THE GLOBAL ENERGY TRANSFORMATION

Eicke R. Weber

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Fraunhofer Institute for
Solar Energy Systems ISE
and
University of Freiburg, Germany

3rd Fraunhofer Innovation and
Technology Platform: *Powering a Greene*
Future

Bangalore, India, November 22, 2014

Fraunhofer
ISE

Fraunhofer Institute for Solar Energy Systems ISE
Research for the Energy Transformation

- largest European Solar Energy Research Institute
- more than 1300 members of staff (incl. students)
- 16 % basic financing
- 84 % contract research , 29 % industry, 55 % public
- € 86,7 M budget (2013, incl. investments)
- >10 % growth rate (until 2013)

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12 Areas of Business

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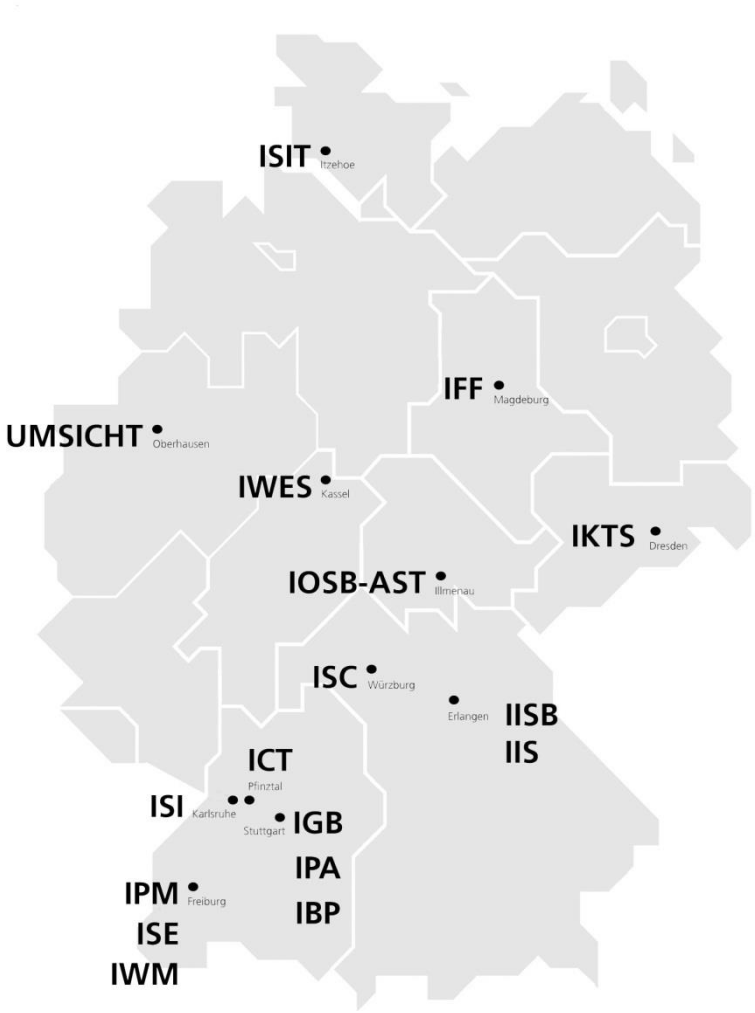
- Energy Efficient Buildings
- Silicon Photovoltaics
- III-V and Concentrator Photovoltaics
- Dye, Organic and Novel Solar Cells
- Photovoltaic Modules and Power Plants
- Solar Thermal Technology
- Hydrogen and Fuel Cell Technology
- System Integration and Grids – Electricity, Heat, Gas
- Energy Efficient Power Electronics
- Zero-Emission Mobility
- Storage Technologies
- Energy Systems Analysis

Fraunhofer Energy Alliance



- Members:18 Fraunhofer Institutes
- Spokesperson:
  Prof. Eicke R. Weber
- Deputy Spokesperson:
  Dr. Peter Bretschneider
- Managing Director:
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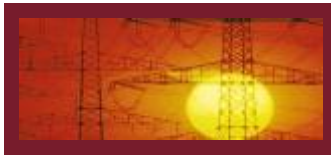
FRAUNHOFER ENERGY ALLIANCE

- We conduct research in the following areas:

Wind energy

Energy-efficient living

Solar energy

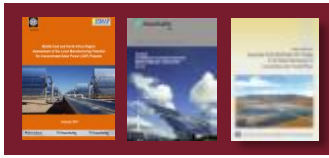


Intelligent energy distribution

Bioenergy

Compact energy storage

Efficient use of energy



Energy technology and system assessment

Images © Fraunhofer, MEV;

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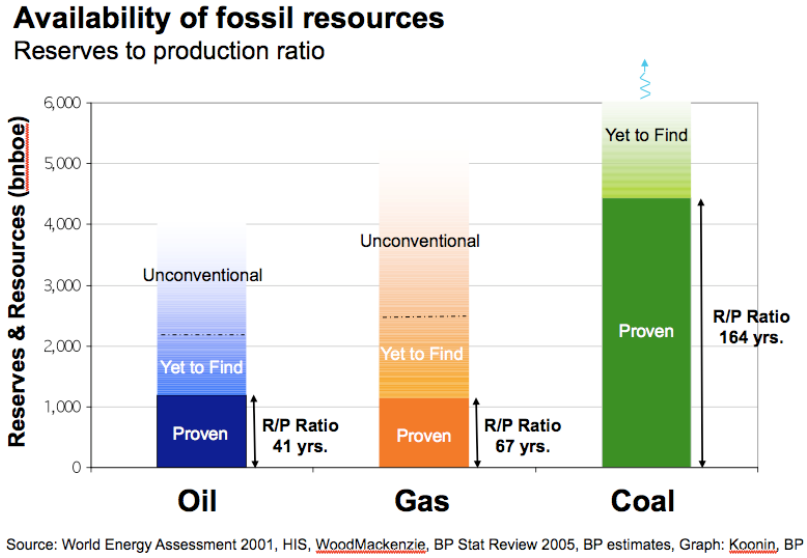
A Radical Transformation of our Energy System is Needed Jeremy Rifkin: We are starting the 3rd Industrial Revolution!

- Limited availability of fossil fuels

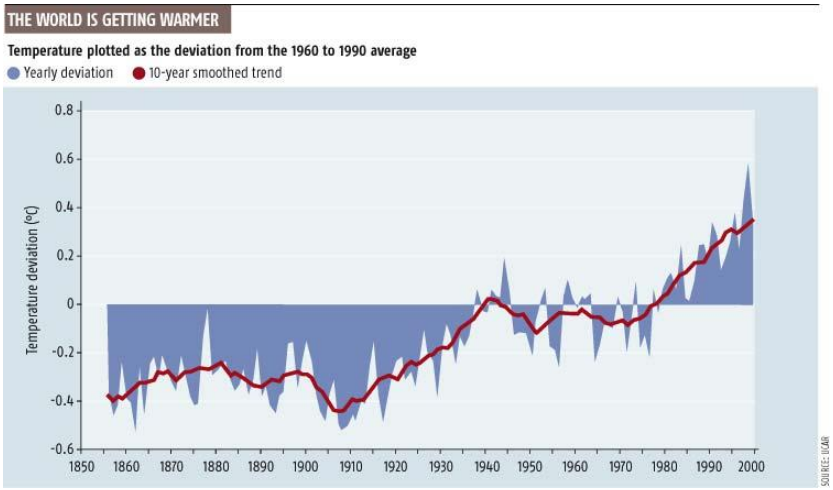


Fossil fuels get scarce

A Radical Transformation of our Energy System is Needed Jeremy Rifkin: We are starting the 3rd Industrial Revolution!

- Limited availability of fossil fuels
- Danger of catastrophic climate change
- Risk of nuclear disasters
- Growing dependency on imports from politically unstable regions

New since recently:



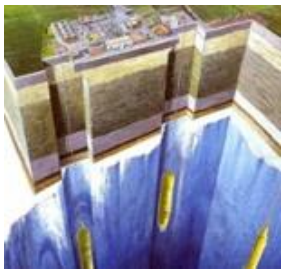
The world gets warmer

Increasing economic opportunities!

