

Key trends in solar PV and wind energy development

Wim C. Turkenburg

Copernicus Institute for
Sustainable Development and Innovation
Utrecht University

Contribution 'new renewables'

1998 share in world primary energy consumption

- Modern biomass:	~ 7	EJ
- Geothermal:	1.8	EJ
- Small hydro:	0.3	EJ
- Wind turbines:	0.07	EJ
- Low temp. solar energy:	0.05	EJ
- Solar Thermal Electricity:	0.004	EJ

Total:	~ 9	EJ
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Technical potential renewables

	Supply in 1998	Technical potential
Biomass	45 ± 10 EJ	200-500 EJ/y
Hydro	9.3 EJ	50 EJ/y
Geothermal	1.7 EJ	5,000 EJ/y
Wind	0.07 EJ	70-180 EJ/y
Solar	0.06 EJ	1,500-50,000 EJ/y
Marine	-	n.e.

Overview Solar PV

- features of PV
- past and future market trends
- cost development of PV
- issue for technology development
- conclusions

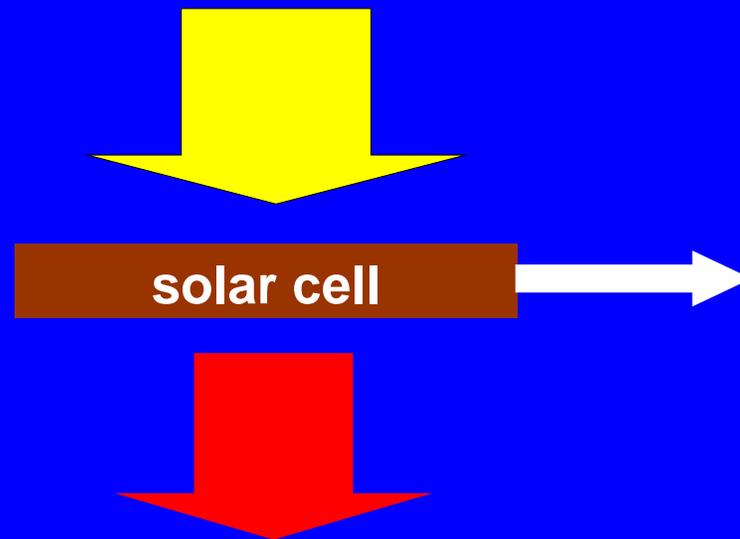


Dutch “NUNA” wins
Solar Challenge 2001



Features of PV

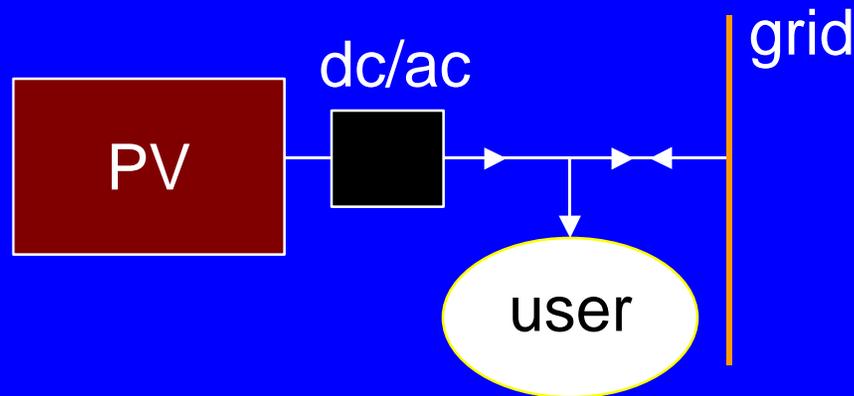
- **renewable / sustainable**
- **direct conversion**
 - quiet
 - reliable
- **modular**
- **widely applicable**
- **large potential**



