



The Abdus Salam
International Centre for Theoretical Physics


United Nations
Educational, Scientific
and Cultural Organization


International Atomic
Energy Agency



Workshop on "Physics for Renewable Energy" October 17 - 29, 2005

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"Physics of Renewable Energy"

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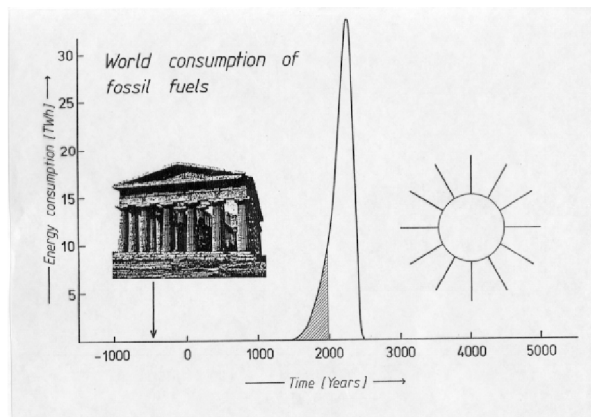
Physics of Renewable Energy

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Workshop on Physics for
'RENEWABLE ENERGY'
October 17 - 29, 2005
Miramare-Trieste, Italy

Achtung: Eingangsdaten



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Besides Physics many other Beside disciplines are needed
for renewable Energy

Chemistry

Materials Science

Engineering – mechanical – electrical

Informatics and Control

Meteorology

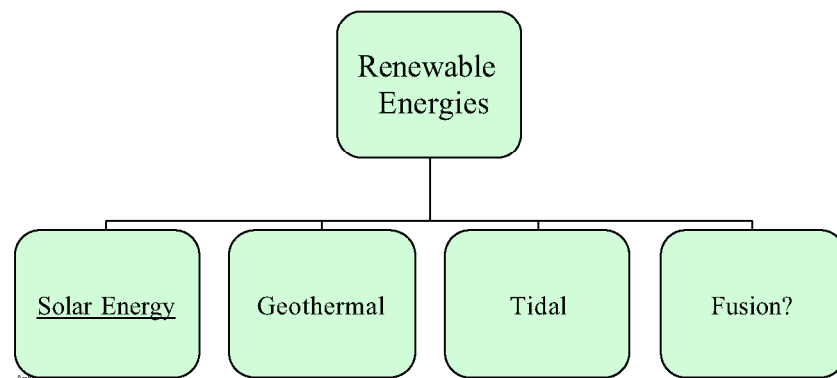
Astronomy

Economics

Sociology

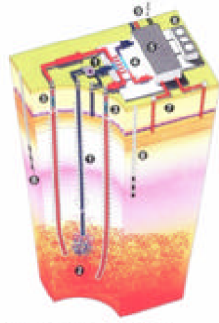
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What is renewable Energy? Energy sources that are not
exhaustible within human time scales



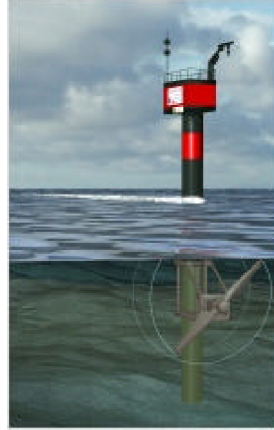
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HOT-DRY-ROCK - Verfahren
Strom und Wärme aus heißem Tiefengestein



- A Injektionsbohrung mit Injektionspumpe
- B Wasserliche Fluidzirkulation (2000 bis 4000 bar, 1 bis 200 °C)
- C Produktionsbohrung
- D Wärmehaube
- E Produktionsrohr
- F Zement
- G Injektionsrohr (Injektionspumpe)
- H Injektionsrohr (Injektionspumpe)
- I Injektionsrohr (Injektionspumpe)

Achtung: Eingangsdaten



Solar Radiation

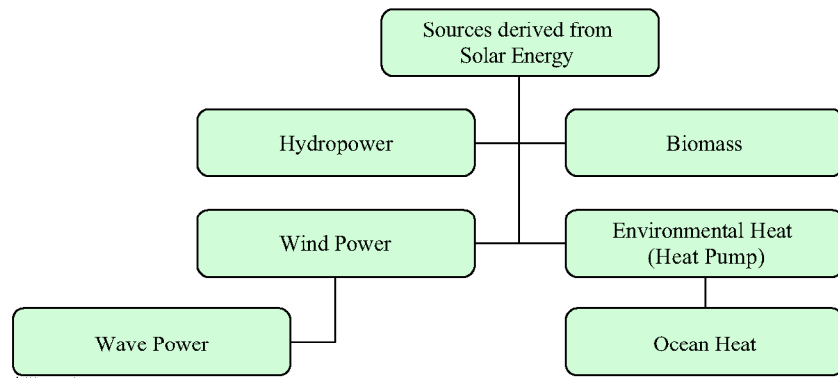
Direct Use

Derived Sources

Heat Energy
Electricity
(by Solar Cell or by Heat)