Cornerstones for the Transformation of our Energy System

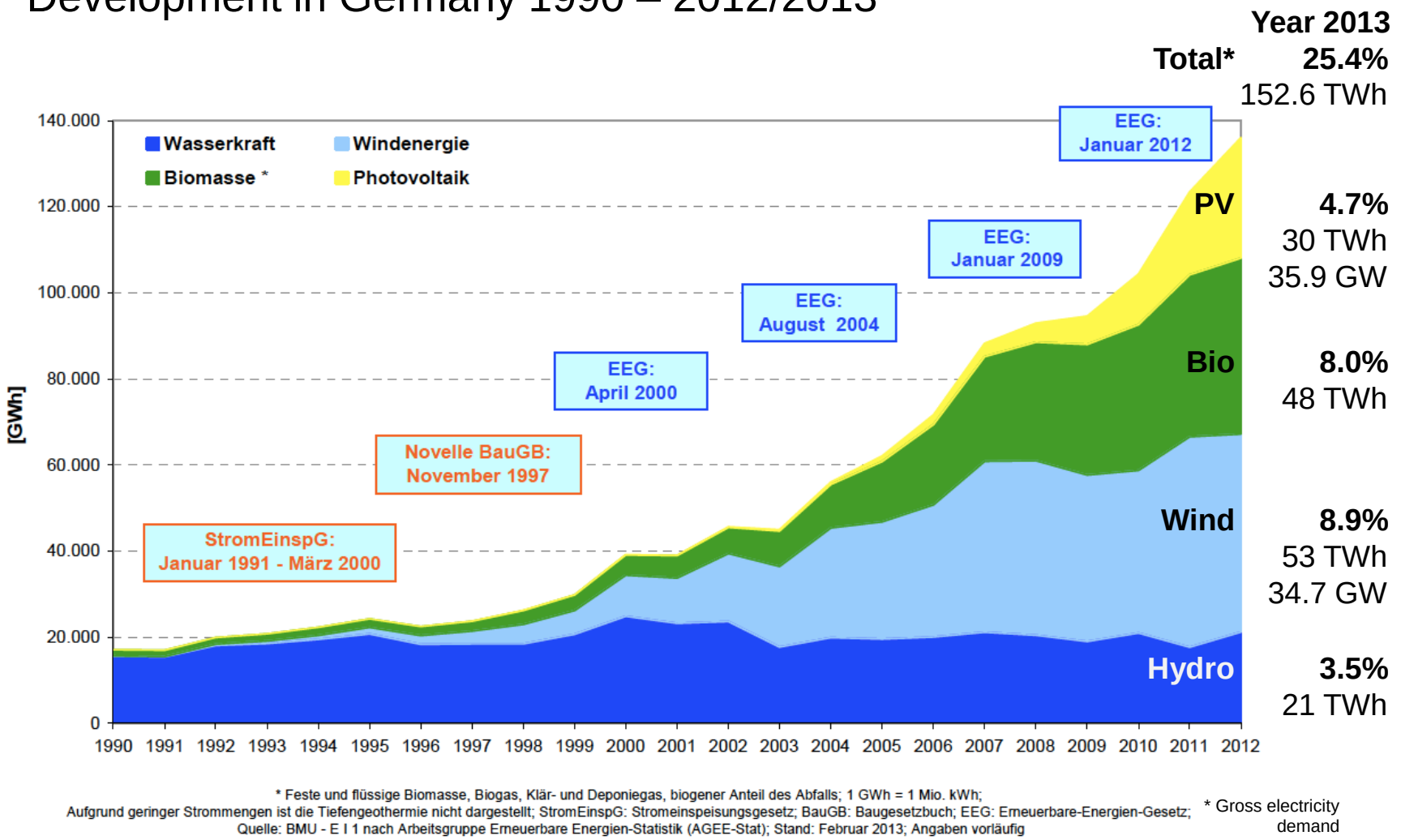
- energy efficiency: buildings, production, transport
- massive increase renewable energies: photovoltaics, solar and geo thermal, wind, hydro, biomass...
- fast development of the electric grid: transmission and distribution grid, bidirectional
- small and large scale energy storage systems: electricity, hydrogen, methane, biogas, solar heat
- mobility as integral part of the energy system: electric mobility by means of batteries and hydrogen/fuel cells




Electricity generation from renewable energy sources

Development in Germany 1990 – 2012/2013



* Feste und flüssige Biomasse, Biogas, Klär- und Deponiegas, biogener Anteil des Abfalls; 1 GWh = 1 Mio. kWh;
Aufgrund geringer Strommengen ist die Tiefengeothermie nicht dargestellt; StromEinspG: Stromeinspeisungsgesetz; BauGB: Baugesetzbuch; EEG: Erneuerbare-Energien-Gesetz;
Quelle: BMU - E I 1 nach Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat); Stand: Februar 2013; Angaben vorläufig

* Gross electricity demand

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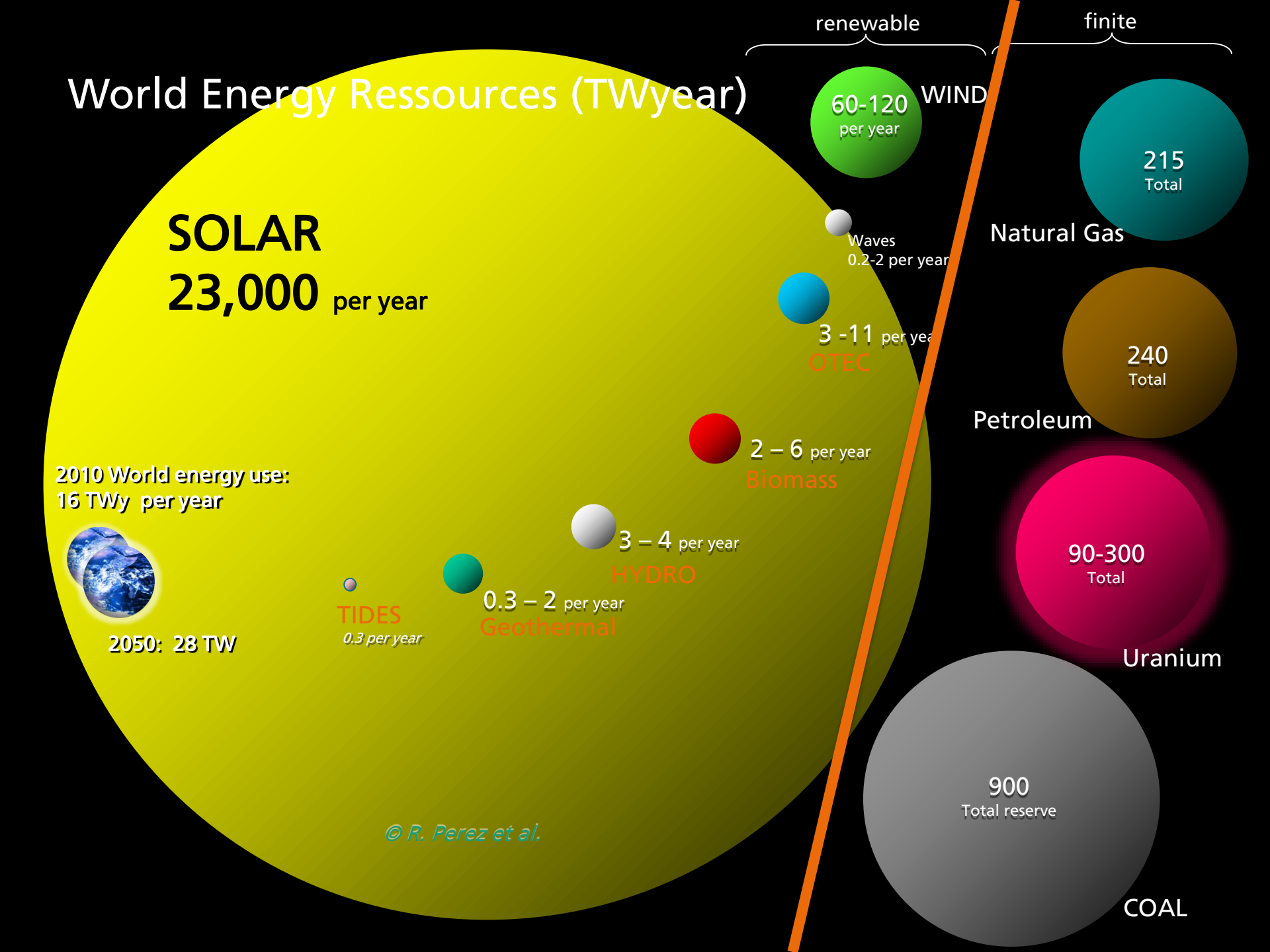
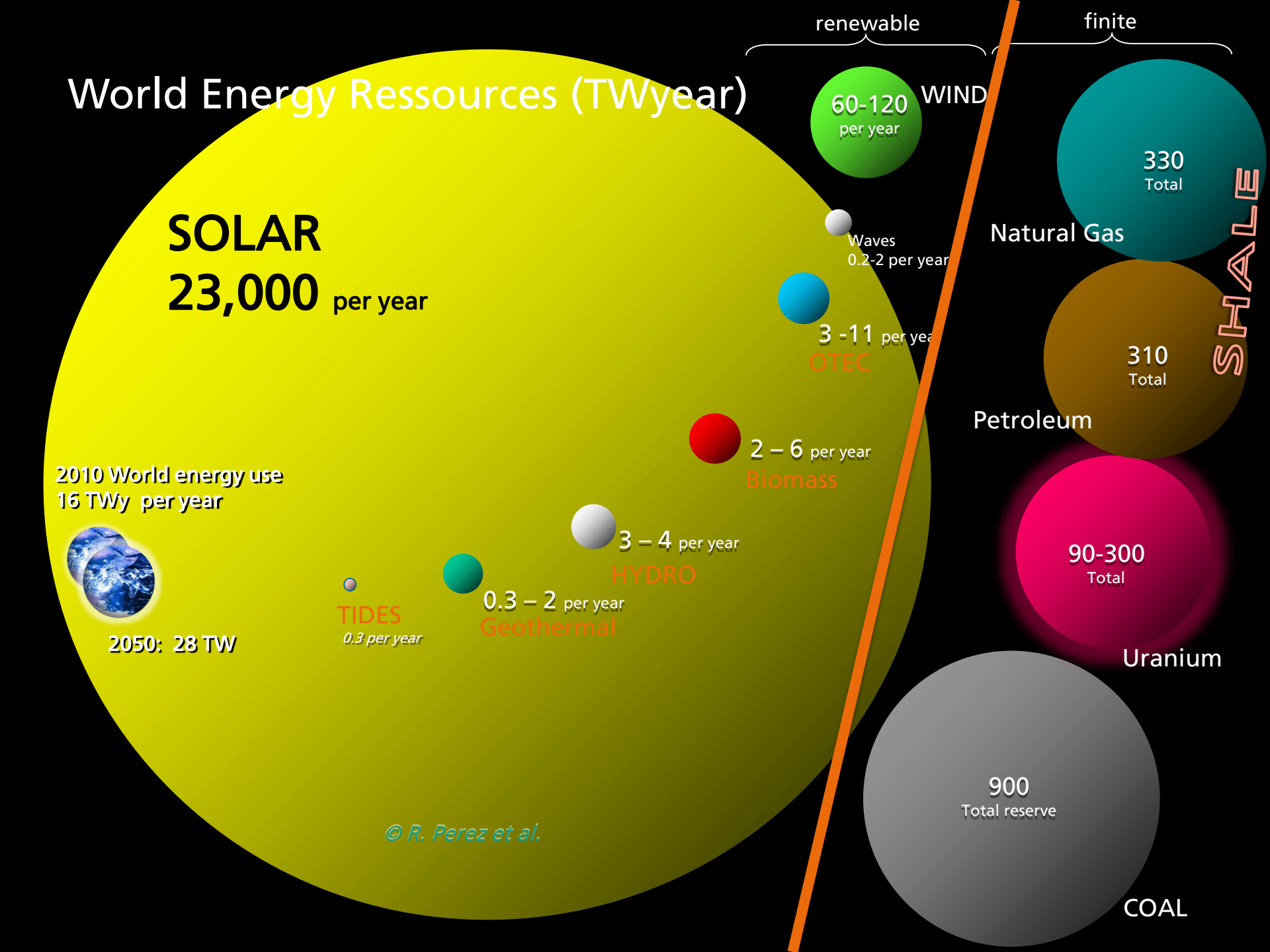

