Photovoltaic systems for Energiestrategie 2050

Urs Walter Muntwyler (Berner Fachhochschule)

Professor Photovoltaics/ Leader PV Laboratory

Former member of the parliament of the state of Berne

Chair of the Technical Collaboration Programm «Hybrid- and Electric Vehicles» of the International Energy-Agency IEA (www.ieahev.org)

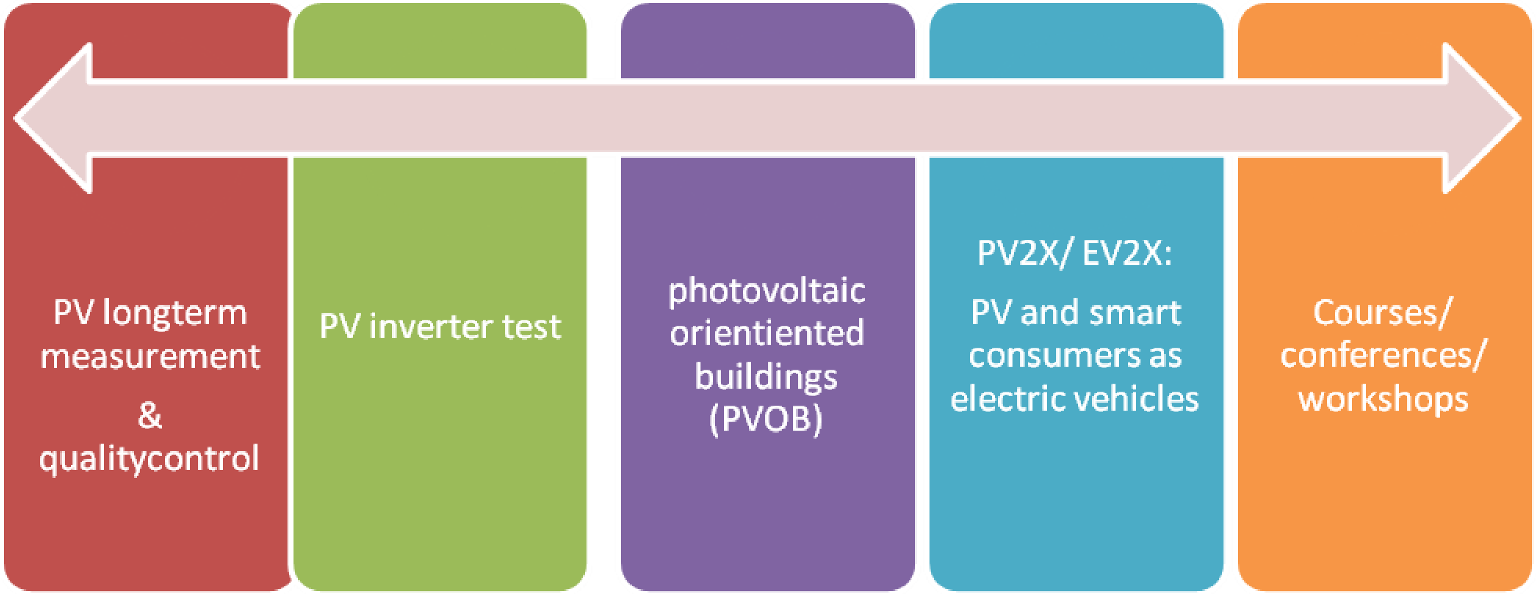
Photovoltaic (PV) system technology

- My background in PV – since 1975/ 1982 in PV
- PV laboratory of Berner Fachhochschule in Burgdorf
- The challenge: the transition to the renewables
- The potential of PV and other renewables
- The sun: the main source of the renewables
- PV Swiss pioneers in the 90-ties and their impact
- PV technologies: … the winner takes it all!
- PV applications – and costs
- Future houses as «Plushouses»
- PV on your house – calculate your PV plant
- What next: 100% renewables in Switzerland!
- W’re looking for master students in 2018!

Berner
Fachhochschule

PV Laboratory BFH (Burgdorf)

- Founded: 1988
- Leader PV Lab: Professor Urs Muntwyler
- 12-15 assistants and scientific collabor.
- website: www.pvtest.ch/



PV longterm measurement & qualitycontrol

PV inverter test

photovoltaic orientented buildings (PVOB)

PV2X/ EV2X:
PV and smart consumers as electric vehicles

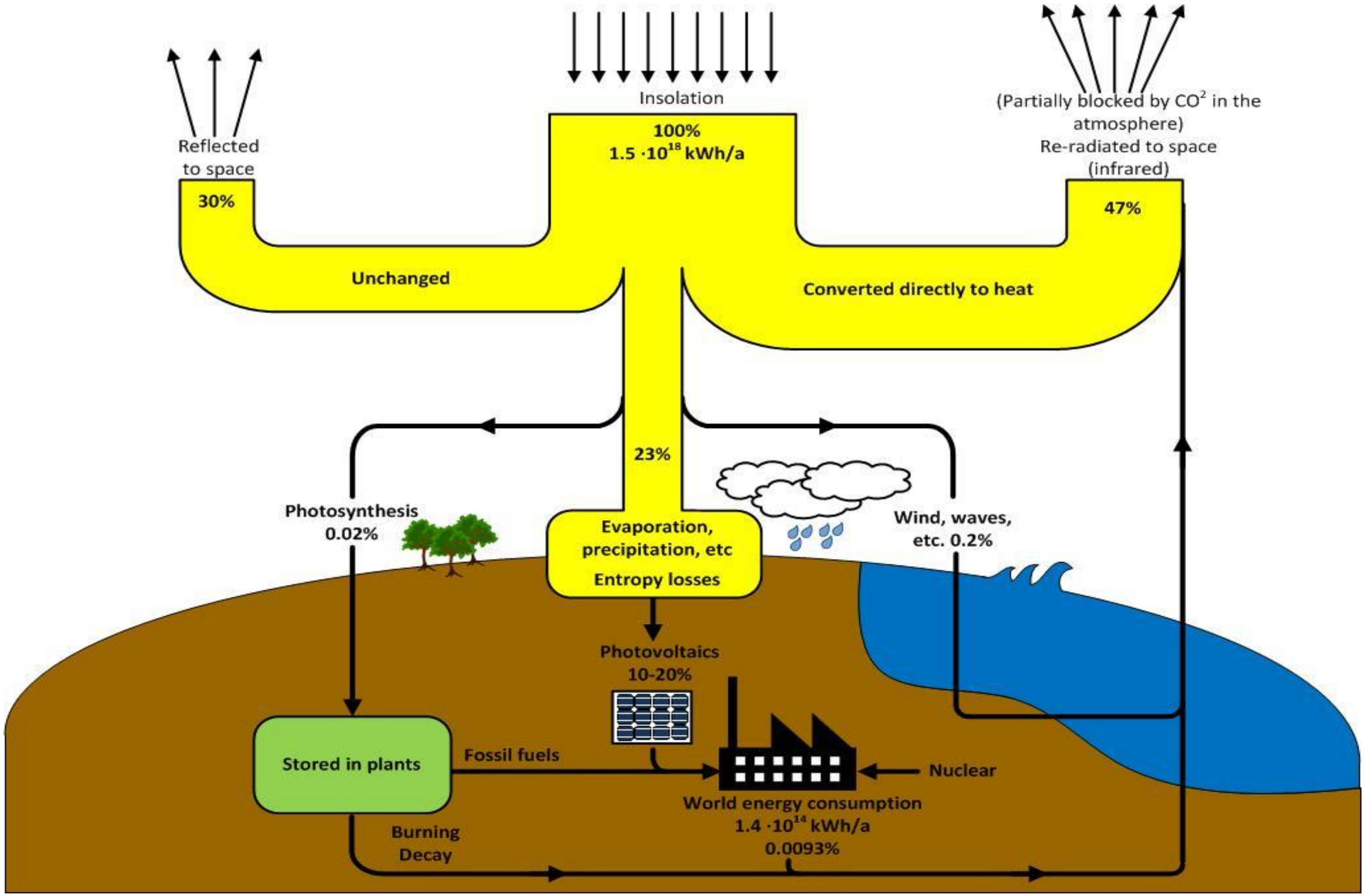
Courses/ conferences/ workshops

SCCER-FURIES Partner (2014-20)
http://sccer-furies.epfl.ch/

SCCER - FURIES
Shaping the FUtuRe SwIss Electrical InfraStructure

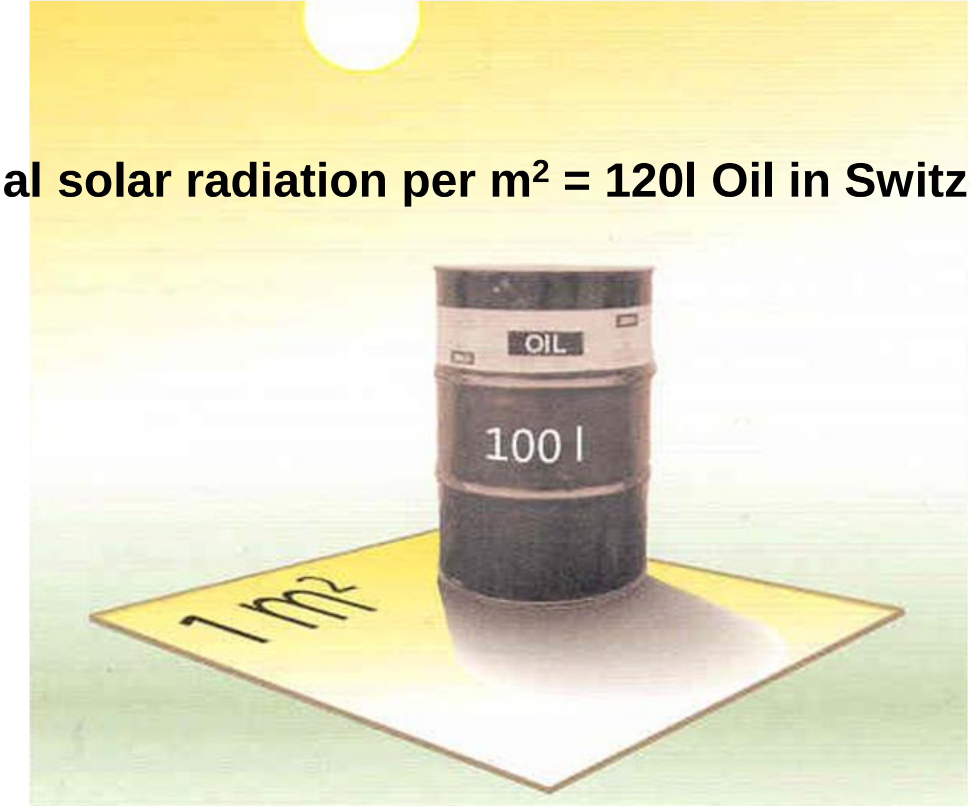
Overview – the challenge
- more consumers
- less CO_2
- towards renewable energies

Energy input from the sun on the earth



The effects on earth are very different… with one winner!