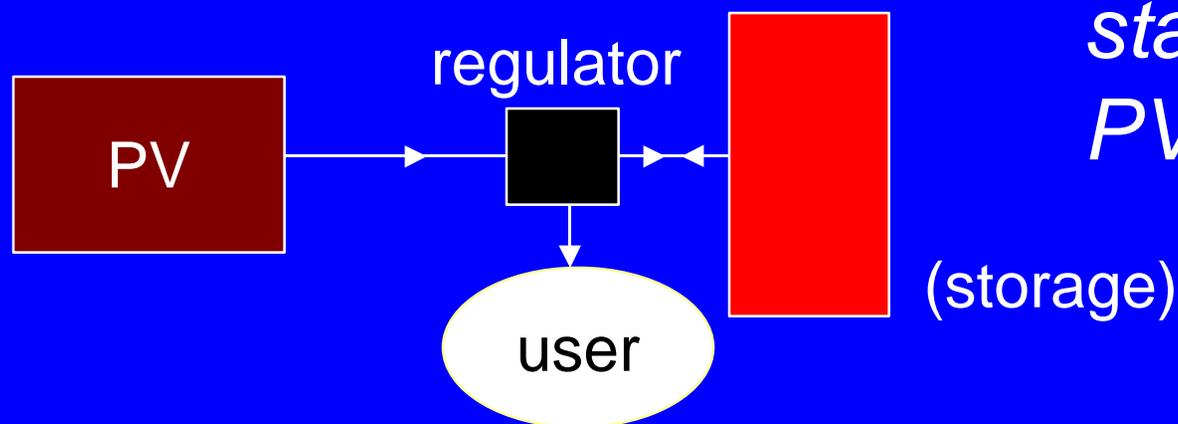
Features of PV

- **intermittent:**
 - power in watt-peak (Wp)
 - capacity factor \approx 8-24% (NL: 9-10%)
- **today's grid-connected systems:**
 - $1 \text{ m}^2 \sim 100 \text{ Wp} \sim 75\text{-}150 \text{ kWh per year}$
- **future systems:**
 - $1 \text{ m}^2 \sim 200\text{-}300 \text{ Wp} \sim 150\text{-}450 \text{ kWh per year}$

Grid-connected and stand-alone PV systems



*grid-connected
PV system*



*stand-alone
PV system*

Solar PV stand-alone systems

- consumer products
- telecom
- leisure
- *water pumping*
- lighting & signalling
- *rural electrification*
- etc.



PV-pumped cattle drinking trough (NL)



Solar Home System
(Bolivia)

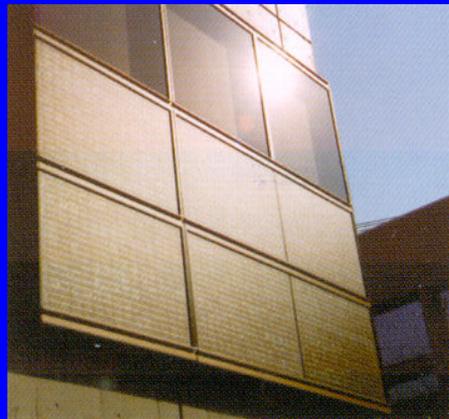
Grid-connected PV systems

- building- & infrastructure-integrated PV

ground-based power plants



PV sound barrier (NL)



“PV gold” (Japan)



“City of the Sun”
50,000 m² PV (NL)

Photovoltaic conversion efficiencies

- **ideal cells:**

- single layer: 30 %
- multiple layers: 40-70 %
- multiple layers + concentrated light:

- **best practical cells:**

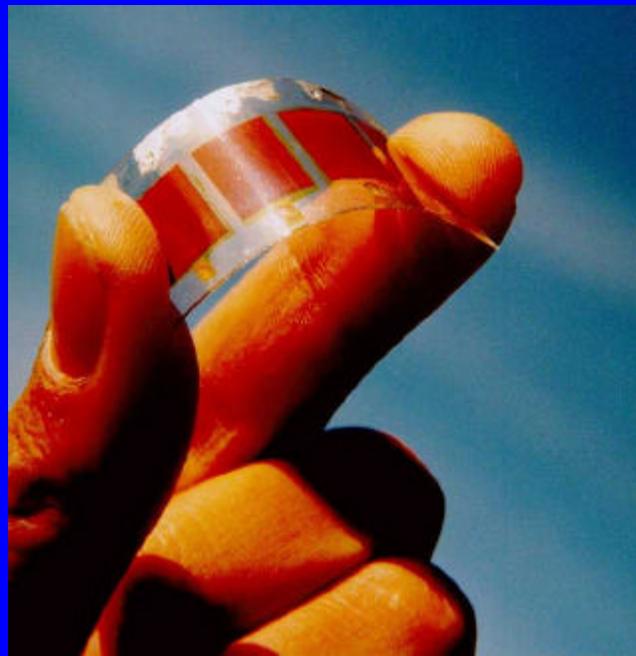
- single layer (Si, GaAs): 25 %
- multiple layers (GaAs-family): 30 %
- multiple layers + concentrated light:

