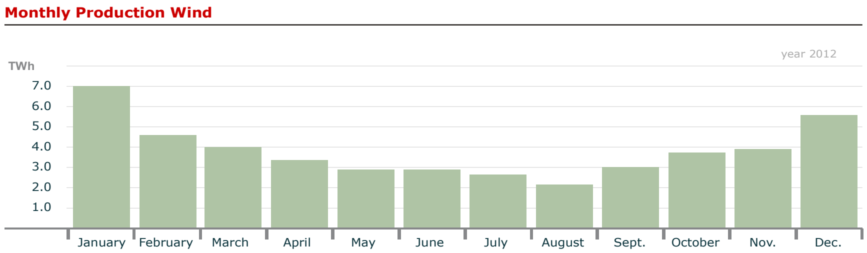
Monthly Production Wind



- The maximal production from wind was reached in January 2012 with 7 TWh
- The minimal production was 2.2 TWh in August 2012

Graph: B. Burger, Fraunhofer ISE; data: EEX Transparency Platform

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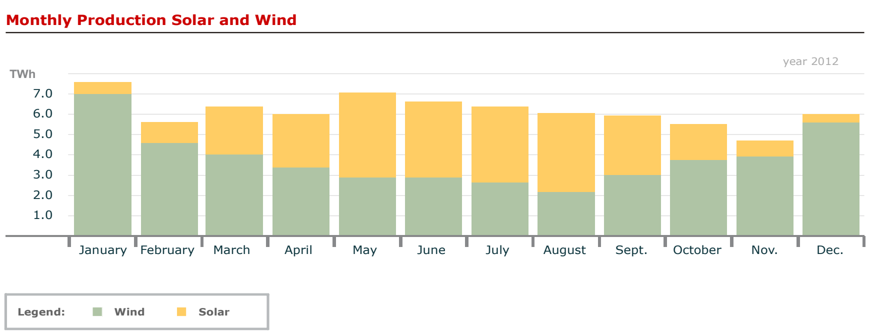
Monthly Production Solar and Wind



- The maximal sum of solar and wind production was 7.6 TWh in January 2012
- The minimal sum was 4.7 TWh in November 2012

Graph: B. Burger, Fraunhofer ISE; data: EEX Transparency Platform

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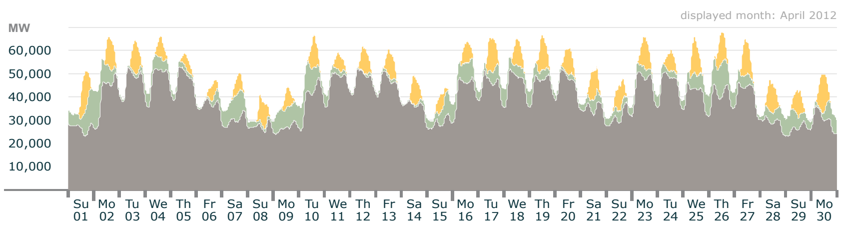
Electricity Production in Germany: April 2012

Actual production



	max. power	date max. power	monthly energy
Solar	16.8 GW	30.04., 12:45 (+2:00)	2.6 TWh
Wind	16.5 GW	01.04., 23:30 (+2:00)	3.4 TWh
Konventionell > 100 MW	53.2 GW	05.04., 08:00 (+2:00)	28.0 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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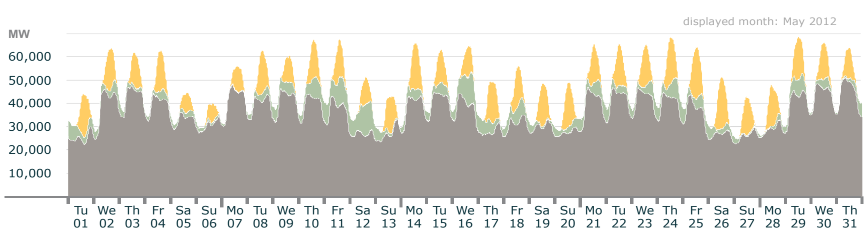
Electricity Production in Germany: May 2012