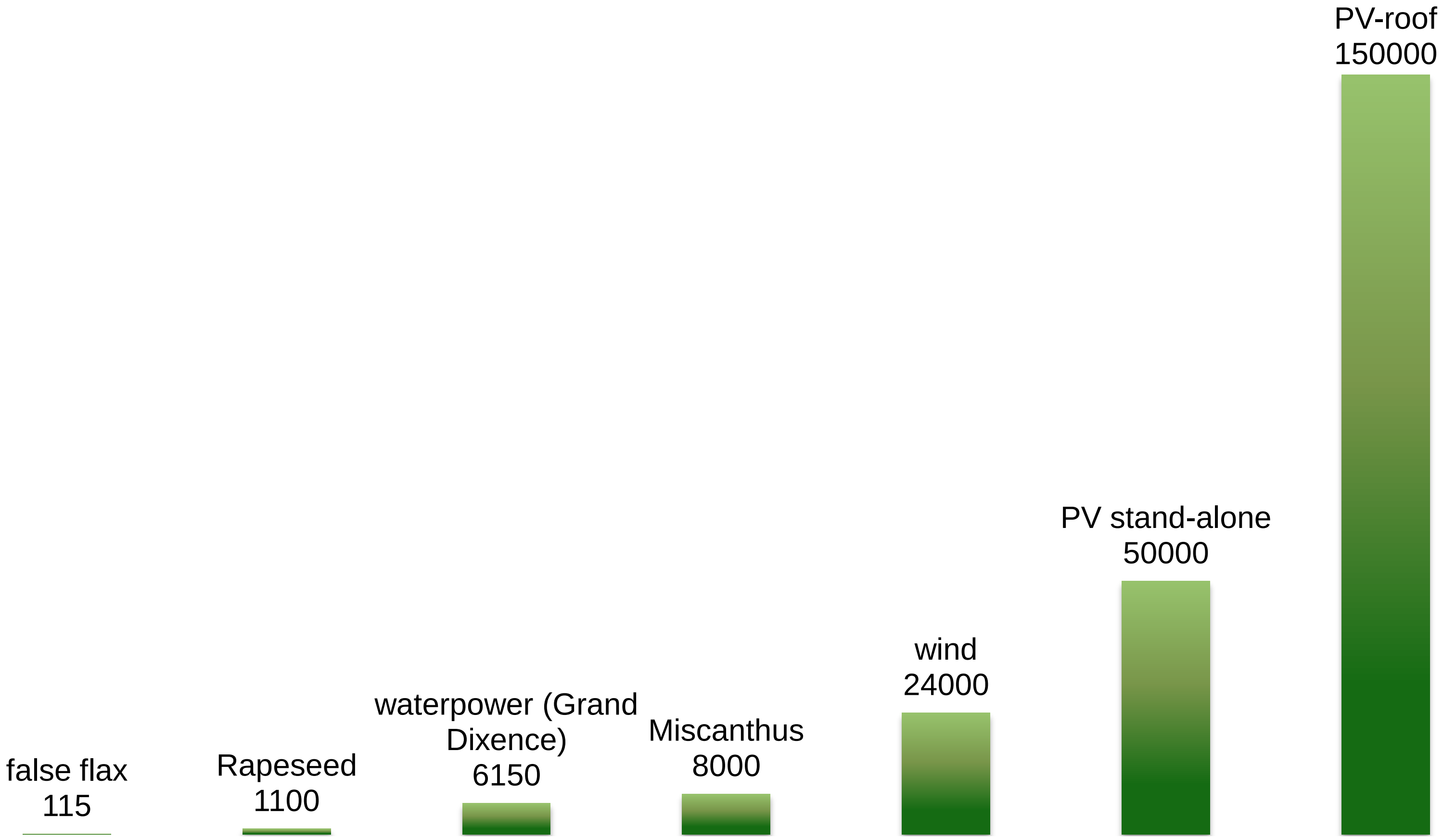
Solar radiation in Oil



Annual solar radiation per m^2 = 120l Oil in Switzerland

Average solar radiation energy (Berlin): 1050 $kWh/m^2/a$
(≈ annual elecricity cosumption of one person)
1l oil: ca.10 kWh

How big are the surface potentials of of different RES (MWh/ km^2)?



No Problems with space with the right choice – **PV!**

Development and application of Photovoltaics

Hasler AG: PV P+D off-grid power supply

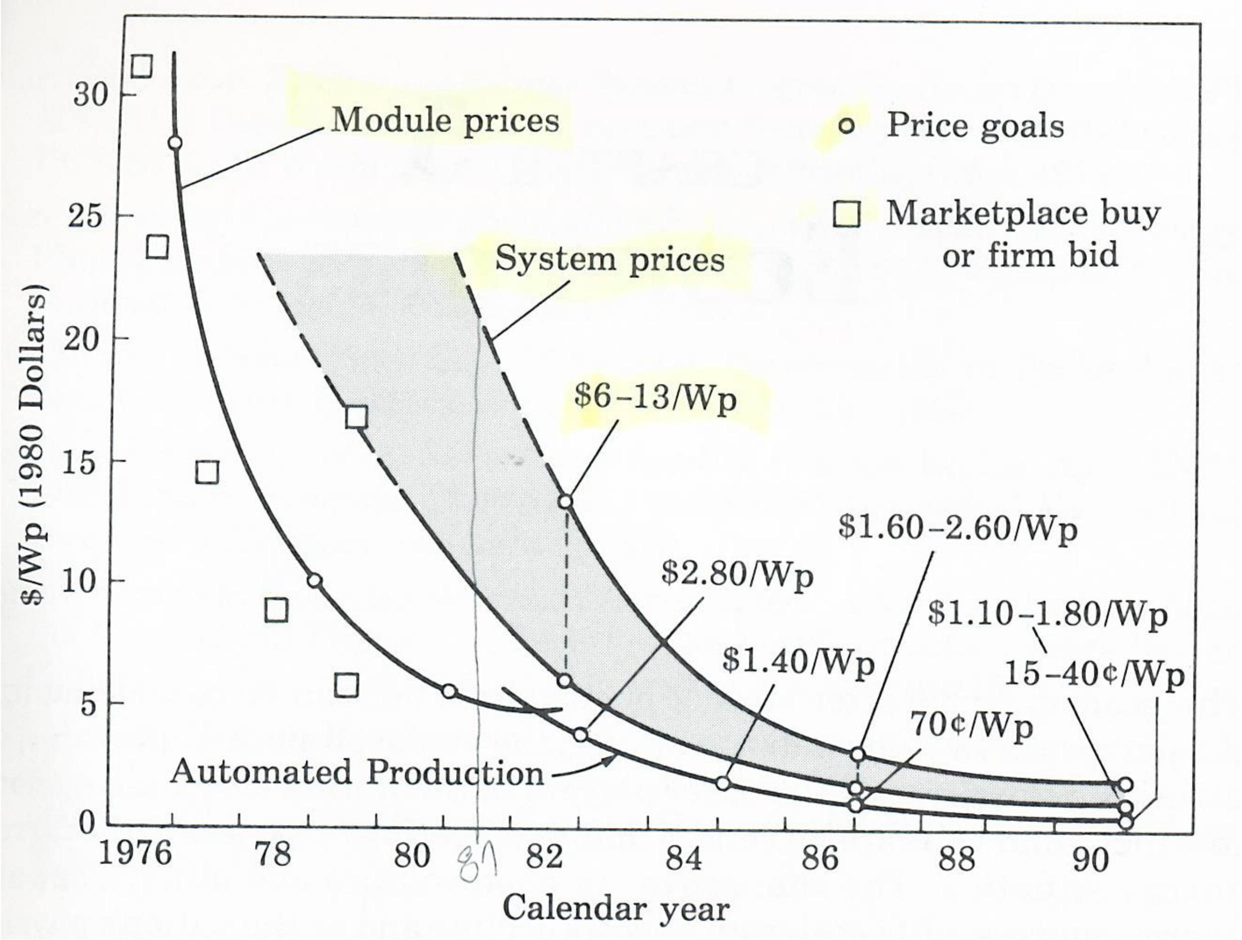
First pilot- and demonstration programm for PV in Switzerland Hasler AG late 70-ties to 1984.

One of the sites:

PTT Tower Chasseral

Solarex HE 51 m-Si with 2 kind of coverage of the solarcells (Photo 1983/ Mu).

PV Marketforecast DOE 1980 with delay…



Change in the administration of the USA (Carter-Reagan): very bad for solar and PV industry ➔ **Politics has a strong influence on the PV market!**

„Solarbreeder“ fromBP Solar/ Solarex (1982-about 2010) in Frederick/ USA

This PV production facility should demonstrate that PV is a reliable source of energy and can produce more energy as needed (several visits 1990-2008).

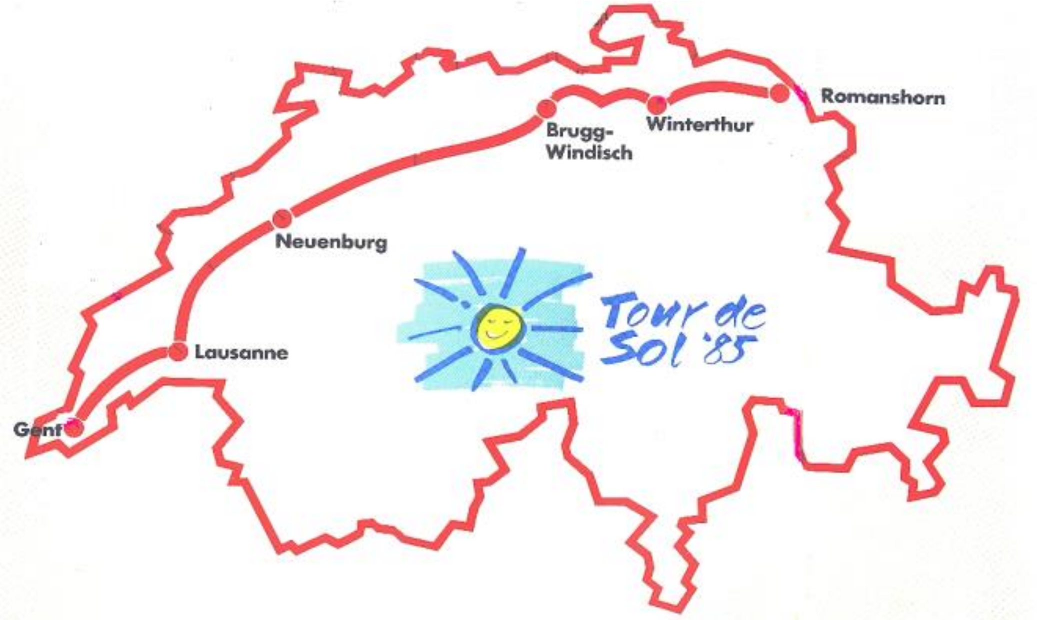
Last visit of the solar breeder in Frederick/USA in 2008!