- **typical (semi-)commercial modules:**

- crystalline silicon: 12-15 %
- thin films (a-SiGe, CIGS, CdTe) 5-10 %

Recent solar cell developments

- organic (polymer or “plastic”) solar cells (lab sensitised oxide cells (lab 11%)



first flexible dye-sensitised solar cell (ECN, NL)

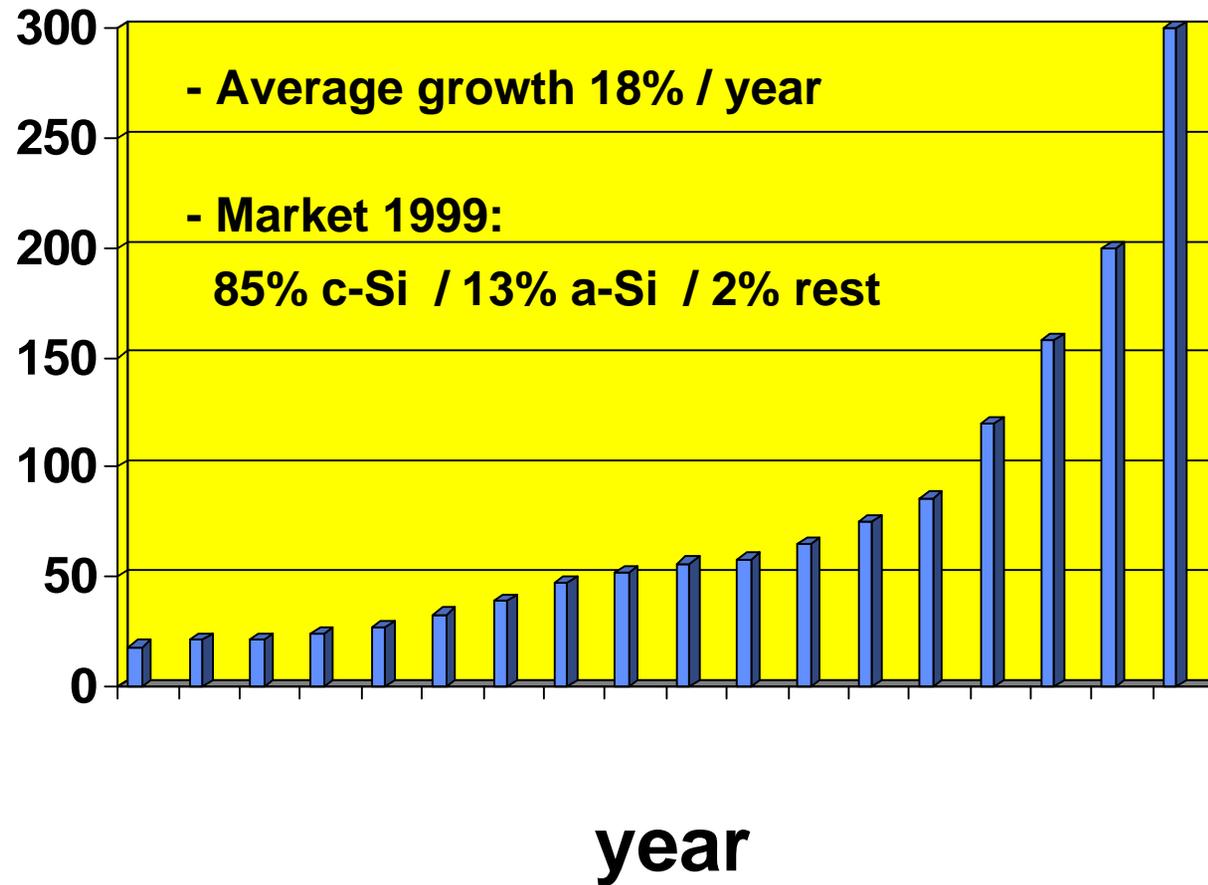


polymers