Actual production



	max. power	date max. power	monthly energy
Solar	22.4 GW	25.05., 12:45 (+2:00)	4.1 TWh
Wind	14.1 GW	12.05., 17:00 (+2:00)	2.9 TWh
Conventional > 100 MW	51.2 GW	31.05., 11:00 (+2:00)	26.6 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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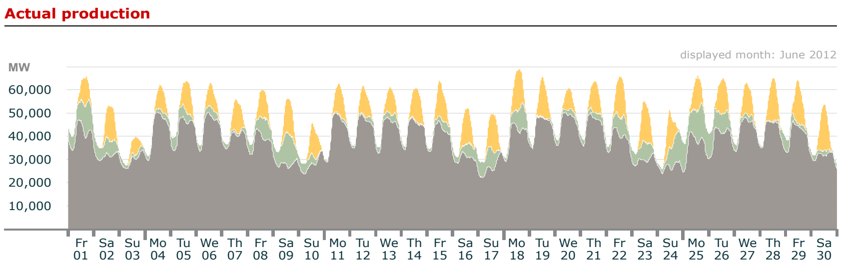
Electricity Production in Germany: June 2012



	max. power	date max. power	monthly energy
Solar	19.7 GW	30.06., 13:00 (+2:00)	3.7 TWh
Wind	15.3 GW	25.06., 18:45 (+2:00)	2.9 TWh
Conventional > 100 MW	50.5 GW	04.06., 11:00 (+2:00)	27.4 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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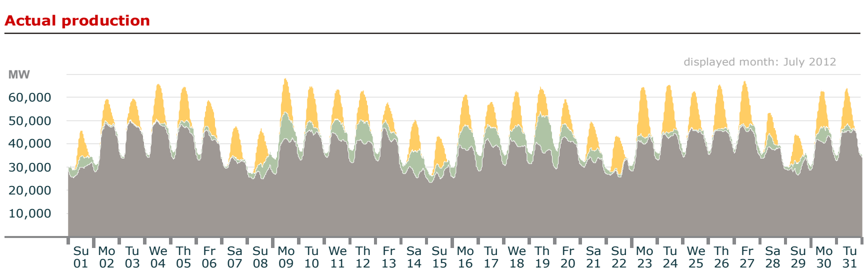
Electricity Production in Germany: July 2012



	max. power	date max. power	monthly energy
Solar	21.8 GW	23.07., 13:15 (+2:00)	3.7 TWh
Wind	16.2 GW	19.07., 16:30 (+2:00)	2.6 TWh
Conventional > 100 MW	50.3 GW	03.07., 10:00 (+2:00)	27.7 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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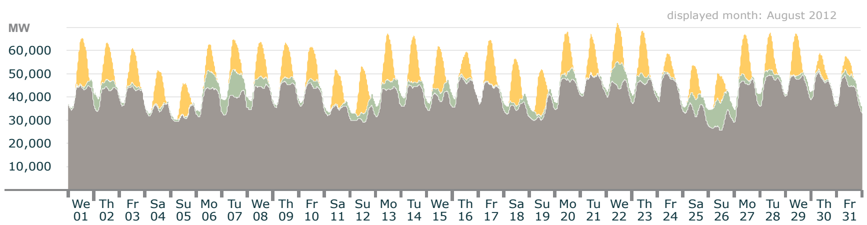
Electricity Production in Germany: August 2012

Actual production



	max. power	date max. power	monthly energy
Solar	20.6 GW	01.08., 13:15 (+2:00)	3.9 TWh
Wind	12.8 GW	26.08., 14:45 (+2:00)	2.2 TWh
Conventional > 100 MW	51.1 GW	30.08., 10:00 (+2:00)	30.0 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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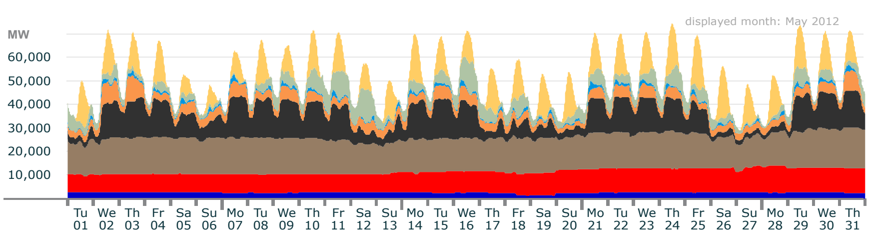
Detailed Electricity Production: Mai 2012