renewable
finite
World Energy Ressources (TWyear)
60-120
per year
WIND
215
Total
Natural Gas
SOLAR
23,000 per year
Waves
0.2-2 per year
3 -11 per yea
OTEC
240
Total
Petroleum
2 – 6 per year
Biomass
2010 World energy use:
16 TWy per year
90-300
Total
Uranium
3 – 4 per year
HYDRO
0.3 – 2 per year
Geothermal
TIDES
0.3 per year
2050: 28 TW
900
Total reserve
COAL
© R. Perez et al.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Total reserve
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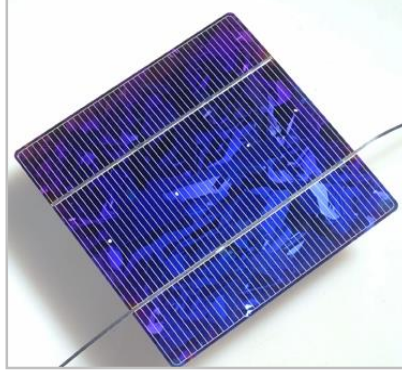
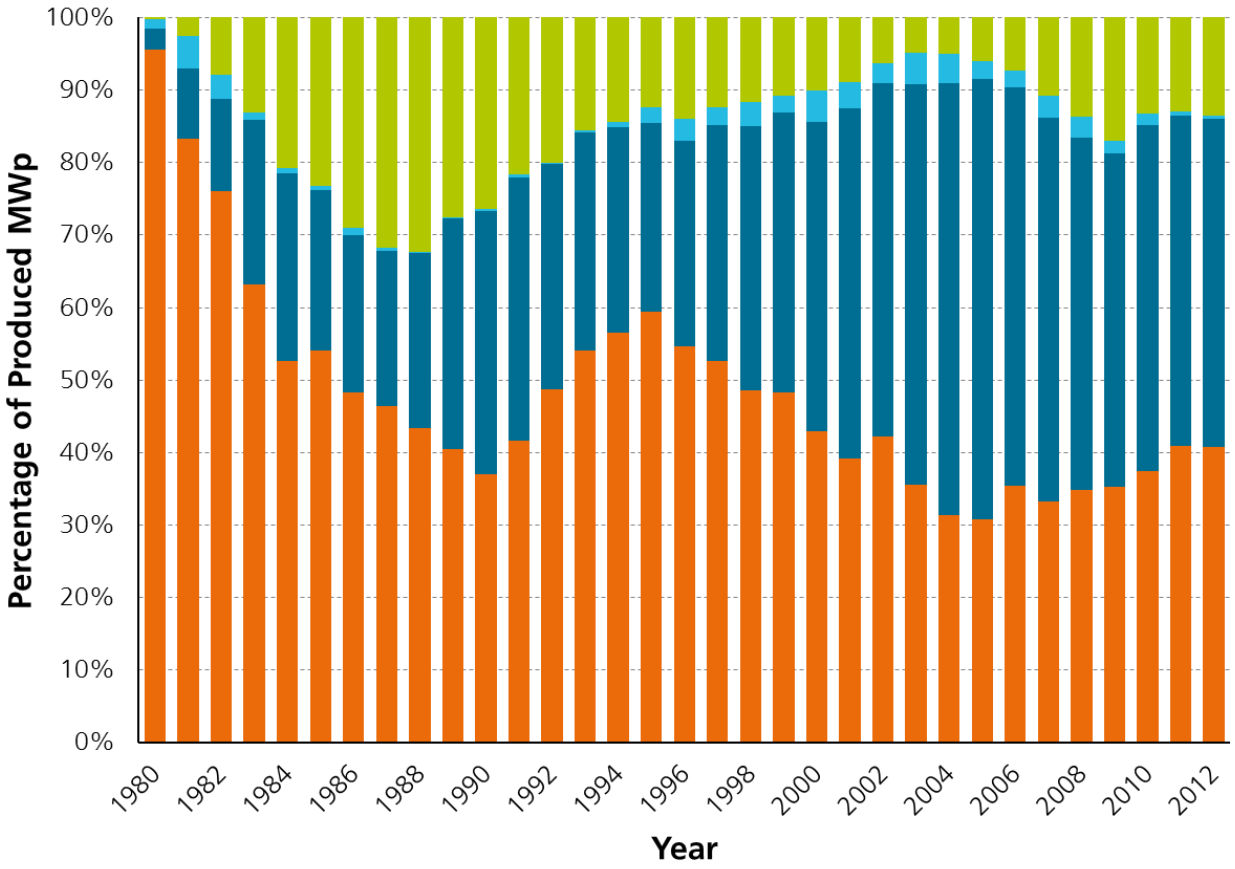
Harvesting Solar Energy: Photovoltaics (PV)
PV Production Development by Technology





Production 2012 (MW_p/a

Thin film	3.224
Ribbon-Si	100
Multi-Si	10.822
Mono-Si	9.751

Daten: Navigant Consulting. Graph: PSE AG 2013

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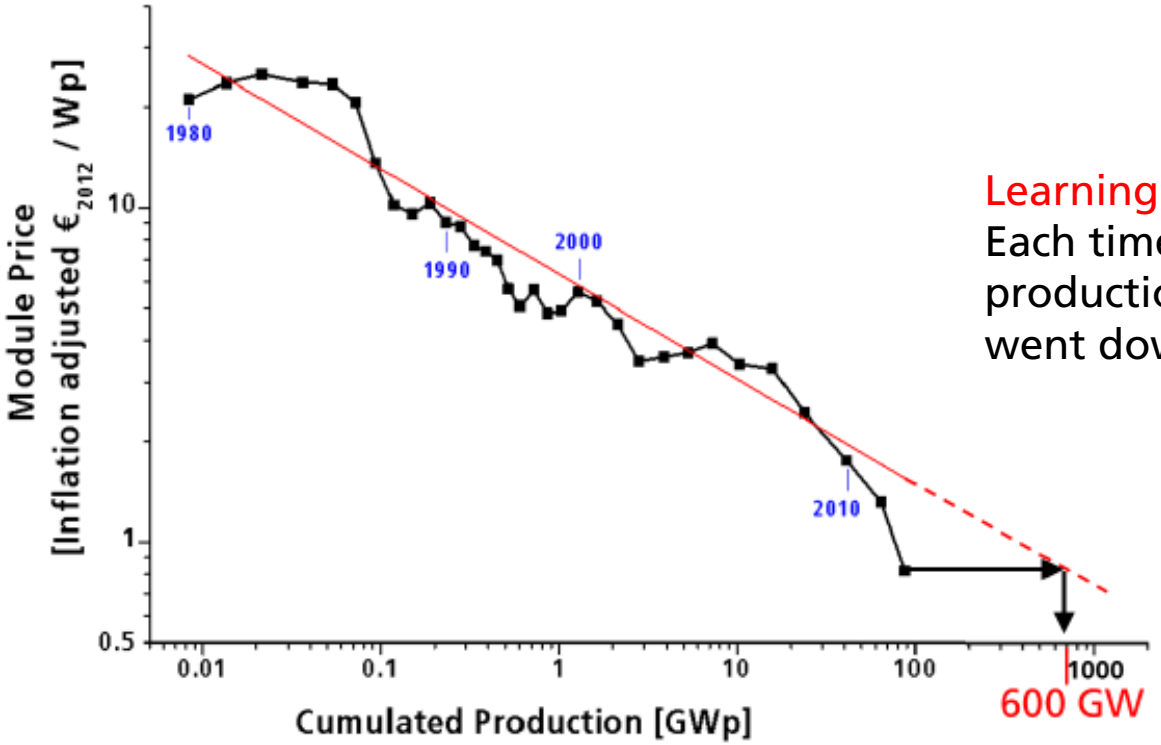
Costs of Solar Energy

Price Learning Curve (all c-Si PV Technologies)



Learning Rate:
Each time the cumulative production doubled, the price went down by 20 %.

PV-electricity in India 2014:
5-8 $ct/kWh!

Price Learning Curve of PV Module Technologies since 1980.