Achtung: Eingangsdaten

Derived Solar Energy Sources



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Wind Power



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Wave Energy



Achtungungangaben

Solar Trough Power Plants



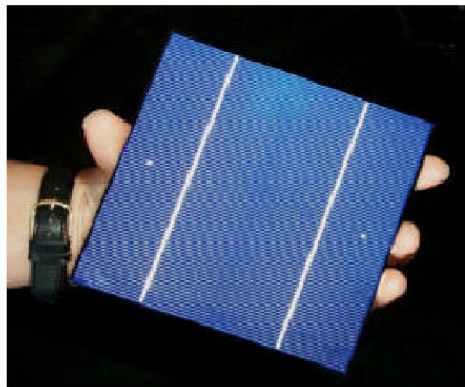
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Solar Tower



Achtung: Eingabefeld

Solar cell



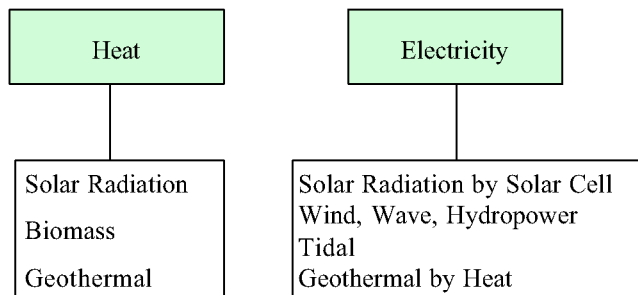
Achtung: Eingabefeld

PV Power PLant



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Other Subdivision: Generation of Heat or Electricity



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Subdivision by Availability of Energy

Available on Demand (dispatchable)	Continuous (base load)	Discontinuous Predictable	Stochastic Short term predictable
Stored Hydro Biomass	Hydro (river) Geothermal	Tidal	Solar radiation Wind Wave
	Storage needed		

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Other important factors

- State of development
- Cost
- Availability as a product
- Potential – theoretical, technical
- Impact on environment – during production or operation
- Geographic distribution e. g. solar radiation, wind

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Physics of Energy Conversion

- Energy is never consumed but only degraded. →
- Conservation of Energy

$$E = E_x + E_A$$

Energy = Exergy + Waste Heat (Anergy)

$E_x = (1 - T_0/T_1)Q$; T_0 = abs. Temp. of Environment,
 T_1 of heat source

Only exergy can be converted into electricity or Mechanical work. Heat at ambient temperature cannot be converted into exergy. (Second law of thermodynamics)

Achtung: Eingangsdaten

Conversion efficiency of solar radiation to electricity

Carnot efficiency: Ideal efficiency (practical ~ (1/2-2/3) Carnot)

$$\eta = 1 - T_0/T_1$$

T_0 = Ambient absolute temperature, T_1 = Temperature of heat source

Temperature of the surface of the sun: ~ 5700K

Theoretical efficiency with concentrated sunlight: 80 - 90%

With diffuse sunlight 70%

With concentrated solar radiation up to 1500°C have been reached and $\eta = 0.2 - 0.3$. Maximum laboratory efficiency of solar cells: With concentration: 38%, without: 0.25%

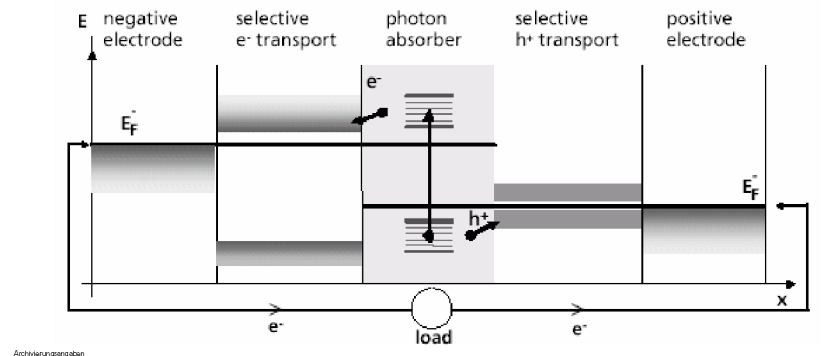
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Conversion Efficiency of Energy Sources

Energy Source	Relevant Parameter	η_{teor}	$\eta_{\text{prakt Labr'}}$
Solar Heat	Concentr. T	80-90%	20-30%
Solar Cell	Concentr. E_G	80-90%	25-38%
Geothermal	T		~25%
Hydropower	? H, flow rate	100%	≤ 100
Wind	$1/2 \sigma_L v^3$	$0.59, 3 \times 1/2 \sigma_L v^3$	
Wave	$c \sigma_W H^2 \omega W$?
Marine Currents	Like wind		
Biomass: Photosynthesis = 0.5%, to electricity 30-50%			