Actual production



Legend: Run of River Uranium Brown Coal Hard Coal Gas Pumped Storage Wind Solar

	RoR	Uran	BC	HC	Gas	PSt	Wind	Solar
max. power (GW)	1.5	6.9	11.2	1.5	1.9	0	0.26	0
monthly energy (TWh)	3.0	11.4	17.6	17.8	11.1	4.0	14.1	22.4
	1.6	6,7	10.3	7.7	3.0	0.54	2.9	4.1

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

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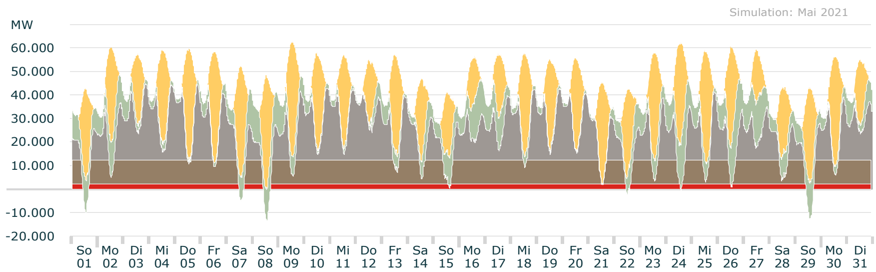
Simulation: Mai 2021
70 GW Solar, 48 GW Wind installed

Simulation



- For Mai 2021 (projection): Solar: max. 48,6 GW; 9,6 TWh, Wind: max. 24,8 GW; 5,2 TWh
- Conventionel: min. -14,1 GW; max. 44,5 GW; 17,9 TWh

Grafik: B. Burger, Fraunhofer ISE; Daten: Leipziger Strombörse EEX

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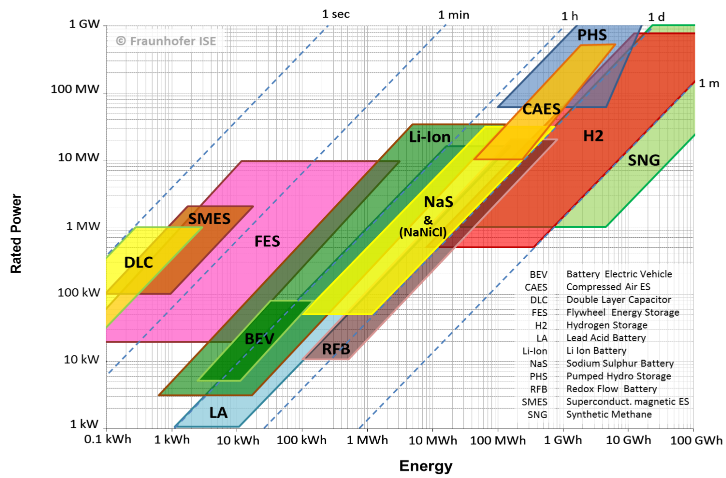
Hydrogen Energy Storage

Storage principles: Electrochemical, Chemical, Mechanical,Electromagnetic



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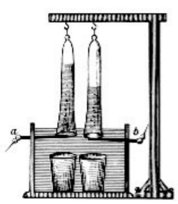
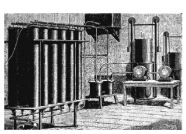
Electrolysis: Electrolytical Water Splitting
For more than 200 years



Test set-up of Ritter



Alkaline electrolyser around 1900

$2 H_2O \rightarrow 2 H_2 + O_2$

- Invention of voltaic pile (1799) enabled investigations of electrolytic approaches
- Main principle demonstrated around 1800 by J. W. Ritter, William Nicholson and Anthony Carlise

Johann Wilhelm Ritter (1776-1810)

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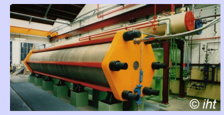
Hydrogen Energy: Main Principles

- Generation of hydrogen from
  - electric power by electrolysis
  - fossil fuels (steam reforming)
  - waste biomass (reforming)



- Storage of hydrogen at
  - elevated pressure level in tanks/pipelines
  - liquified at low temperature
  - geological, underground

- Hydrogen usage in many applications
  - power generation
  - fuel for mobility
  - chemical industry (methanol, ammonia,..)

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Hydrogen Energy: How to Store Hydrogen?