Source: Navigant Consulting; EUPD PV module prices (since 2006), Graph: PSE AG 2012

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Crystalline Silicon Technology Portfolio

c-Si PV is not a Commodity, but a High-Tech Product!

material quality

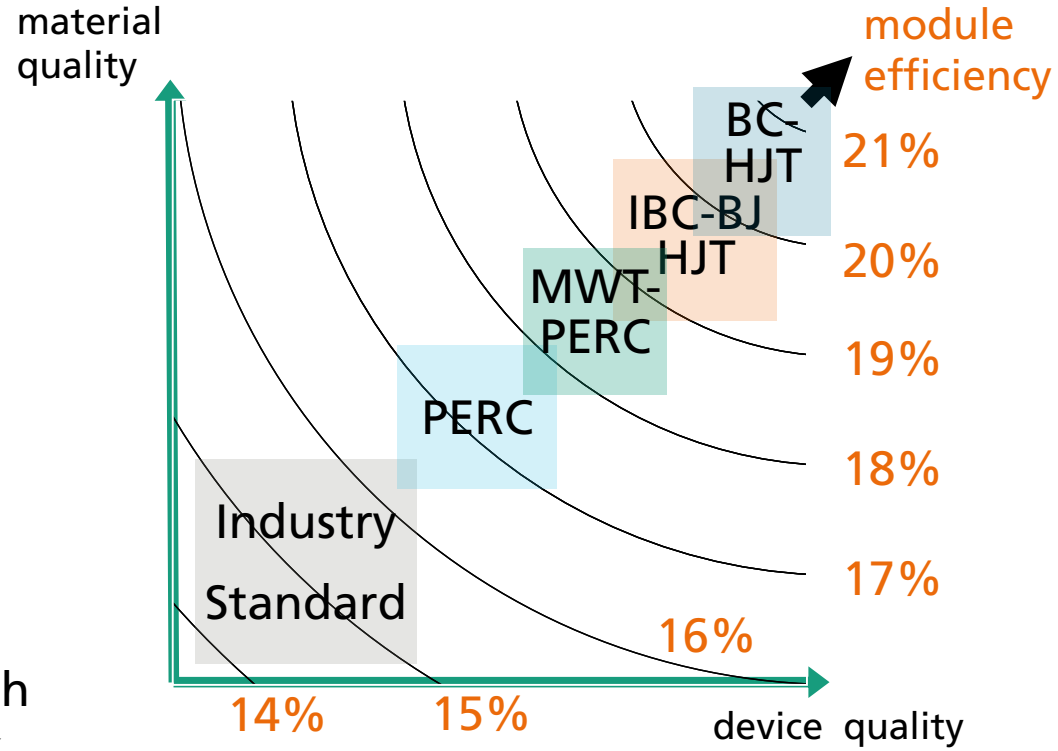
- diffusion length
- base conductivity

device quality

- passivation of surfaces
- low series resistance
- light confinement

cell structures

- PERC: Passivated Emitter and Rear Cell
- MWT: Metal Wrap Through
- IBC-BJ: Interdigitated Back Contact – Back Junction
- HJT: Hetero Junction Technology



Adapted from Preu et al., EU-PVSEC 2009

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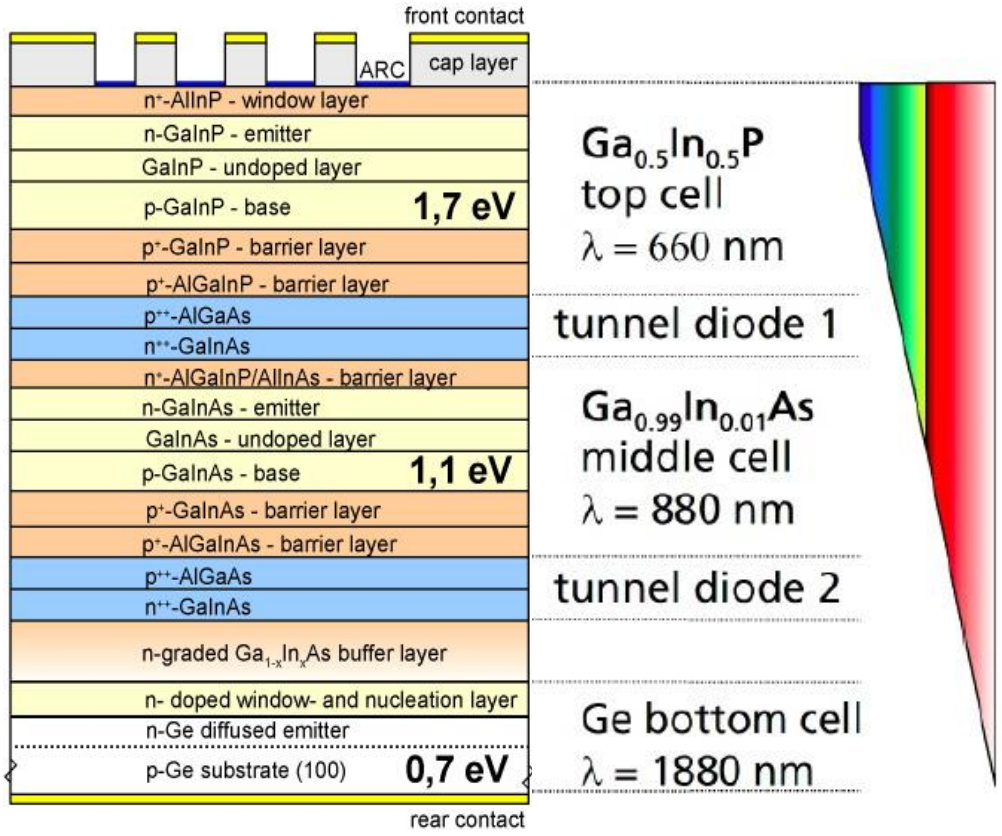
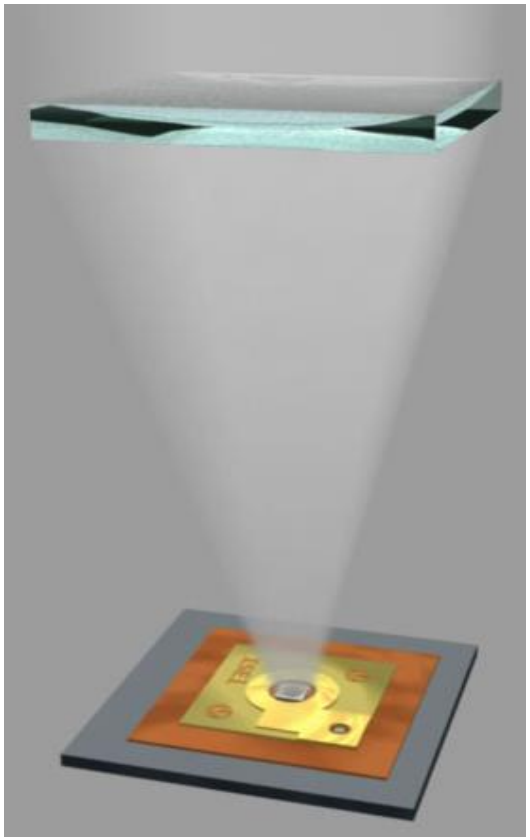
High-Efficiency III/V Based Triple-Junction Solar Cells





Slide: courtesy of F. Dimroth

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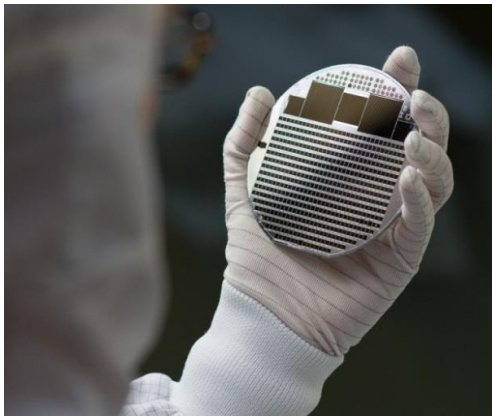
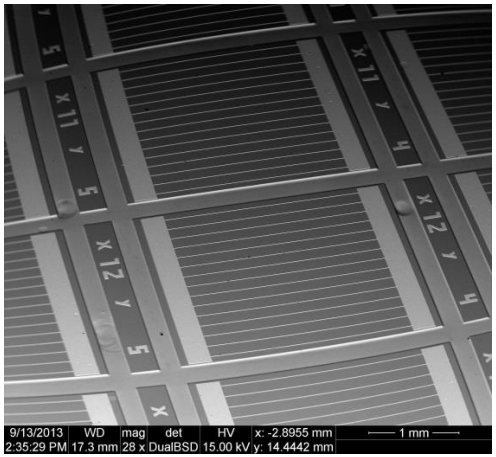
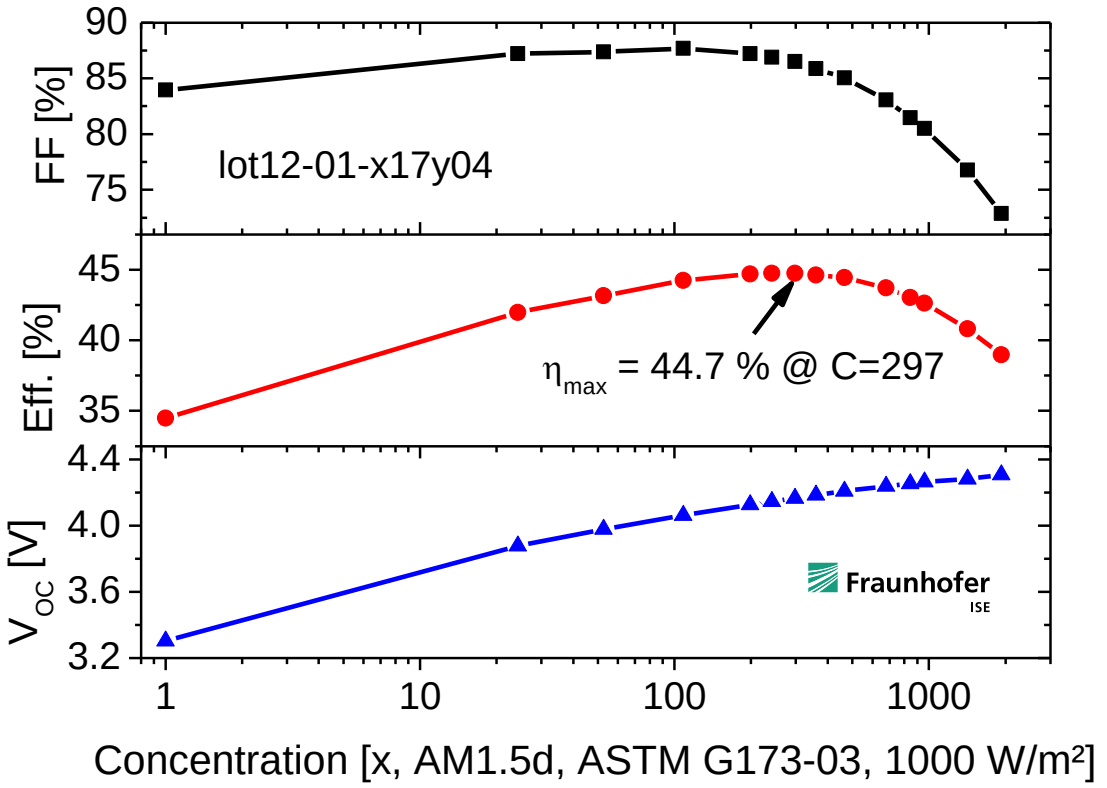
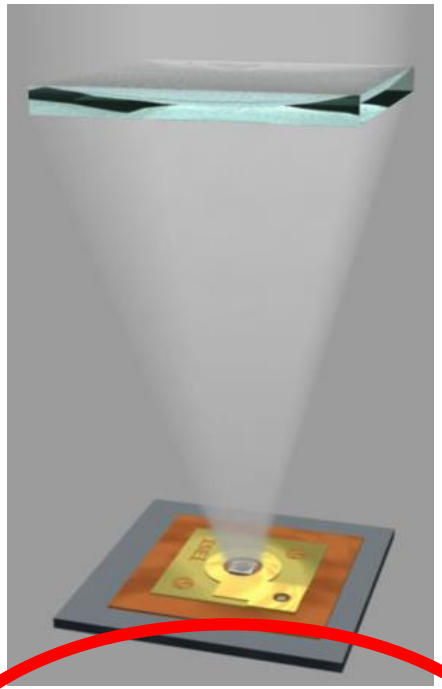
World Record 44.7 % Efficiency Solar Cell
Wafer-Bonded, 4-Junction Technology
Fraunhofer ISE with SOITEC, CEA-LETI, HZB