Solarcenter Muntwyler AG/ Muntwyler Energietechnik AG was official Swiss importer of Solarex since 1990!

Off-grid power supply for hospital in Rwanda (1984)

Power supply for six houses in a dispensaire for light, light beam for medical treatmant and fridge for drugs.

Tour de Sol – PR tour for solar energy



The world`s first solarcar-race, with 58 entries in 2 categories - < $6m^2$ (max. 480 Wp)

Tour de Sol 85-92: creates spin-off's for technology and promotion measures

Winner of the Tour de Sol 87: light EVs with grid-connected PV-installations.

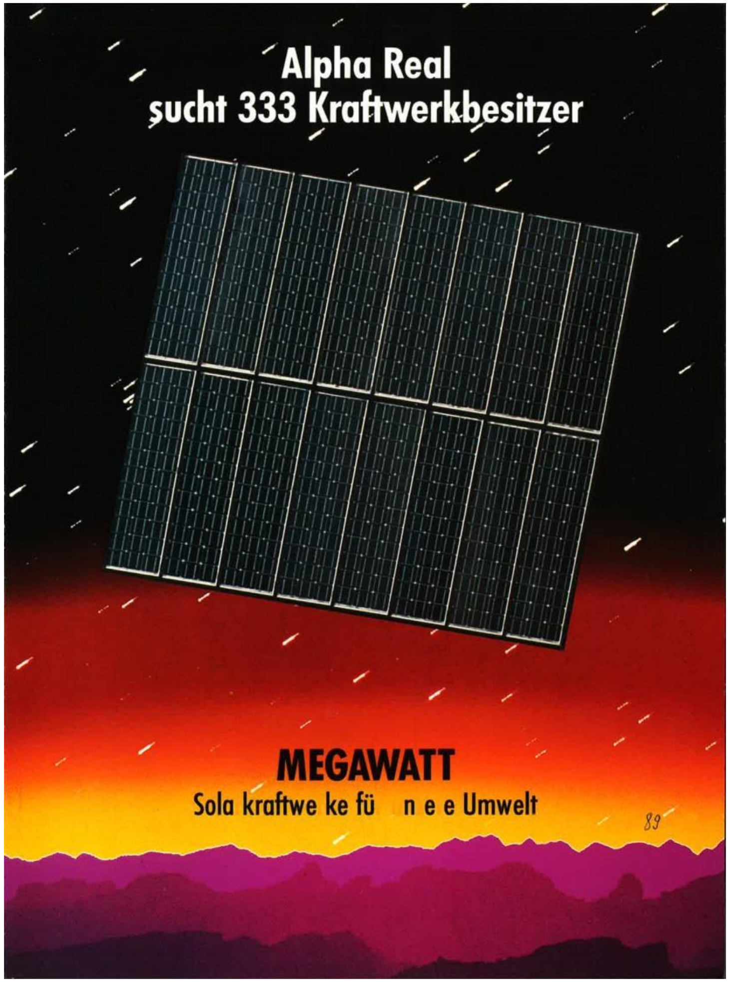
Grid-connected PV-plant: city of Burgdorf created feed-in-tariff (FIT) for PV in 1989! Swiss world leader in PV up to 1992!

Smart car a spin-off of the Tour de Sol – created by the Swiss watch company Swatch

Promotion activity for 1 MWp

Tour de Sol 85-winners Alpha Real AG an engineering office raised capital of (1 Mio) and started several activities as:

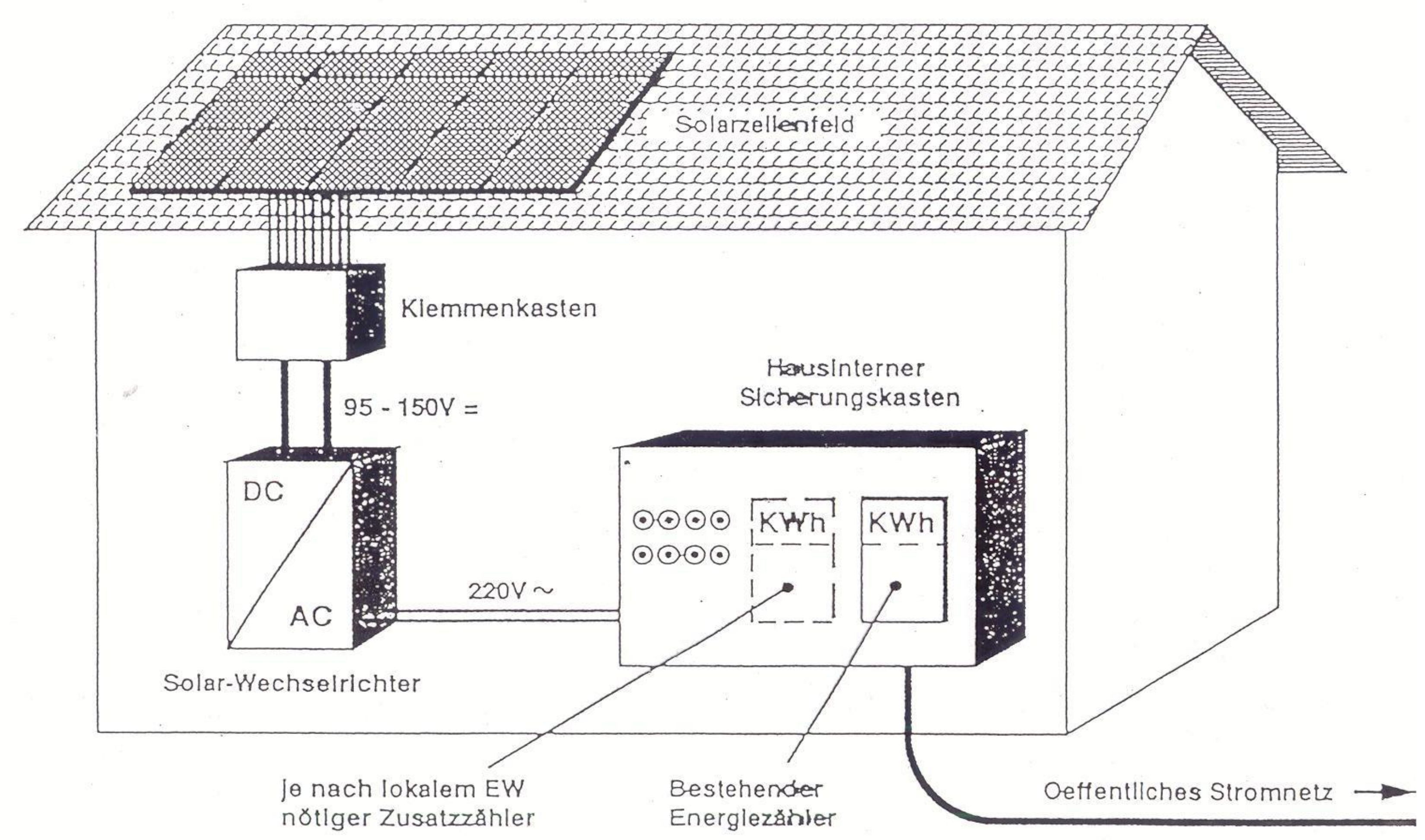
- 1986: Darieus Windgenerator
- 1989: 1MWp action – a 3kWp PV-plant for cheap Fr. 48’000.--!
- Alpha Real AG puts more technical novelties and closed 1994.
- Several employees started new PV companies (Tritec AG, Enecolo AG, Energiebüro etc.)!



First promotion of decentralized PV plants instead of big MWp plants!

PV system technology

Grid connected PV installation



On-grid PV installation scheme from the 90-ties….

Private solar market in Switzerland

Technical and ecological oriented private customers allowed a small market for solar and PV (-2009/ PV in 2009: 10 MWp/a; 2017: about 300 MWp/ year).

“Plushouse” in Switzerland

Retrofit of a multi-level house built 1947:

The house produces now 187% of the energy for heating/ hot water and electricity but has only 20% own consumption!

Energy potential for 6 Electric vehicles!

Roof integrated PV installation in East-West configuration

Cable car on Muottas Muraigl/ St. Moritz

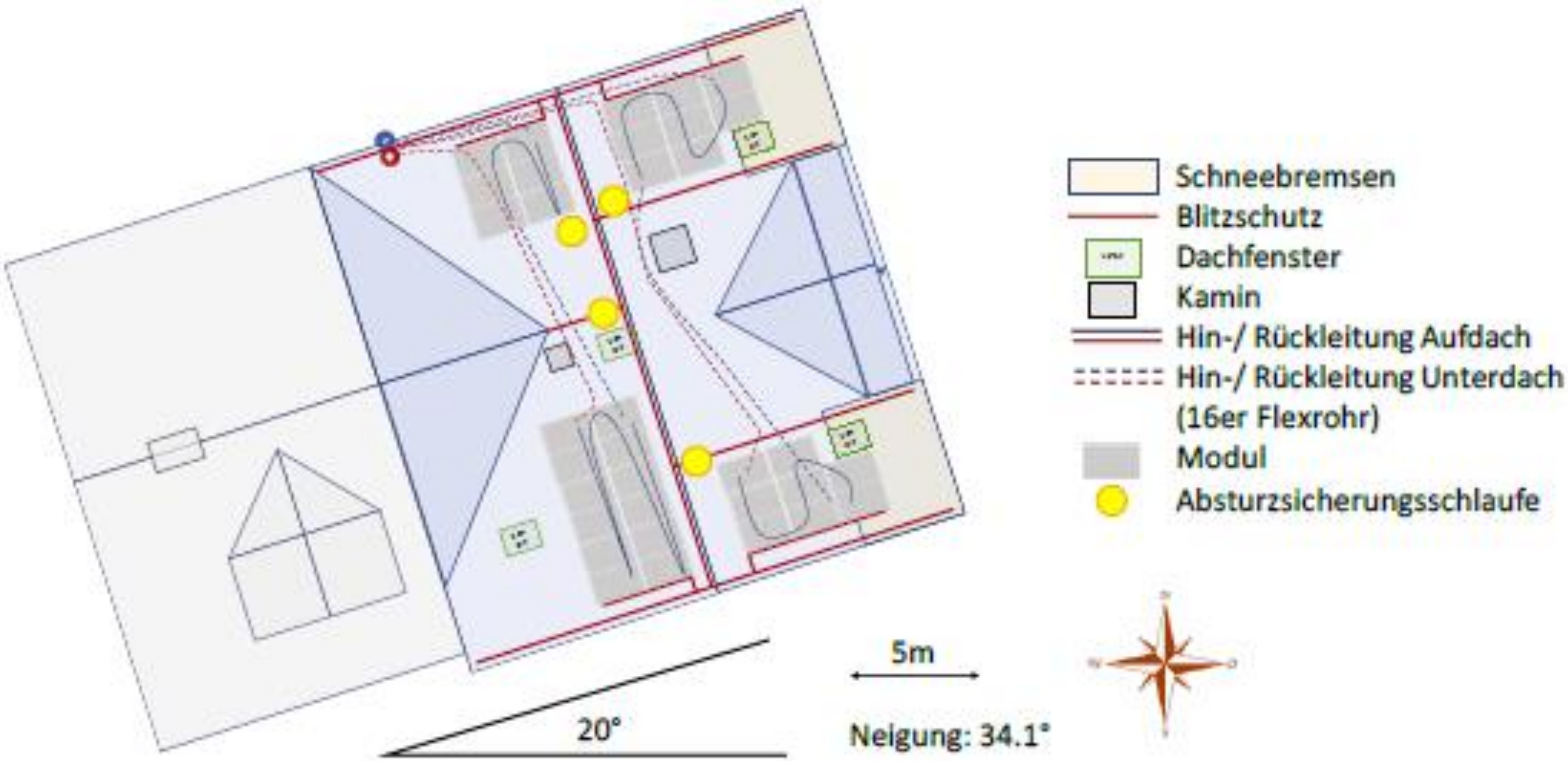
Highest annual production in Switzerland over 1‘600 kWh/ kWp per year! This value is in the range of good sites in North Africa!