Picture Credits:
Top: Dynetek, Quantum, Linde, Magna Steyr, NASA
Bottom: Westfalen Gas, Wystrach, Dynetek, Hyfleet, NASA, KBB UT

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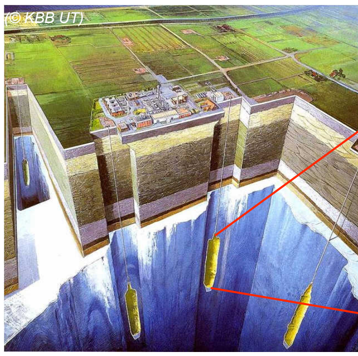
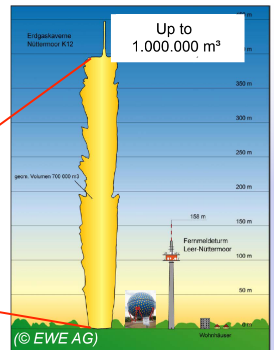
Hydrogen Energy Storage : Underground Storage in Salt Caverns

- In the past: Storage of town gas in Germany
- Today: Natural gas reserve in Germany
- Hydrogen salt cavernes in UK and US





Echometric cavern survey

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Hydrogen Storage in Salt Caverns

Town gas in Germany 1850 - 1950
(H_2-proportion > 50%) in salt caverns and pipelines

Hydrogen caverns in operation:

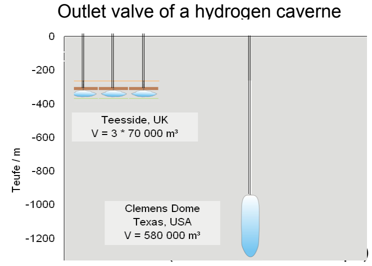
Teeside, UK, Operator: Sabic Petrochemicals,
3 x 70.000m3, 4.5MPa (konst.), 25 GWh,
30 years in operation

Clemens, Dome, Lake Jackson, Texas, USA,
Operator: ConocoPhillips, 580.000 m3,
7,0 – 13,5 MPa, 92 GWh, since 1986

Moss Bluff Salzdom, Liberty County, Texas,
Operator: Praxair, 566.000 m3 storage
volume, 7,6 – 13,4 MPa, 80 GWh,
since 2007

(Source: KBB UT)

Outlet valve of a hydrogen caverne



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Local Hydrogen Storage
1.5 GWh Storage Capacity (filled with hydrogen, 1.6 ha)

Source: Rosetti Marino - Italy

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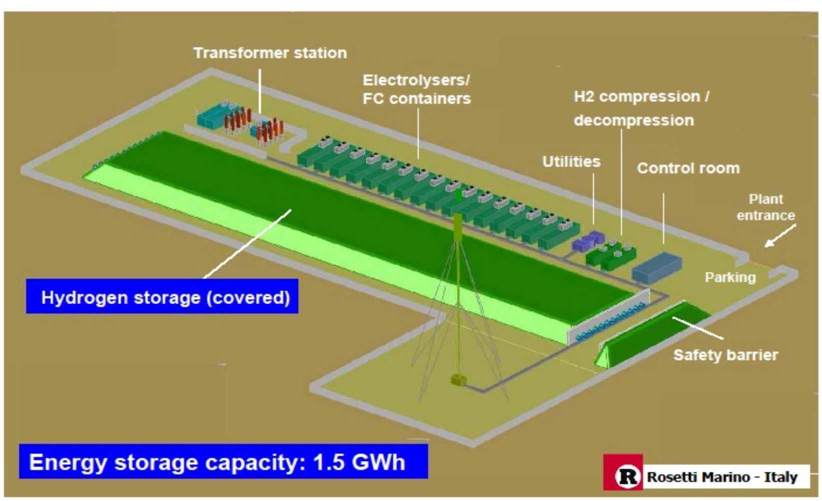
Renewable Energy Peakshaving Facility with Hydrogen Storage



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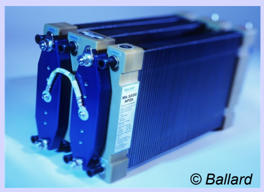
Hydrogen Energy: Power generation

Fuel Cells
- High efficiency
- Mobile (fuel cell car)
- (Portable / stationary)
- 1 W - 100 kW



Gas Engines
- Internal combustion
- Robust and reliable
- Stationary
- 10 kW - 5 MW

Gas Turbines
- Power plant technology
- Moderate efficiency
- Stationary
- 1 MW - 300 MW