Advantage of Two-Axis Tracking in CPV: Land Use!

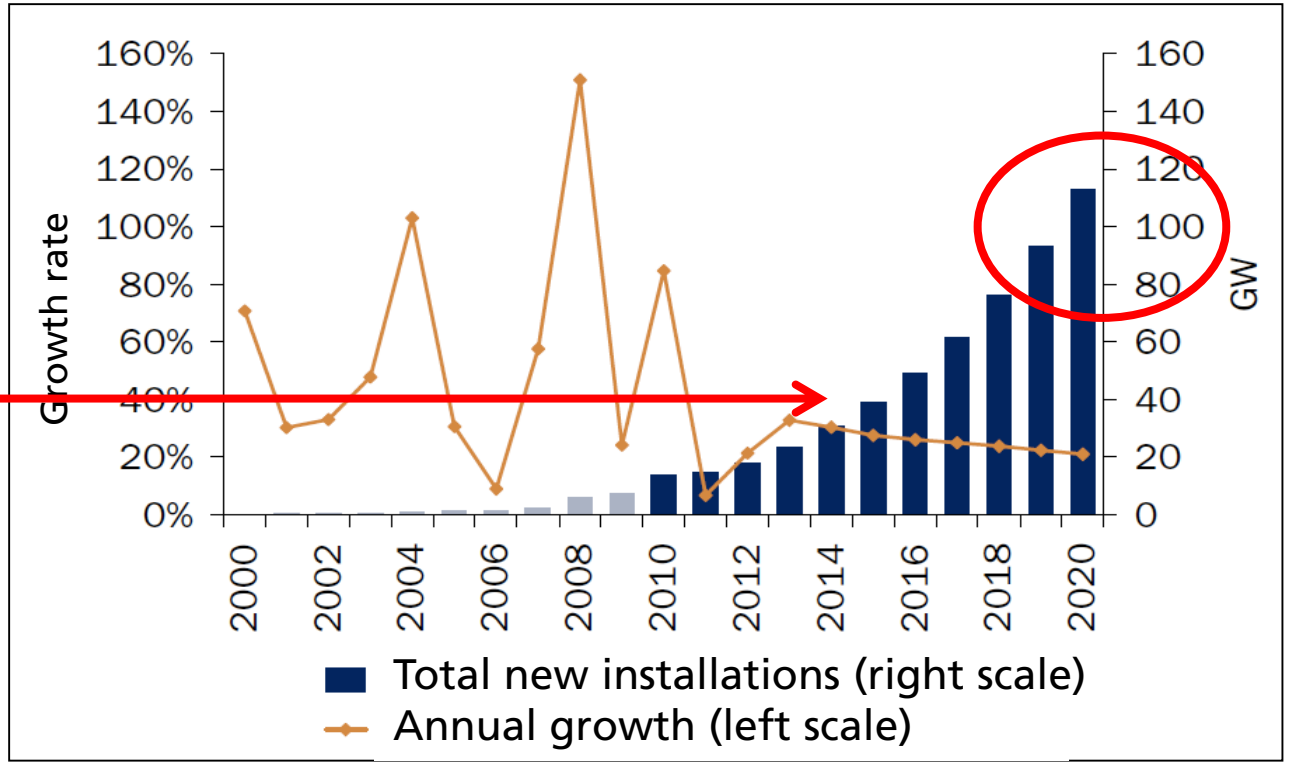


2014: SOITEC SOLAR builds a 300 MW CPV installation, using the new 150 MW_p/yr factory near San Diego, CA!

World Market Outlook: Experts are Optimistic
Example Sarasin Bank, November 2010

- market forecast: 30 GW_p in 2014, 110 GW_p in 2020
  annual growth rate: in the range of 20 % and 30 %

2014:
ca. 46 GW_p,
50 % above
forecast!



Source: Sarasin, Solar Study, Nov 2010

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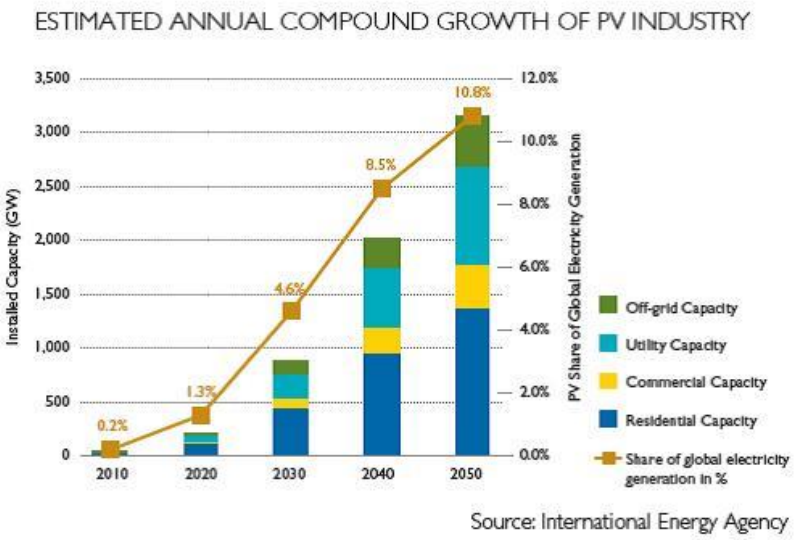
IEA Outlook on PV Production Worldwide

- Rapidly declining cost of PV generated electricity opens up new market opportunities.
- Current 45 GWp/a market will increase to a 100+ GWp/a market in 2020; for 2050 IEA expects more than 3,000 GWp of globally installed PV capacity; for **10 % of energy demand** we need more than **10,000 GWp!**
- Strong increase necessitates construction of GW-scale, highly automated PV production plants.



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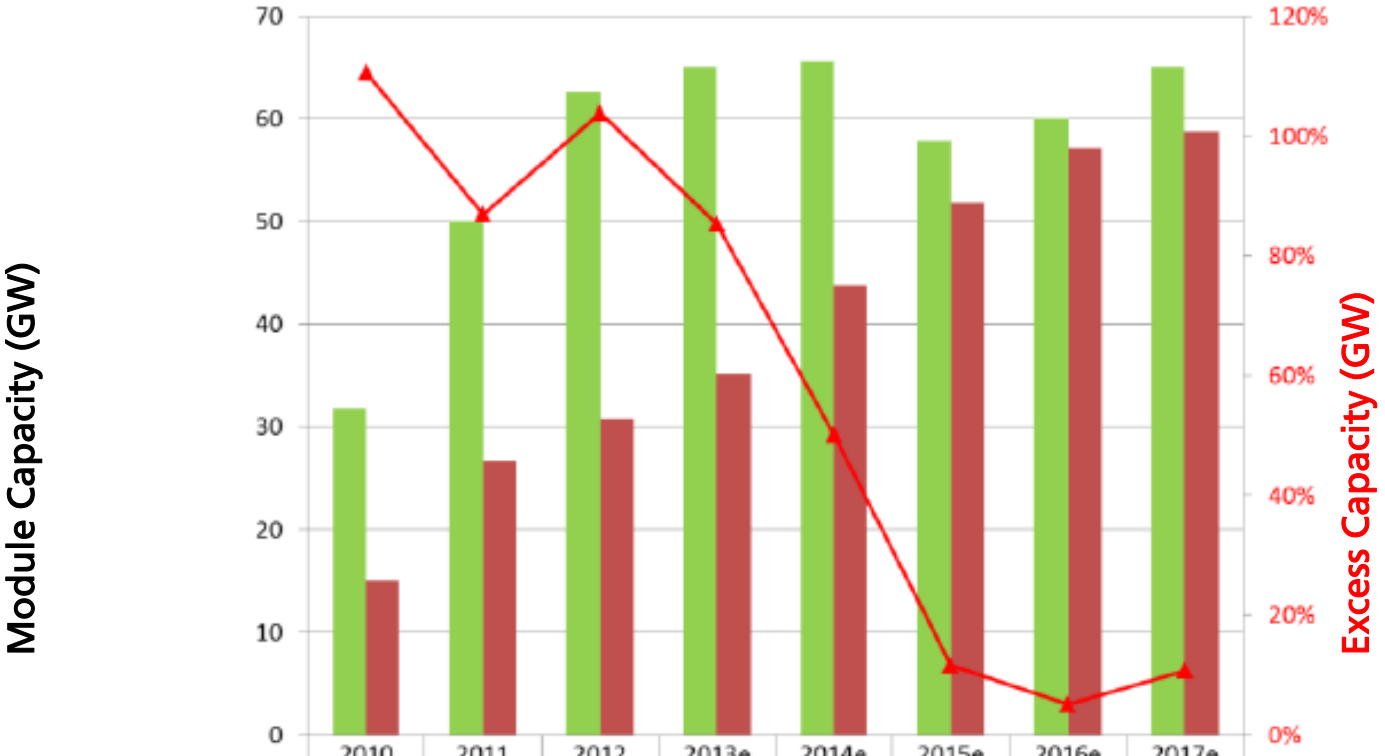
Global PV Production Capacity and Installations