The Plushouse – PV on my home:

Consumer	Size	Specific consumption	Energy
Heating	100 m² heated surface	16 kWh/ m²	1‘600 kWh
Hot water	…x50 l/ Pers	200 l/ 43ºK 3	1‘250 kWh
Electricity	Household	4x1‘000 kWh	4‘000 kWh
Car	12’000 km/J	15kWh/100 km	1’800 kWh
Totale			8‘650 kWh

Calculation PV installation: ➔ Check the house: www.sonnendach.ch
➔ Website Swissolar: www.solardach.ch/
Quick check power: Totale annual consumption/ 1’000 h ➔Power PV-plant!
Surface: totale kWh/ 250 kWh x 1,6 m^2 (8’650 kWh/250 kWhx1,6m^2= 35m^2)

MSE Student Marco Müller (HSLU)



Marco Müller passed the MSE-PV course 2017: He planned a “PV on my home”!
See the difficult situation on the roof of the existing house!

MSE Student Marco Müller (HSLU)

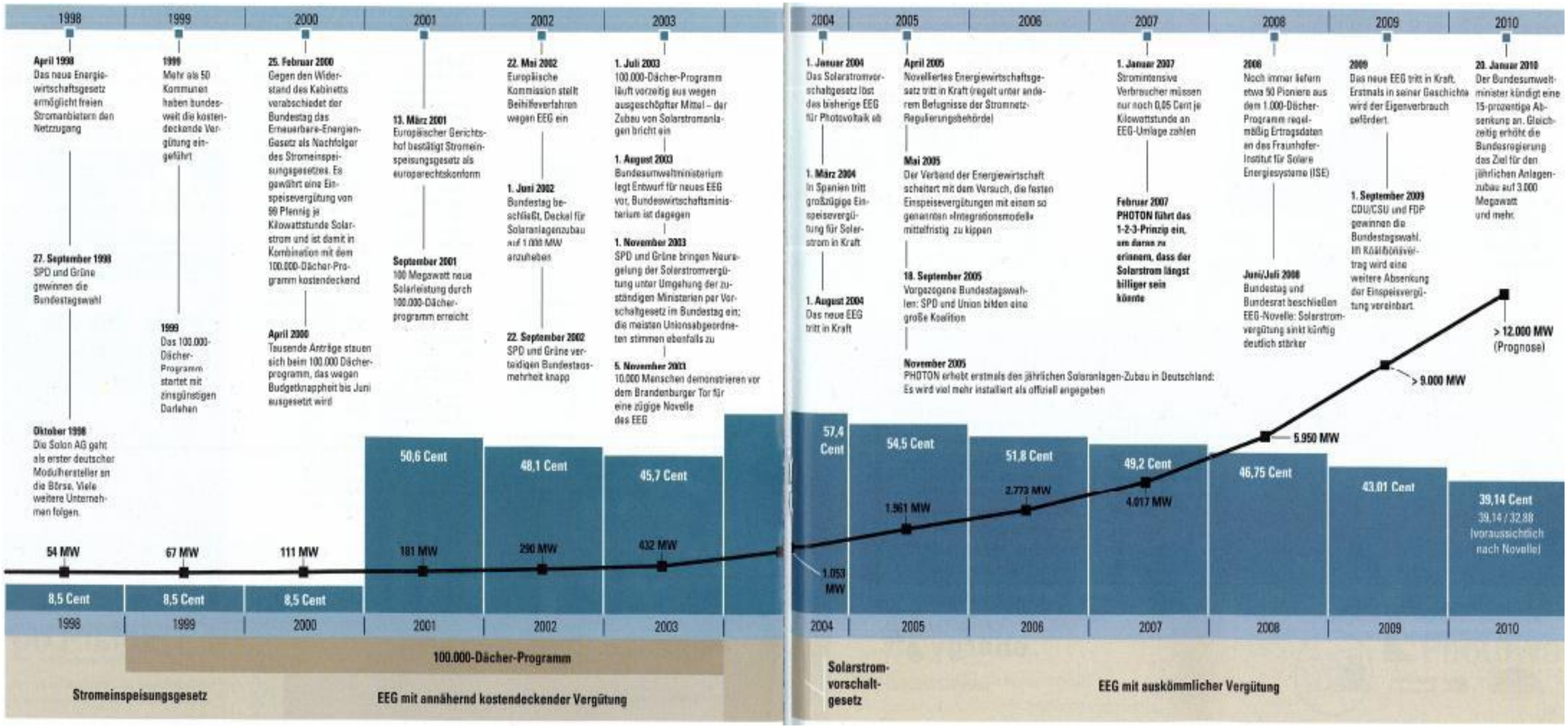
The situation from the street – 2 fields covered with PV! See the safety measures for the installers on the roof!

MSE Student Marco Müller (HSLU)

The backside of the roof – another two PV fields! The total power is 7,2 kWp and the costs for Marco Müller are about 15’000.-- - before the “one time payment - subsidizes (EIV)”!

Cost of PV power

Burgdorf started PV with FIT in 1989 – industry breaktrough with the new „Energiegesetz“ with FIT in Germany 2000!



April 1998
Das neue Energiewirtschaftsgesetz ermöglicht freien Stromanbietern den Netzzugang

27. September 1998
SPD und Grüne gewinnen die Bundestagswahl

Oktober 1998
Die Solon AG geht als erster deutscher Modulhersteller an die Börse. Viele weitere Unternehmen folgen.

1999
Mehr als 50 Kommunen haben bundesweit die kostendeckende Vergütung eingeführt

1999
Das 100.000-Dächer-Programm startet mit zinsgünstigen Darlehen

25. Februar 2000
Gegen den Widerstand des Kabinetts verabschiedet der Bundestag das Erneuerbare-Energien-Gesetz als Nachfolger des Stromeinspeisungsgesetzes. Es gewährt eine Einspeisevergütung von 99 Pfennig je Kilowattstunde Solarstrom und ist damit in Kombination mit dem 100.000-Dächer-Programm kostendeckend

April 2000
Tausende Anträge stauen sich beim 100.000 Dächerprogramm, das wegen Budgetknappheit bis Juni ausgesetzt wird

13. März 2001
Europäischer Gerichtshof bestätigt Stromeinspeisungsgesetz als europarechtskonform

September 2001
100 Megawatt neue Solarleistung durch 100.000-Dächerprogramm erreicht

22. Mai 2002
Europäische Kommission stellt Beihilfeverfahren wegen EEG ein

1. Juni 2002
Bundestag beschließt, Deckel für Solaranlagenzubau auf 1.000 MW anzuheben

22. September 2002
SPD und Grüne verteidigen Bundestagsmehrheit knapp

1. Juli 2003
100.000-Dächer-Programm läuft vorzeitig aus wegen ausgeschöpfter Mittel – der Zubau von Solarstromanlagen bricht ein

1. August 2003
Bundesumweltministerium legt Entwurf für neues EEG vor, Bundeswirtschaftsministerium ist dagegen

1. November 2003
SPD und Grüne bringen Neuregelung der Solarstromvergütung unter Umgehung der zuständigen Ministerien per Vorschaltgesetz im Bundestag ein; die meisten Unionsabgeordneten stimmen ebenfalls zu

5. November 2003
10.000 Menschen demonstrieren vor dem Brandenburger Tor für eine zügige Novelle des EEG

1. Januar 2004
Das Solarstromvorschaltgesetz löst das bisherige EEG für Photovoltaik ab

1. März 2004
In Spanien tritt großzügige Einspeisevergütung für Solarstrom in Kraft

1. August 2004
Das neue EEG tritt in Kraft

April 2005
Novelliertes Energiewirtschaftsgesetz tritt in Kraft (regelt unter anderem Befugnisse der Stromnetz-Regulierungsbehörde)

Mai 2005
Der Verband der Energiewirtschaft scheitert mit dem Versuch, die festen Einspeisevergütungen mit einem so genannten »Integrationsmodell« mittelfristig zu kippen

18. September 2005
Vorgezogene Bundestagswahlen: SPD und Union bilden eine große Koalition

November 2005
PHOTON erhebt erstmals den jährlichen Solaranlagen-Zubau in Deutschland: Es wird viel mehr installiert als offiziell angegeben

1. Januar 2007
Stromintensive Verbraucher müssen nur noch 0,05 Cent je Kilowattstunde an EEG-Umlage zahlen

Februar 2007
PHOTON führt das 1-2-3-Prinzip ein, um daran zu erinnern, dass der Solarstrom längst billiger sein könnte

2008
Noch immer liefern etwa 90 Pioniere aus dem 1.000-Dächer-Programm regelmäßig Ertragsdaten an das Fraunhofer-Institut für Solare Energiesysteme (ISE)