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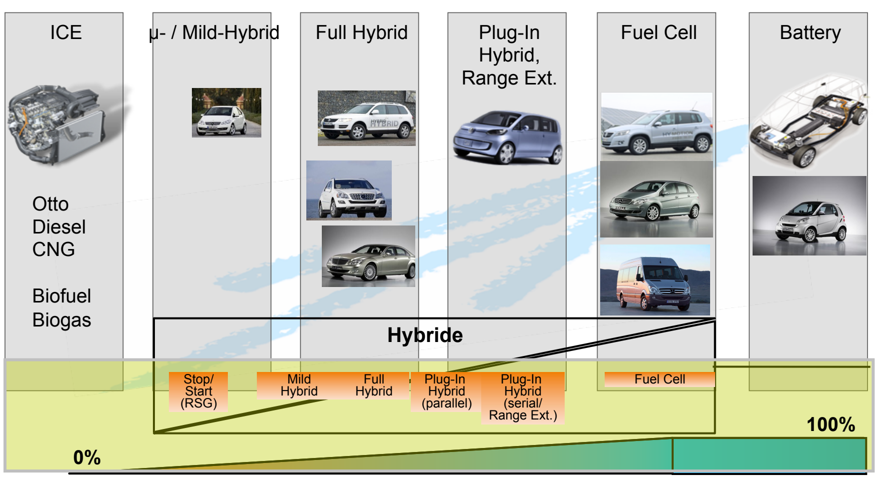
Hydrogen usage: Mobility



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Conclusions

- The transformation to a sustainable energy system for the world requires a fast transition towards the use of 100% renewable energy
- Photovoltaic electricity costs are today already less than 10ct/kWh in sun-rich areas, and costs will come further down. The market will create exciting business opportunities worldwide.
- Increased energy storage capabilities and long-range grid interconnections integrate large amounts of fluctuating electricity sources into the energy system
- Hydrogen will play an important role as an universal energy carrier for storing energy, as a fuel in the transportation sector and a chemical component
- The reward for this transformation will be long-term sustainability of the world's energy needs at lower, stable and thus predictable energy costs.

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Challenges and Solutions for a Renewable Energy Economy

Or:

‚White man keeps warm by running for wood'

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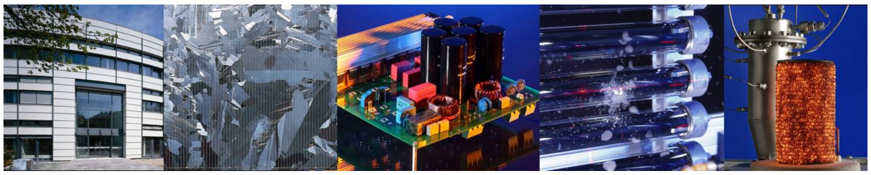
Thank you



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Conclusion: The Bright Future of PV

- Globally needed power: today 16 TW, 2050 at least 30 TW
- PV: at least 10%, optimistically 30-40% of energy need
- 3 TW power correspond to 12 TW PV, 12,000 GW
- PV globally installed till 2011: 66 GW, 2012 alone: additional 30-32 GW!
- **To reach 12.000 GW we would need almost 300 years at this rate!**
- **The PV market will move from a 30GW / $ 70 bn market to a 300GW market in a few years, prediction: by 2025!**
- This will be accompanied by a drastic cost reduction, making PV one of the most inexpensive ways to produce energy, in the range of 5 cts/kWh, comparable with hydro, onshore wind, much less than nuclear, fossil fuels in 2030!

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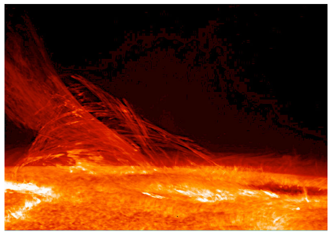
The actual energy economy



In three weeks time the suns sends the same energy as all remaining fossil energy reserves.