	2010	2011	2012	2013e	2014e	2015e	2016e	2017e
Production Capacity	31,8	50,1	62,7	65,1	65,6	57,9	60,0	65,1
Installations	15,1	26,8	30,8	35,1	43,7	51,9	57,1	58,8
Excess Capacity	110,6%	86,9%	103,8%	85,3%	50,1%	11,6%	5,1%	10,7%

Outlook for the development of supply and demand in the global PV market

Source: Luz Research Inc., Grafik: PSE AG

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Deutsche Bank
Markets Research

Date
6 January 2014

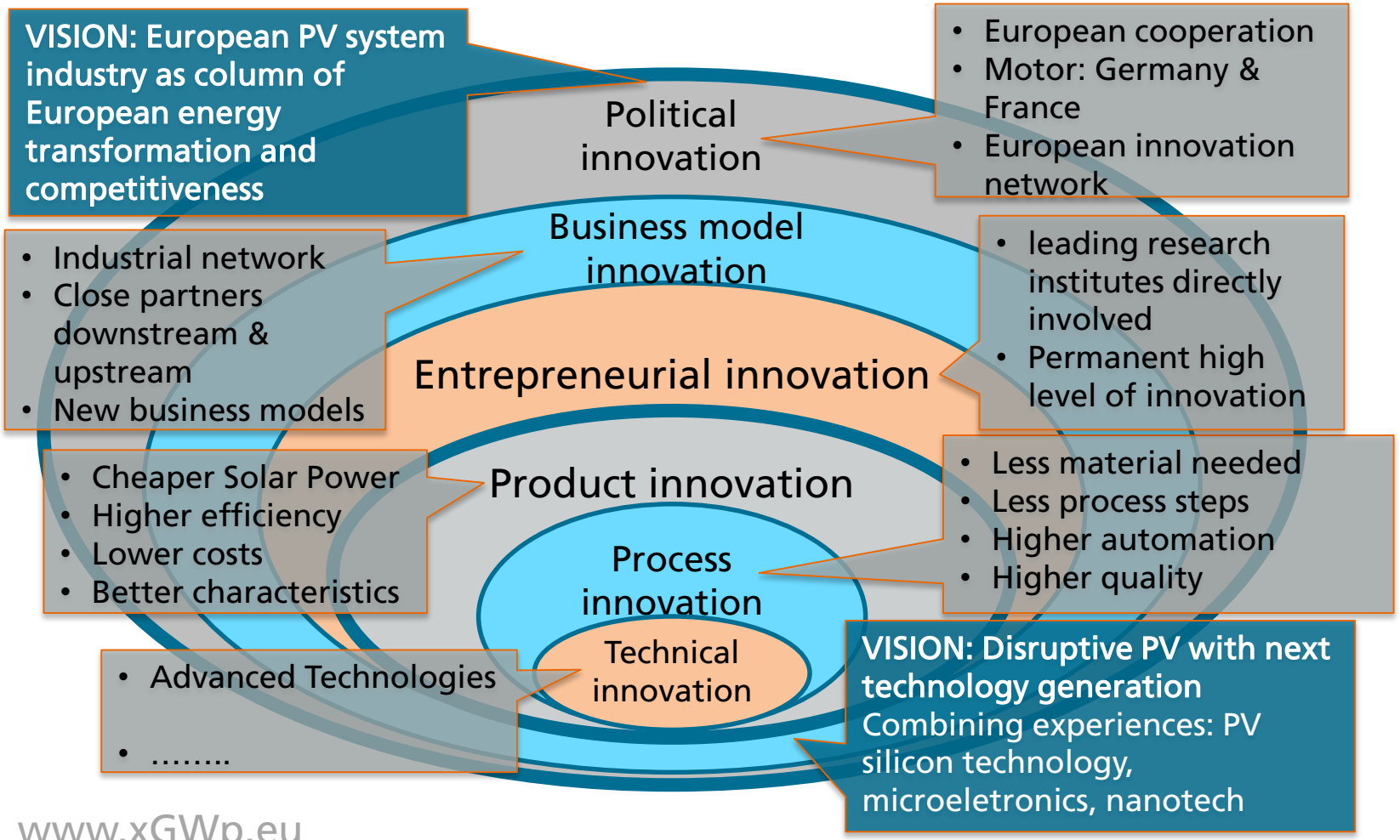
Industry Update

Let the Second Gold Rush Begin

Demand Could Continue to Surprise to the Upside

While we have been generally constructive on the global demand outlook, we are raising our 2014 and 2015 demand expectations from 44.5 to 46.1GW and from ~52 to ~56GW respectively. We believe upside demand surprises from the US, Japanese and Chinese markets could continue in 2014. We expect a combination of streamlined incentive programs in China, additional subsidy cut signals in end 2014 and decreasing financing constraints to act as catalysts for upside demand surprises. While these 3 markets showed the most upside relative to expectations in 2013, we expect many more international markets to become meaningful growth contributors from 2014. Specifically, we expect India, South Africa, Mexico, Australia, Middle East, South America and South East Asia to all act as strong growth contributors. The majority of these markets are at grid parity and as such sustainable. Moreover, we believe some of the grid and financing constraints that have inhibited growth so far are set to improve in 2014.