Juni/Juli 2008
Bundestag und Bundesrat beschließen EEG-Novelle: Solarstromvergütung sinkt künftig deutlich stärker

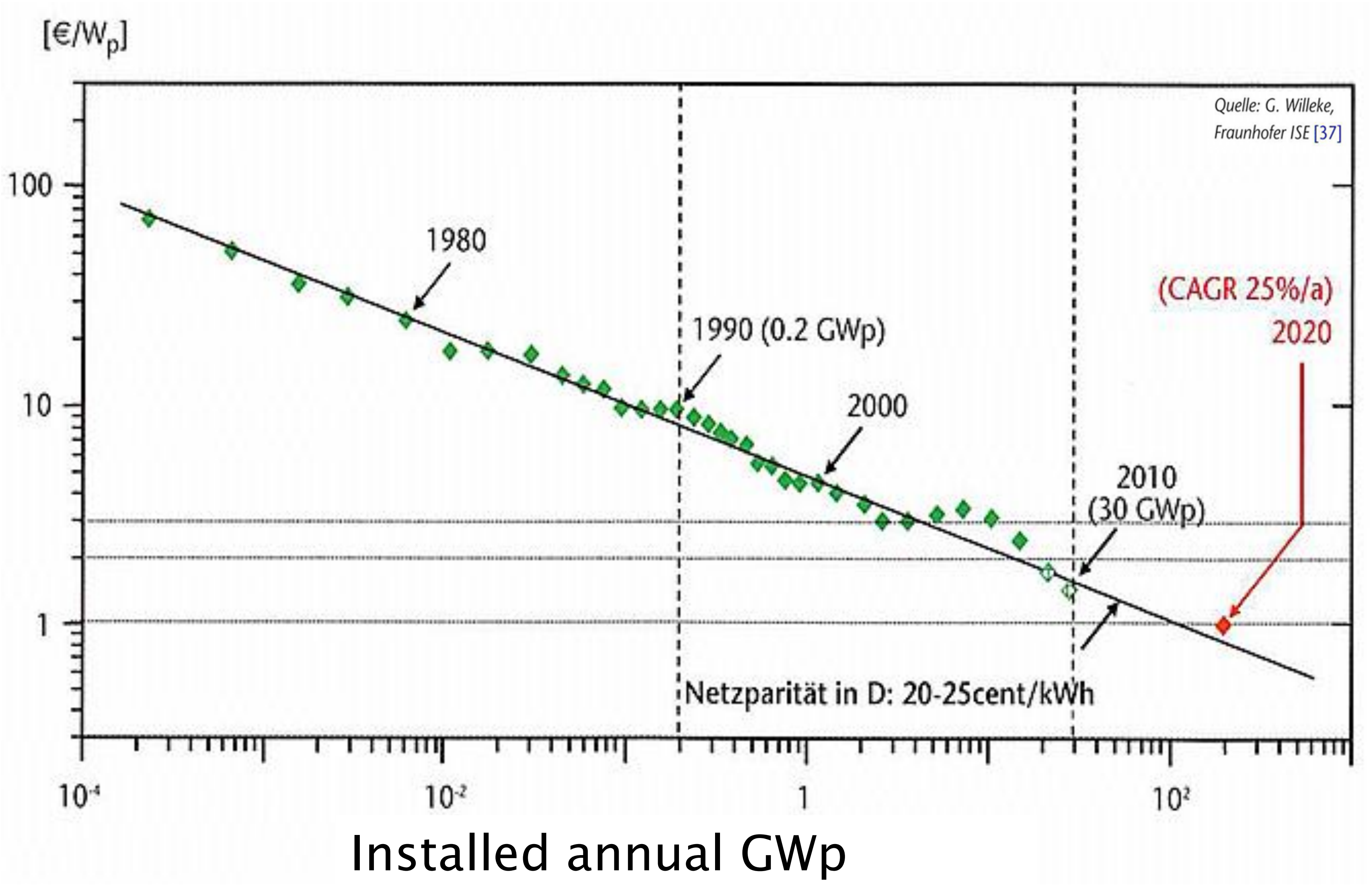
2009
Das neue EEG tritt in Kraft. Erstmals in seiner Geschichte wird der Eigenverbrauch gefördert.

1. September 2009
CDU/CSU und FDP gewinnen die Bundestagswahl. Im Koalitionsvertrag wird eine weitere Absenkung der Einspeisvergütung vereinbart.

20. Januar 2010
Der Bundesumweltminister kündigt eine 15-prozentige Absenkung an. Gleichzeitig erhöht die Bundesregierung das Ziel für den jährlichen Anlagenzubau auf 3.000 Megawatt und mehr.

Germany started PV breaktrough – now is China the leading market/ world market 2016: 75’000 MWp/ 75 GWp!

Price-learning curve of c-Si PV-modules



Costs of a grid connected PV installation 2017 (30 kWp) – fixed on a inclined roof

PV module: …………………..

Inverter: …………………..

Mounting Structure: …………………..

Cables and grid connection: ………………….

Planning/ preparation/ safety: ………………….

Labor costs: ………………….

Profit (5%): ………………….

Total investment costs: <2‘000.--/ kWp

Annual deprecation rate

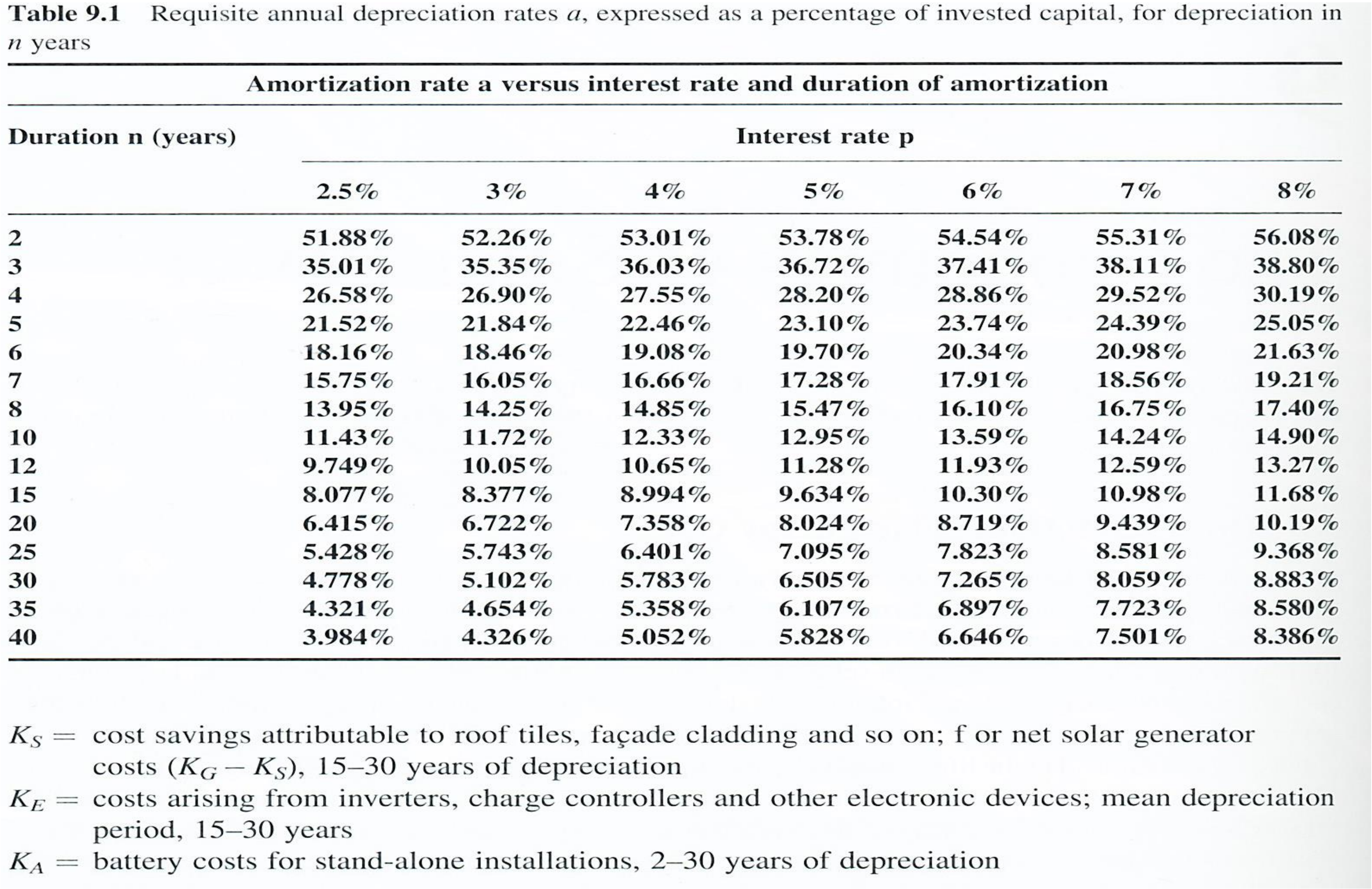


Table 9.1 Requisite annual depreciation rates a, expressed as a percentage of invested capital, for depreciation in n years