Amount of remaining fossil energy reserves in 10^9 t coal equivalent:

Oil	210
Gas	170
Coal	660
Total	1040

(Source P. Würfel, Wiley)

World primary consumption (2002): 13.2 10^9 t coal equivalent

Energy stream from sun to earth 180000 x 10^9 t SKE/a

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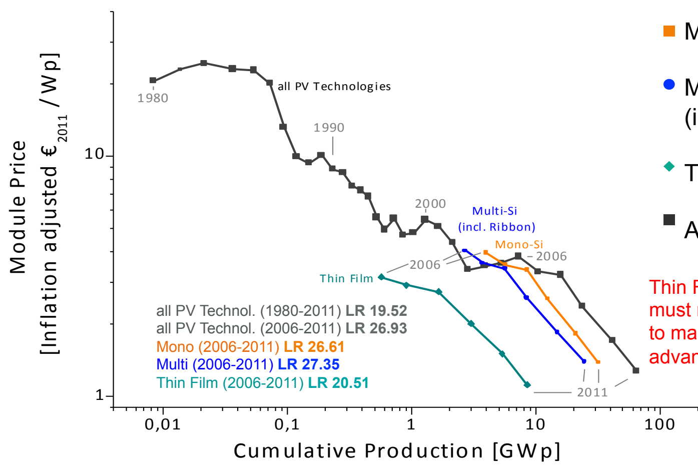
Price Learning Curve by Technology

Cumulative Production End of 2011:

- Mono-Si 24.5 GWp
- Multi-Si 31.6 GWp (incl. Ribbon-Si)
- Thin Film 8.5 GWp
- All PV Technologies



Thin Film Technologies must ramp up fast enough to maintain a clear cost advantage at lower effciencies!

Source: Navigant Consulting; EuPD Module price (since 2006)
Design: PSE AG 2012

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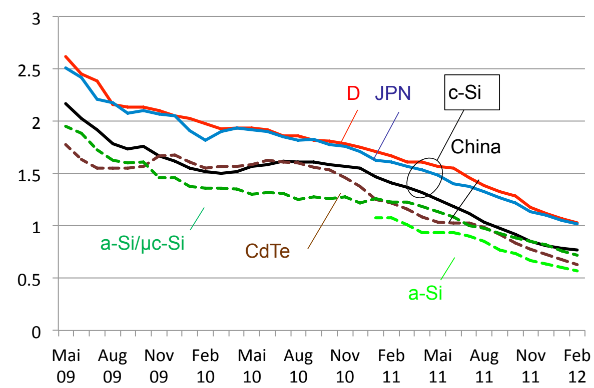
Development of Module Prices – Spot Market 05/09 – 02/12

Average Price
Intnernational Spot
Market (net)
[€/Wp]

Quelle: Photovoltaik-Preisindex, www.solarserver.de; pvxchange, 03/2012



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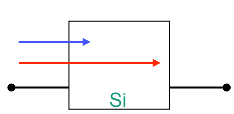
The efficiency limit for a single-material PV Cell

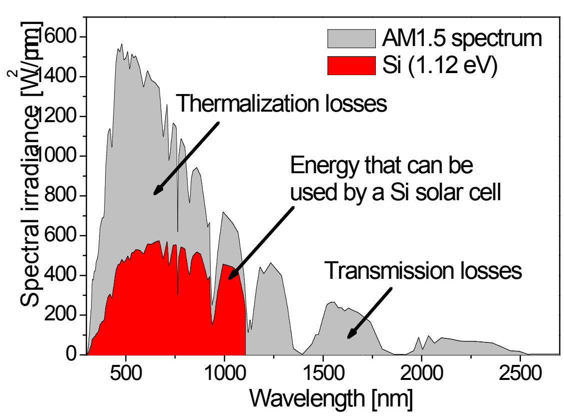
For Silicon:

(AM1.5g, 1000 W/m², 25°C)

$h_{max, theo}$ = 28 %

Lab cell = 24 %





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The benefit of multi-junction solar cells

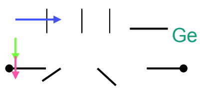
For triple-junction concentrator cells:

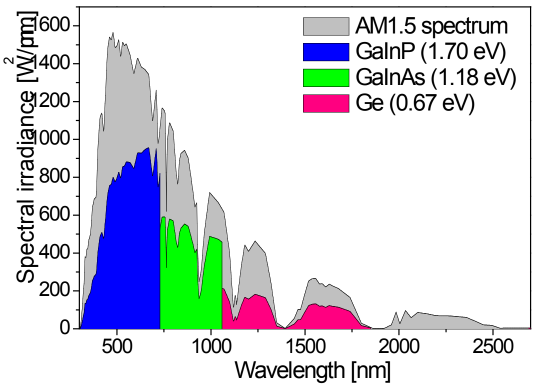
$h_{max, theo}$ = 61 %

(1000xAM1.5d, 1000 W/m²)

Lab. cell = 40.8 %

230xAM1.5d, 1000 W/m²)





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