xGWp: European Gigawatt PV Production



www.xGWp.eu

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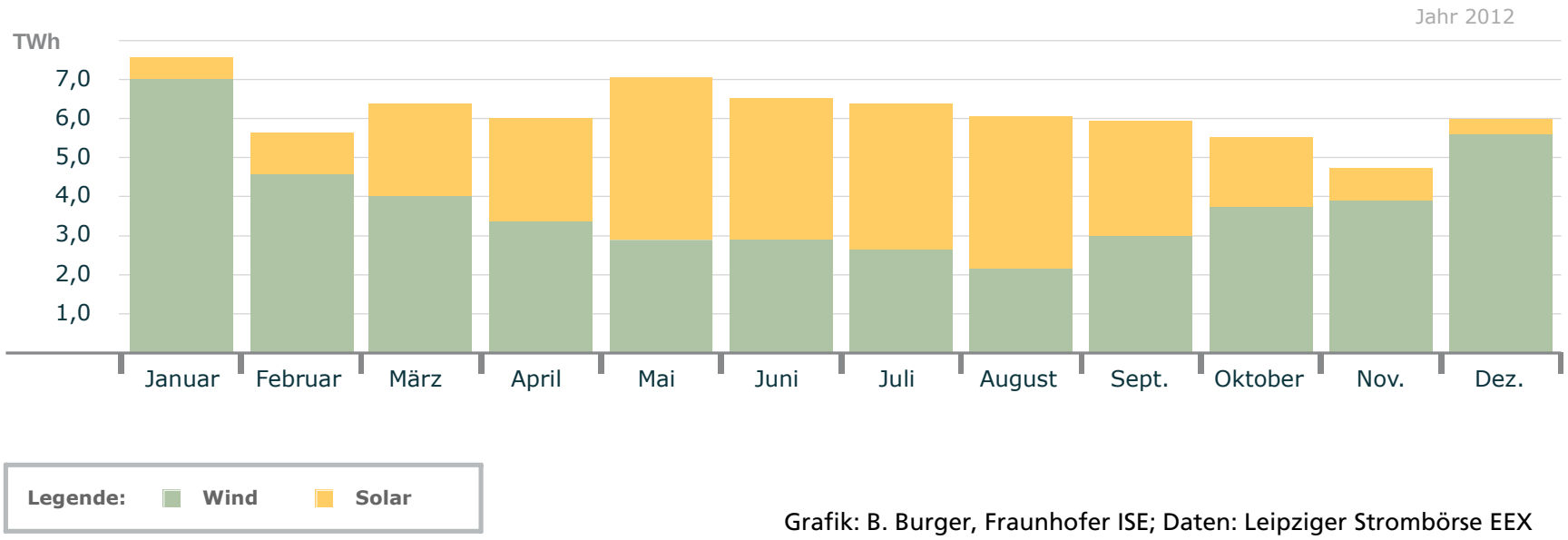
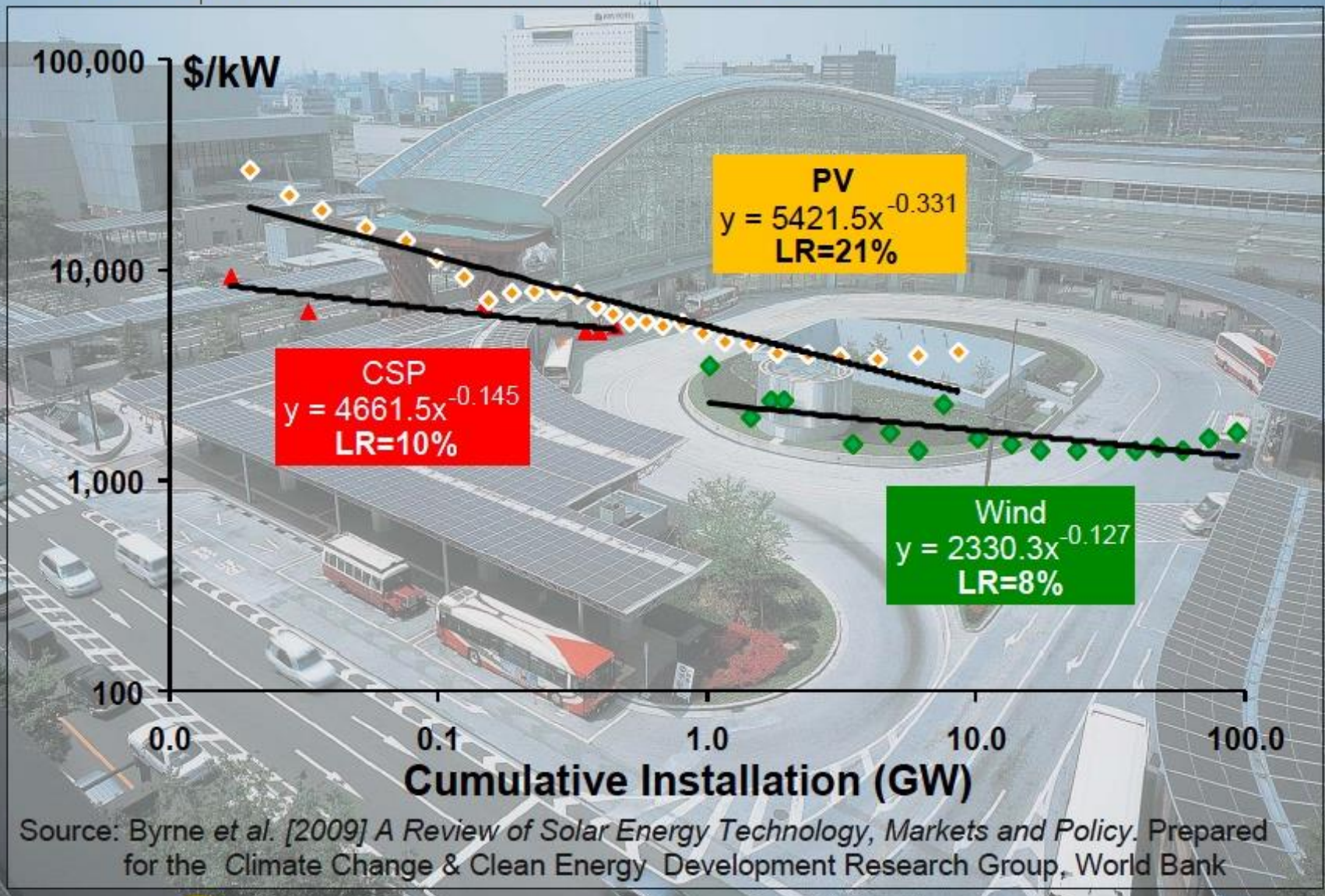
Monthly Electricity Production of PV and Wind Germany 2012



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

- each month, solar and wind produced between 5 and 7 TWh of electricity in Germany
- sun dominates in summer, wind in winter, the combination works best!

EXPERIENCE CURVES FOR SELECTED RENEWABLE ELECTRIC POWER TECHNOLOGIES



Source: Byrne *et al. [2009] A Review of Solar Energy Technology, Markets and Policy*. Prepared for the Climate Change & Clean Energy Development Research Group, World Bank

Center for Energy and Environmental Policy

Combined CSP-CPV power plant

Example calculated for a location in Chile:

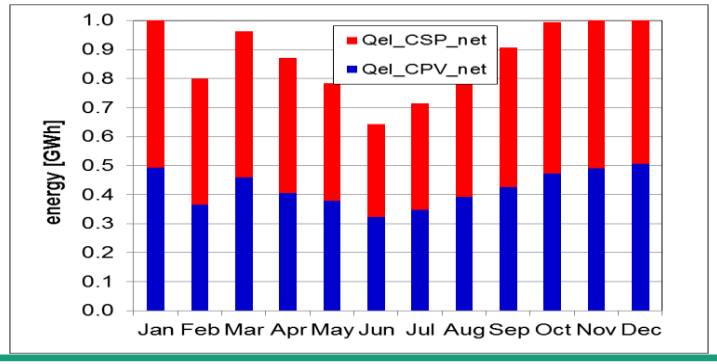
1MW CPV, 1MW CSP-turbine, 18hrs storage, 24hrs stable elctricity

Combination of solar generators:

- CPV -> electricity **supply for the day**
- CSP+Storage -> **supply for the night**

Results:

- Yearly solar yield: 10.4 GWh
- Operation hours: 8640 h
- Cost of electricity LEC: ca.14 $ct/kWh
- Electricity from Diesel: >20 $ct/kWh



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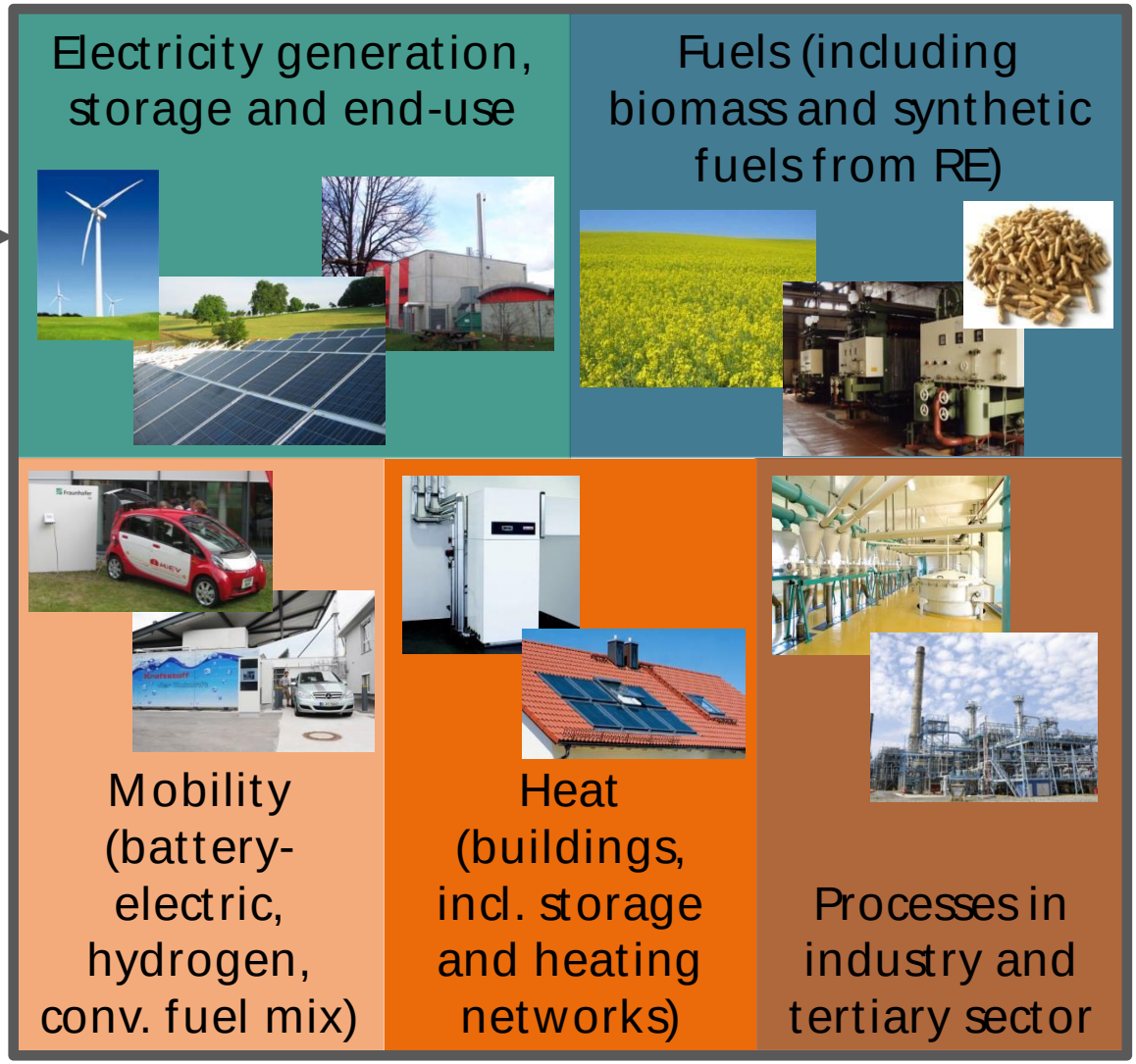
Optimization of Germany's future energy system based on hourly modeling