Amortization rate a versus interest rate and duration of amortization

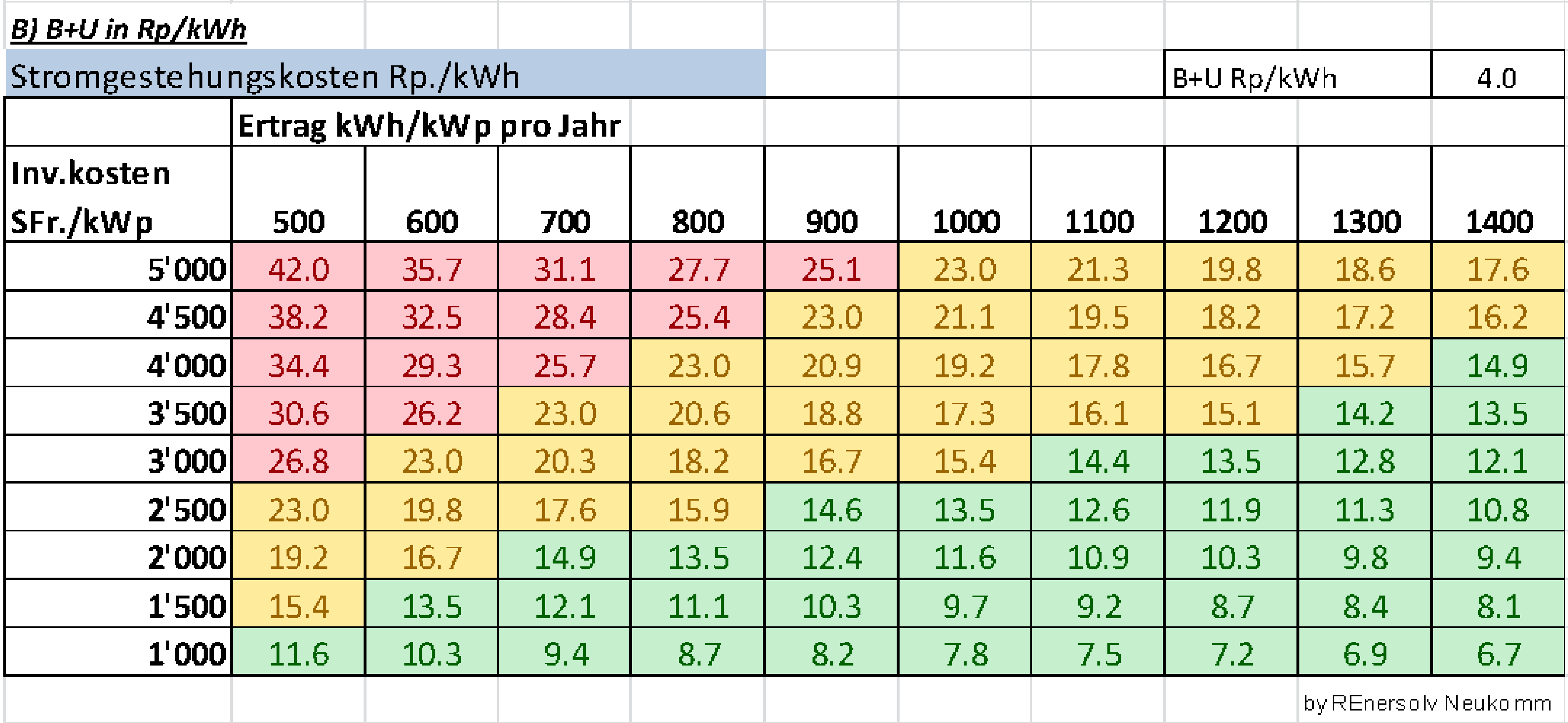
Duration n (years)	**Interest rate p**						
	2.5%	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**
2	51.88%	52.26%	53.01%	53.78%	54.54%	55.31%	56.08%
3	35.01%	35.35%	36.03%	36.72%	37.41%	38.11%	38.80%
4	26.58%	26.90%	27.55%	28.20%	28.86%	29.52%	30.19%
5	21.52%	21.84%	22.46%	23.10%	23.74%	24.39%	25.05%
6	18.16%	18.46%	19.08%	19.70%	20.34%	20.98%	21.63%
7	15.75%	16.05%	16.66%	17.28%	17.91%	18.56%	19.21%
8	13.95%	14.25%	14.85%	15.47%	16.10%	16.75%	17.40%
10	11.43%	11.72%	12.33%	12.95%	13.59%	14.24%	14.90%
12	9.749%	10.05%	10.65%	11.28%	11.93%	12.59%	13.27%
15	8.077%	8.377%	8.994%	9.634%	10.30%	10.98%	11.68%
20	6.415%	6.722%	7.358%	8.024%	8.719%	9.439%	10.19%
25	5.428%	5.743%	6.401%	7.095%	7.823%	8.581%	9.368%
30	4.778%	5.102%	5.783%	6.505%	7.265%	8.059%	8.883%
35	4.321%	4.654%	5.358%	6.107%	6.897%	7.723%	8.580%
40	3.984%	4.326%	5.052%	5.828%	6.646%	7.501%	8.386%

$K_S =$ cost savings attributable to roof tiles, façade cladding and so on; f or net solar generator costs ($K_G - K_S$), 15–30 years of depreciation

$K_E =$ costs arising from inverters, charge controllers and other electronic devices; mean depreciation period, 15–30 years

$K_A =$ battery costs for stand-alone installations, 2–30 years of depreciation

PV-price Switzerland „single houses“:



B) B+U in Rp/kWh

Stromgestehungskosten Rp./kWh

B+U Rp/kWh 4.0

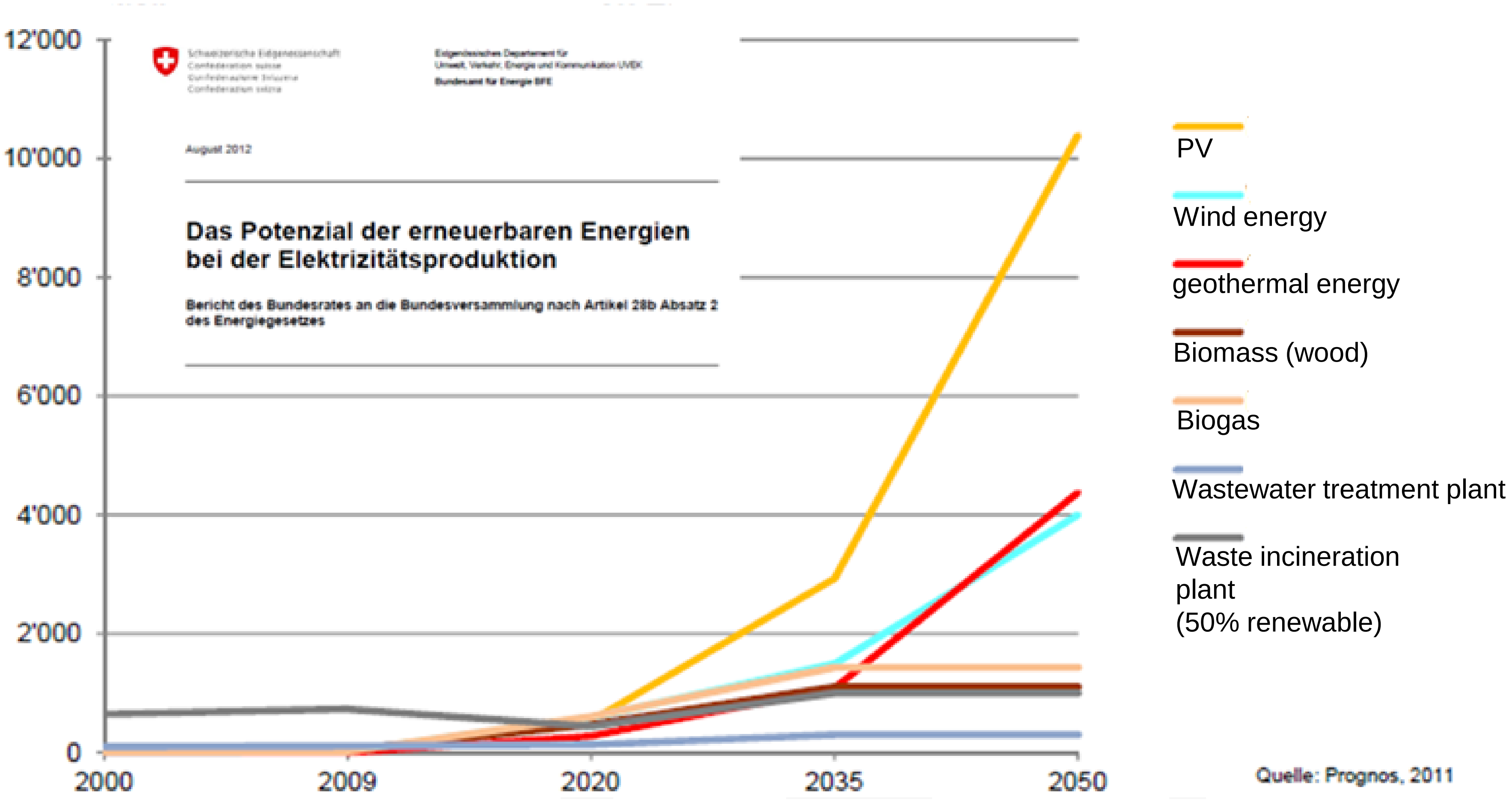
	Ertrag kWh/kWp pro Jahr									
Inv.kosten SFr./kWp	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**
5'000	42.0	35.7	31.1	27.7	25.1	23.0	21.3	19.8	18.6	17.6
4'500	38.2	32.5	28.4	25.4	23.0	21.1	19.5	18.2	17.2	16.2
4'000	34.4	29.3	25.7	23.0	20.9	19.2	17.8	16.7	15.7	14.9
3'500	30.6	26.2	23.0	20.6	18.8	17.3	16.1	15.1	14.2	13.5
3'000	26.8	23.0	20.3	18.2	16.7	15.4	14.4	13.5	12.8	12.1
2'500	23.0	19.8	17.6	15.9	14.6	13.5	12.6	11.9	11.3	10.8
2'000	19.2	16.7	14.9	13.5	12.4	11.6	10.9	10.3	9.8	9.4
1'500	15.4	13.5	12.1	11.1	10.3	9.7	9.2	8.7	8.4	8.1
1'000	11.6	10.3	9.4	8.7	8.2	7.8	7.5	7.2	6.9	6.7

by REnersolv Neukomm

PV prices with 2.5% interests and 30 % tax deductions!

PV and the Energiestrategie 2050

Content of the “Energiwende 2050”