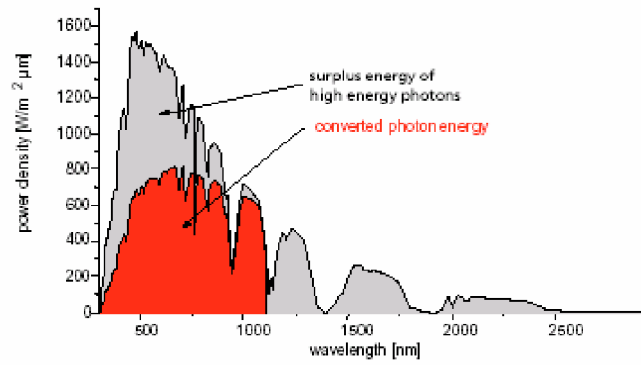
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Principle of photovoltaic energy conversion



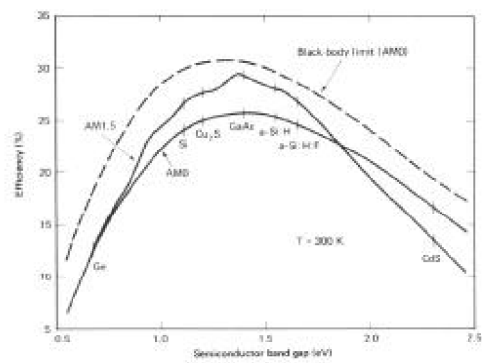
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Solar Spectrum



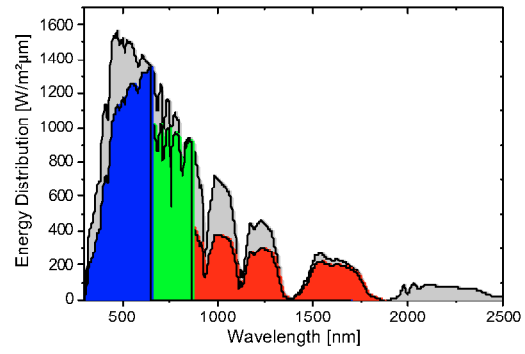
Achtung: Langzeit

Dependence of solar cell efficiency on band gap



Achtung: Langzeit

Solar Spectrum subdivided

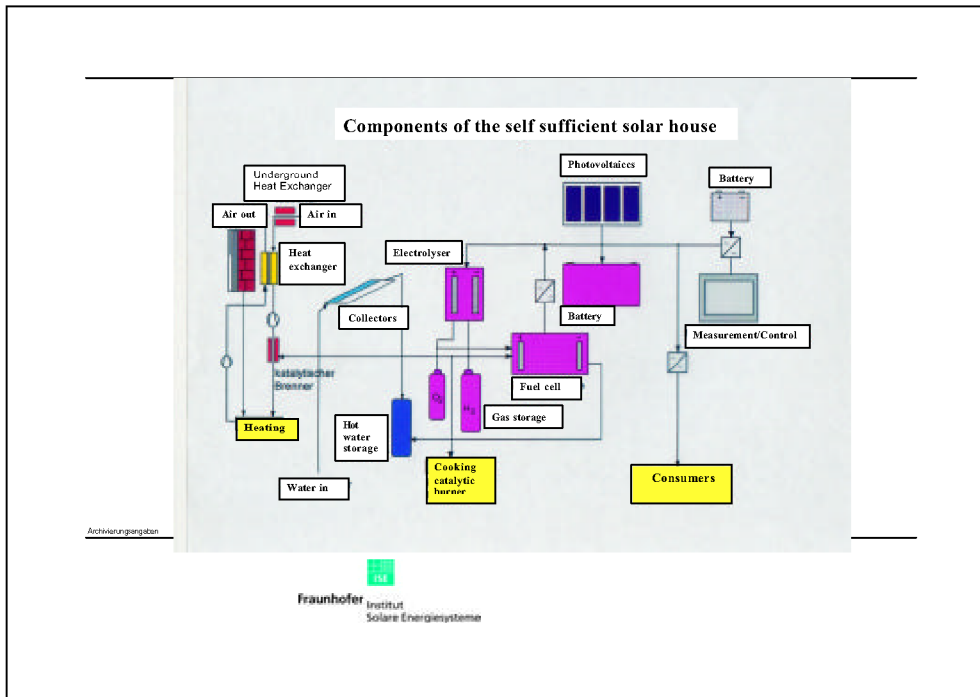


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The Self Sufficient Solar House



Achtbaurgangaben



Electricity production from renewable sources, technical potential of RES and electricity generation costs

	World electricity production 2003 (TWh)	World energy technical potential heat and electricity (x 1 000 TWh/year ⁶)	Electricity generation costs 2003 (€cents/kWh)
Hydroelectricity	2 631	14	2 - 8
Bio-energy	175	>77	5 - 6
Wind energy	75	178	4 - 12
Geothermal power	50	1400	2 - 10
Marine energy	0.8	32	[8 - 15]*
Solar thermal energy	0.5	>440	12 - 18
PV	2.5	>440	25 - 65
Total renewable electricity production	2 960	>2 100	
Total world consumption	Electricity ~ 16,700 Total primary energy ~ 120,000		

* estimated costs

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Summary

- Many different renewable energy sources exist
- Most of them result from solar radiation
- They have different stages of development
- They can be used to generate heat or electricity or both
- The technical potential of renewable energy sources is at least 20 times present primary energy consumption

Achtungungangsten