Comprehensive analysis of the overall system

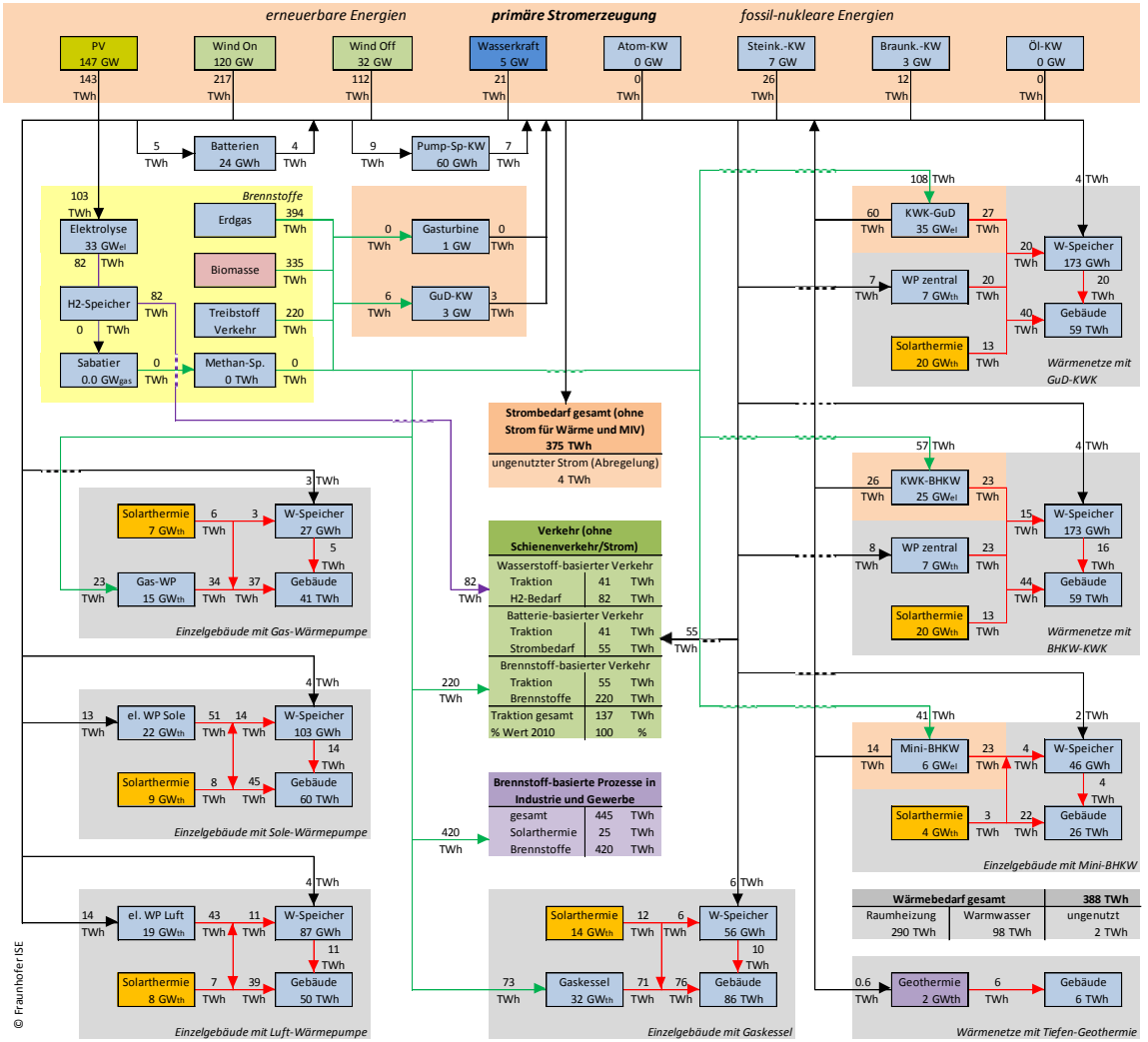


REMod-D

Renewable Energy Model – Deutschland

Slide courtesy Hans-Martin Henning 2014

Optimization of Germany's future energy system based on hourly modeling



REMod-D

Renewable Energy Model – Deutschland

Slide courtesy Hans-Martin Henning 2014

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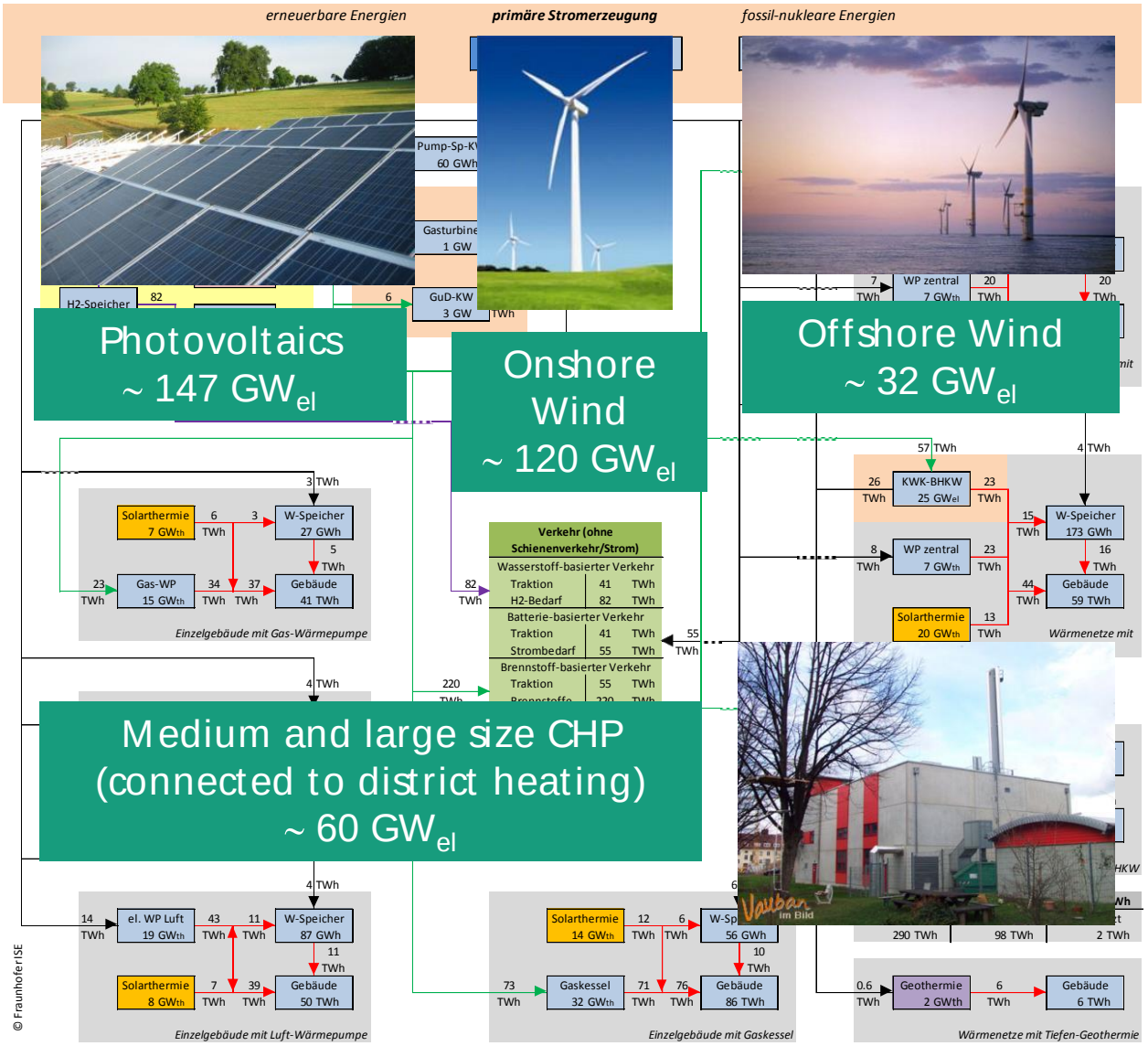
Electricity generation



Slide courtesy Hans-Martin Henning 2014

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Storage

Stationary batteries
Total ~24 GWh (e.g. 8 Mio units with 3 kWh each)

Pumped storage power plants
42 units with a total of 60 GWh

Electrolysers with total capacity of 33 GW_{el} (needed for mobility)

Heat buffers in buildings
Total ~320 GWh (e.g. 7 Mio units with 800 Litres each)

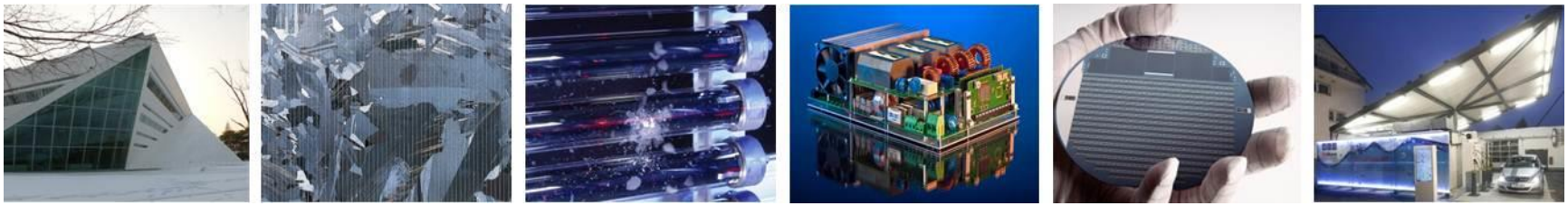
Large scale heat storage in district heating systems
Total ~350 GWh (e.g. 150 units with 50.000 m³ each)

Slide courtesy Hans-Martin Henning 2014

The Global Energy Transformation - *not a Transition!*

- The global energy transformation is **the** challenge of our generation, as first step of our needed transformation to sustainability.
- A near-100% renewable energy system is possible, at similar cost as today's energy supply.
- Harvesting energy from the sun and wind will be the key pillars of our future, renewable energy system
- The needed technologies are in principle available today; however, much work is needed for higher efficiency technologies at lower production cost.
- India could potentially have one of the largest PV markets worldwide, and develop the needed industrial infrastructure along the food chain!
- Fraunhofer ISE offers unbiased technology advice and applied research for industry interested to enter this field.
- Politics needs to be bold and visionary – to grab the obvious opportunities of this process for our economies, for innovation, technology development and, ultimately, for healthy, sustainable economies in Germany and India!

Thank you for your Attention!



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Zayed Future Energy Prize
World Future Energy Summit – Abu Dhabi, January 20, 2014