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK
Bundesamt für Energie BFE

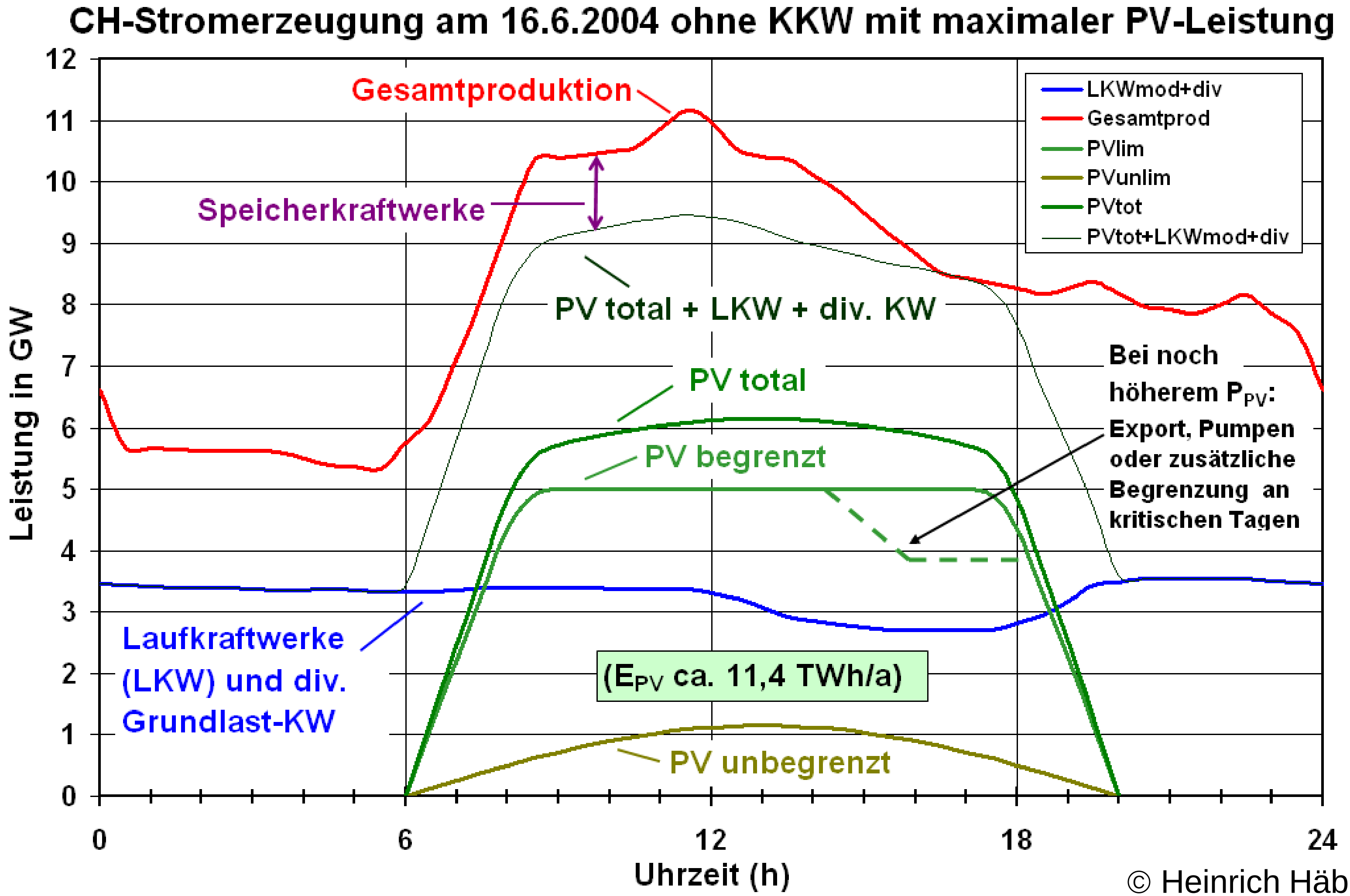
August 2012

Das Potenzial der erneuerbaren Energien bei der Elektrizitätsproduktion

Bericht des Bundesrates an die Bundesversammlung nach Artikel 28b Absatz 2 des Energiegesetzes

Quelle: Prognos, 2011

First description of the goals for the different technologies for the electric production in the «Energystrategy 2050» in MWh_{el}/a



© Heinrich Häberlin, BFH-TI

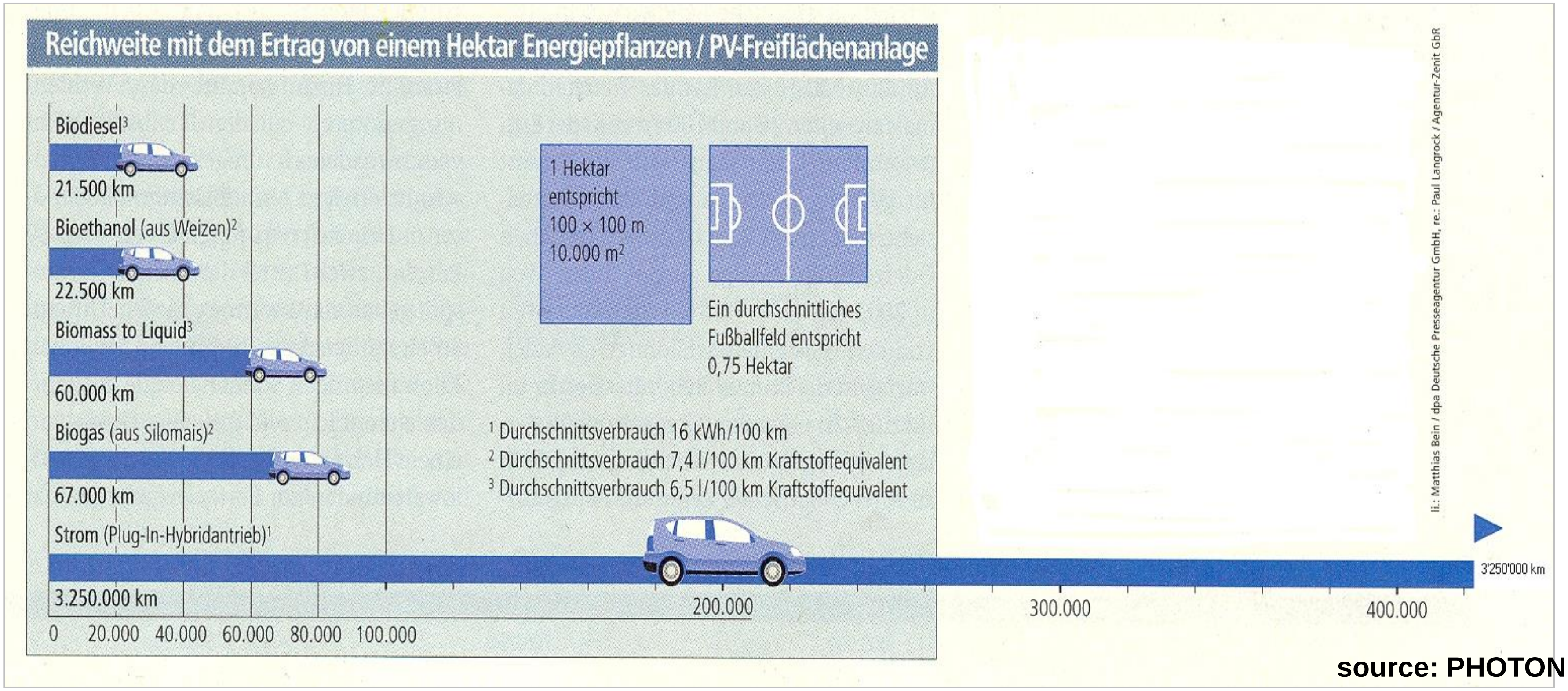
CH-electricity production (without NPP) on April 16 2004, with the maximum tolerable production by PV installations with and without regulation at PV optimized regime of the run-of-river power plants.

Managing PV overproduction is simple:

Nr.	Action	+ PV power	Costs of the action
1	Limit 30% of the PV power	+42%	3%
2	Regulated consumers	+20%	< 5%
3	Consumers as EVs, heat pumps with storage etc.	+20%	0-50%
4	Limit 50% of the PV power	+100%	18%
5	East-west PV installations	+50%	ca. 20%
6	Local batteries	+50%	<50%
7	Pump storage plants	+50%	50%
8	Grid reinforcement (high voltage)	about 20%	ca. 25%

Disruptive technologies – combining PV and EV

Winning combination for the future: PV+EV!



[1] Durchschnittsverbrauch 16 kWh/100 km
[2] Durchschnittsverbrauch 7,4 l/100 km Kraftstoffequivalent
[3] Durchschnittsverbrauch 6,5 l/100 km Kraftstoffequivalent

li.: Matthias Bein / dpa Deutsche Presseagentur GmbH, re.: Paul Langrock / Agentur-Zenit GbR

source: PHOTON

Range achieved by the energy produced on 1 ha land (the bar of the plug-in-hybrid vehicle is 7 times longer than shown here).

➔ The PHEV (consumption 16 kWh/100 km) using solar energy produced by a PV installation on 1 ha drives 150 times further than a car (consumption 6,5 l/ 100 km fuel equivalent) using bio-ethanol extracted from grain produced on 1 ha.

Replacement of all swiss cars with EVs

To run the 5 Million cars in Switzerland we need 7,2TWh (8 GWp) PV (12’000 km/ year with 12kWh/100km).

This costs less than 16 Bn€ and is the energy for 30 years – much cheaper than gasoline!

Opel Ampera at the solarcarport in Burgdorf

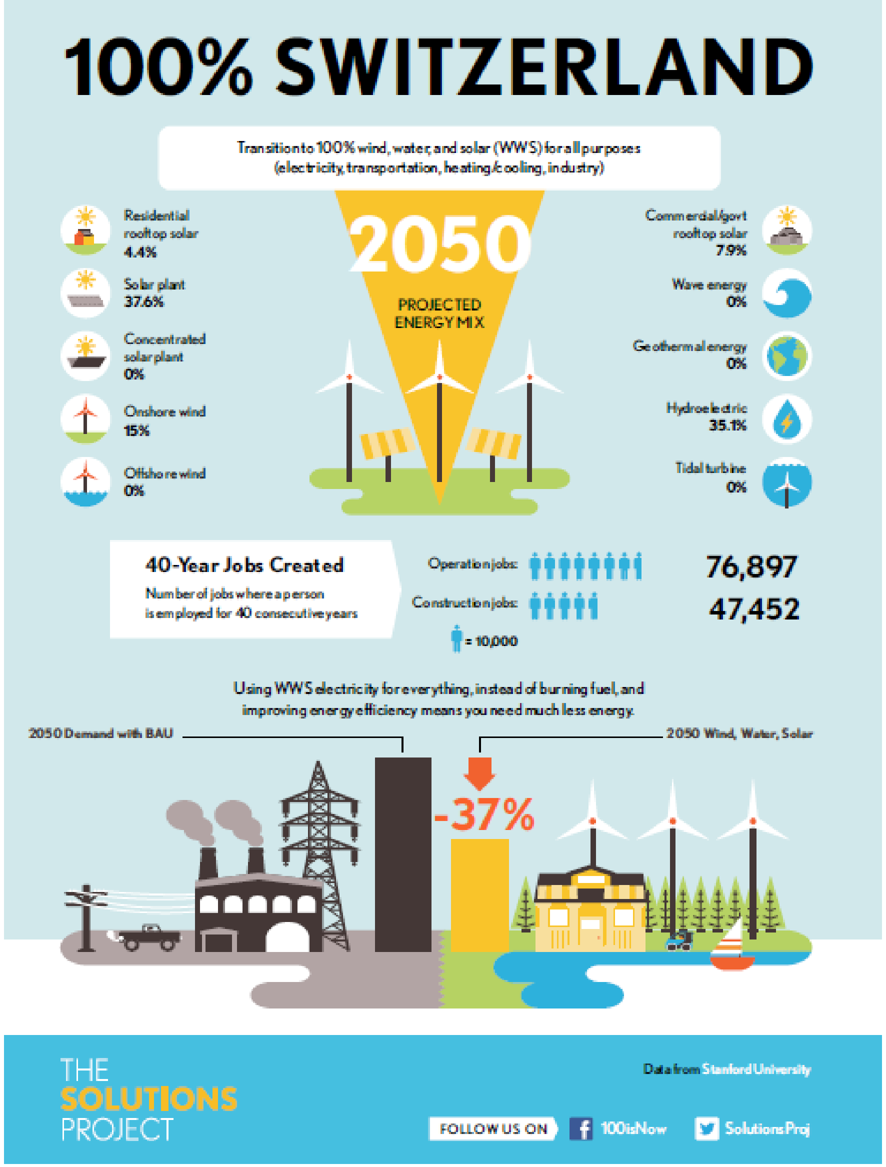
Electric vehicles EVs are a **disruptive technology** and can be cheaper than gasoline cars to buy – and to use!

Towards 100% renewable energie supply for the world

Strategie Stanford University (CA/ USA):

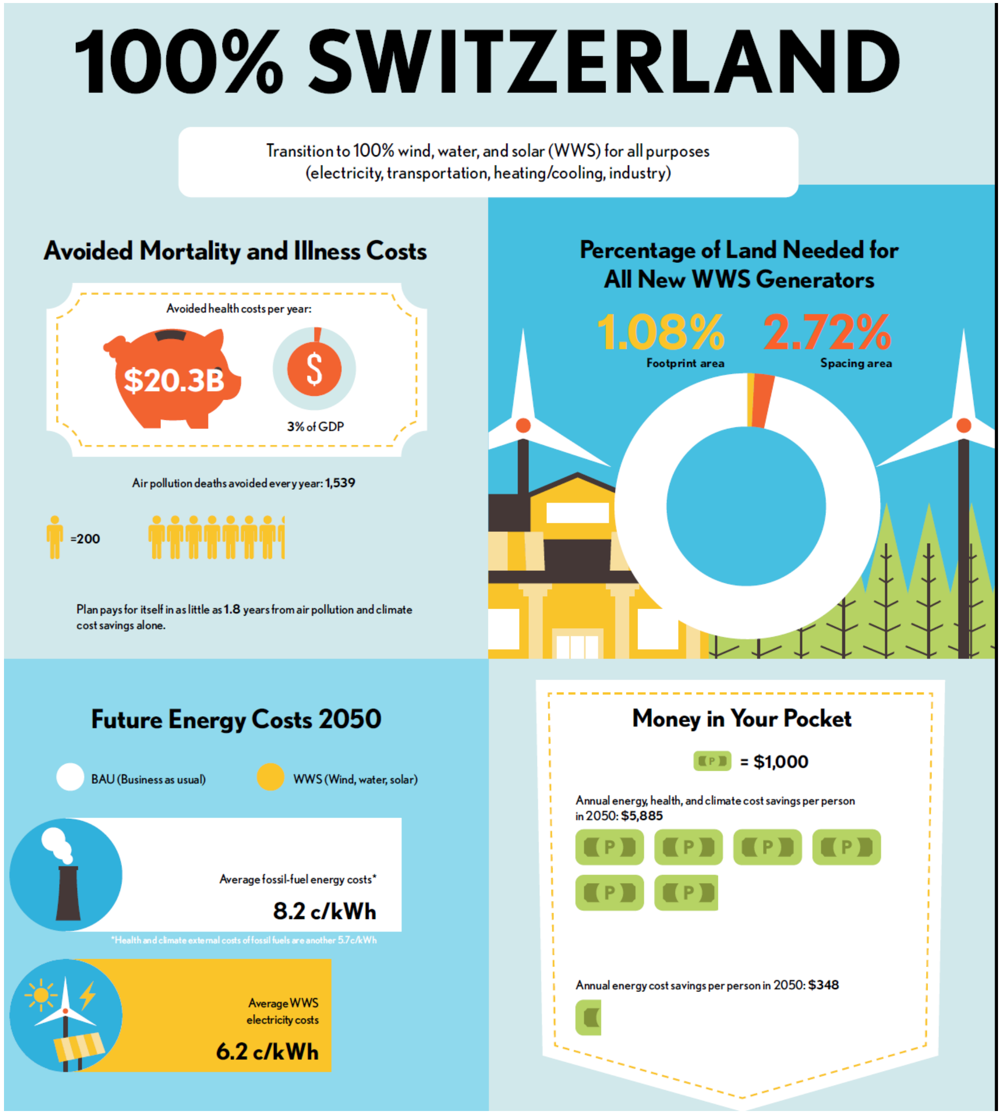
Projekt Professor Mark Z. Jacobson (Director of the Atmosphere and Energy Program, Stanford University) studies how all 50 states of the USA and about 160 countries of the world can be transformed to 100% renewable energies..

There is now a NGO with the same name supported by Professors, actors, etc.



Figures shows that the transition for Switzerland is simple due to the high percentage of hydro which is mainly still realized.
The «solution project» considers only WWS «water-wind-sun».

Other solutions as biomass, waste desposal etc. makes it even easier to reach the target.



100% SWITZERLAND

Transition to 100% wind, water, and solar (WWS) for all purposes
(electricity, transportation, heating/cooling, industry)

Avoided Mortality and Illness Costs

Avoided health costs per year:

$20.3B

3% of GDP

Air pollution deaths avoided every year: **1,539**

=200

Plan pays for itself in as little as **1.8** years from air pollution and climate cost savings alone.

Percentage of Land Needed for All New WWS Generators

1.08% Footprint area

2.72% Spacing area

Future Energy Costs 2050

○ BAU (Business as usual)

● WWS (Wind, water, solar)

Average fossil-fuel energy costs*

8.2 c/kWh

*Health and climate external costs of fossil fuels are another 5.7c/kWh

Average WWS electricity costs

6.2 c/kWh

Money in Your Pocket

= **$1,000**

Annual energy, health, and climate cost savings per person in 2050: **$5,885**

Annual energy cost savings per person in 2050: **$348**

Lower energy costs and more jobs with «100% RES-Switzerland».

Conclusion

- Even for IEA, PV can produce 12‘000 TWh electricity worldwide in 2060/ market of 600 GWp/y (2016:75 GWp)
- «...the market main driver for RES was PV» (IEA Renewables report 2017)
- PV-plants will cost less 1€/ Wp - PV electricity will cost less than 5-10 cent €/ kWh even in Switzerland
- The energy revolution (Swiss Energy Strategy 2050) will save Switzerland much more than 10 billion annually
- The Swiss Energy Strategy 2050 als controls the CO_2!
- 100% renewable energy systems is possible!

We have the technology – lets implement it!

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

Thank you for your interest!

contact: Prof. Urs Muntwyler – urs.muntwyler@bfh.ch

Levelized cost of electricity (LCOE)

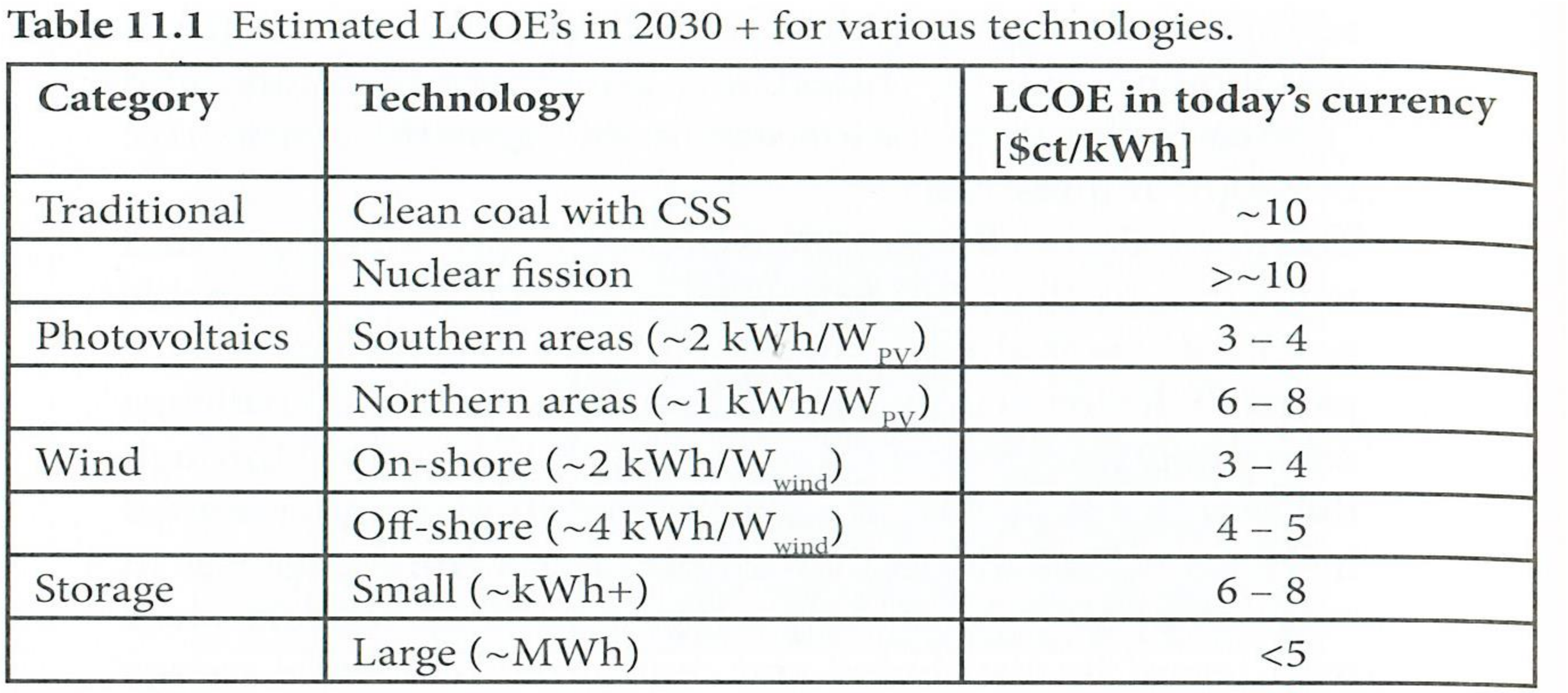


Table 11.1 Estimated LCOE's in 2030 + for various technologies.

Category	Technology	LCOE in today's currency [$ct/kWh]
Traditional	Clean coal with CSS	~10
	Nuclear fission	>~10
Photovoltaics	Southern areas (~2 kWh/W_{PV})	3 – 4
	Northern areas (~1 kWh/W_{PV})	6 – 8
Wind	On-shore (~2 kWh/W_{wind})	3 – 4
	Off-shore (~4 kWh/W_{wind})	4 – 5
Storage	Small (~kWh+)	6 – 8
	Large (~MWh)	<5

The new renewable energy sources produce cheap electricity with less risks (nuclear) and less CO2 (coal etc.).