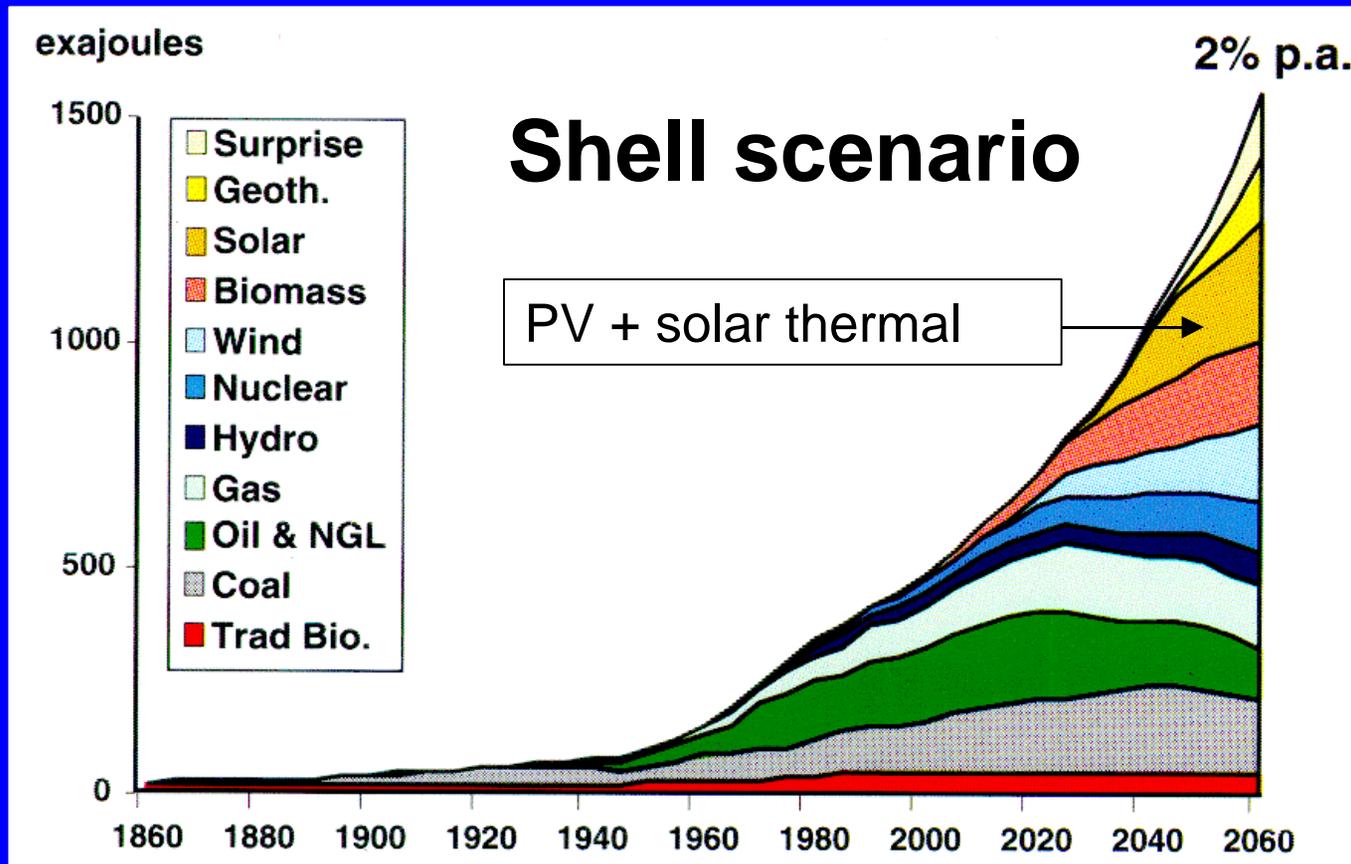


bucky balls

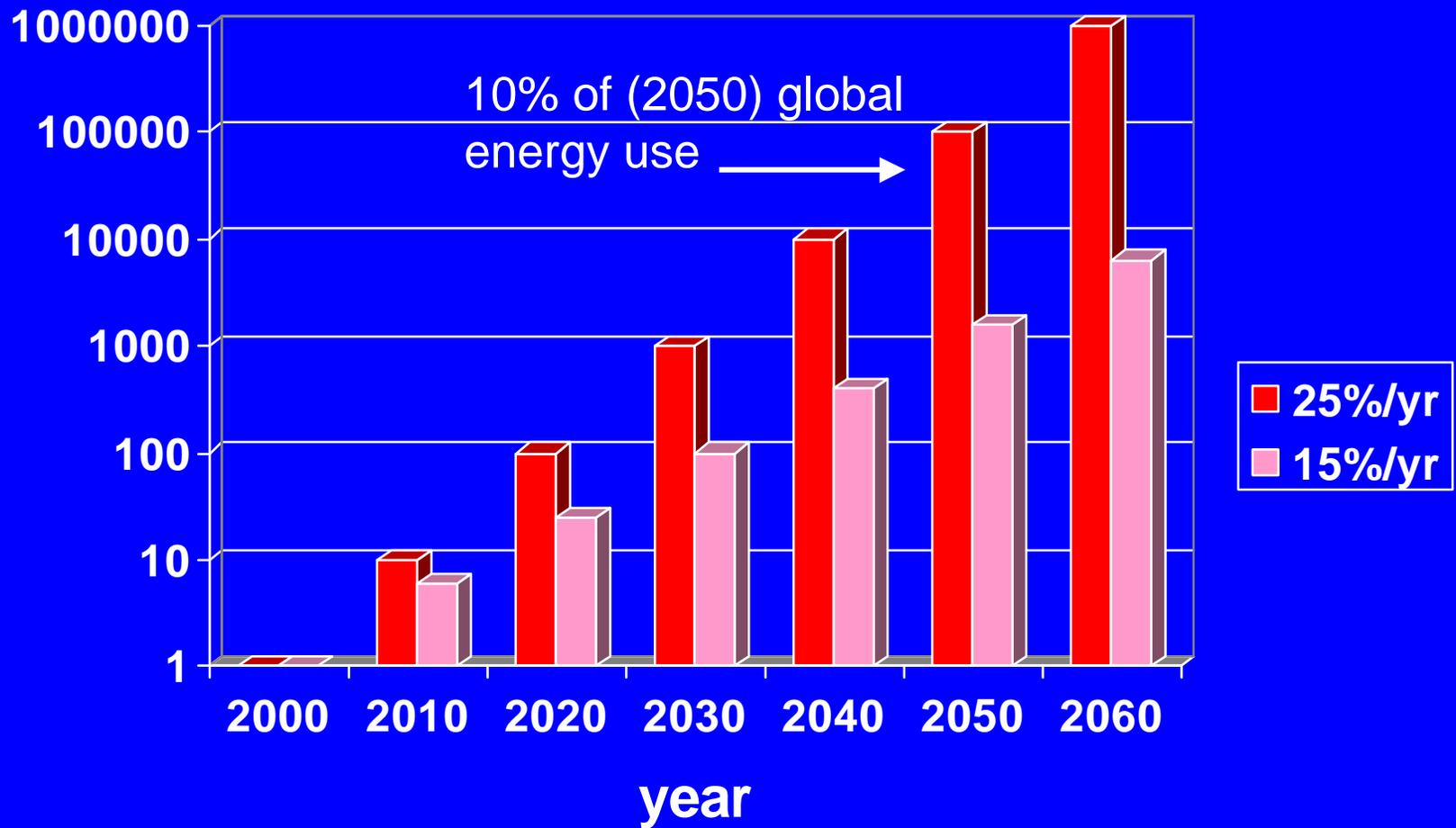
Annual PV shipments



Potential contribution renewables



Cumulative installed PV power

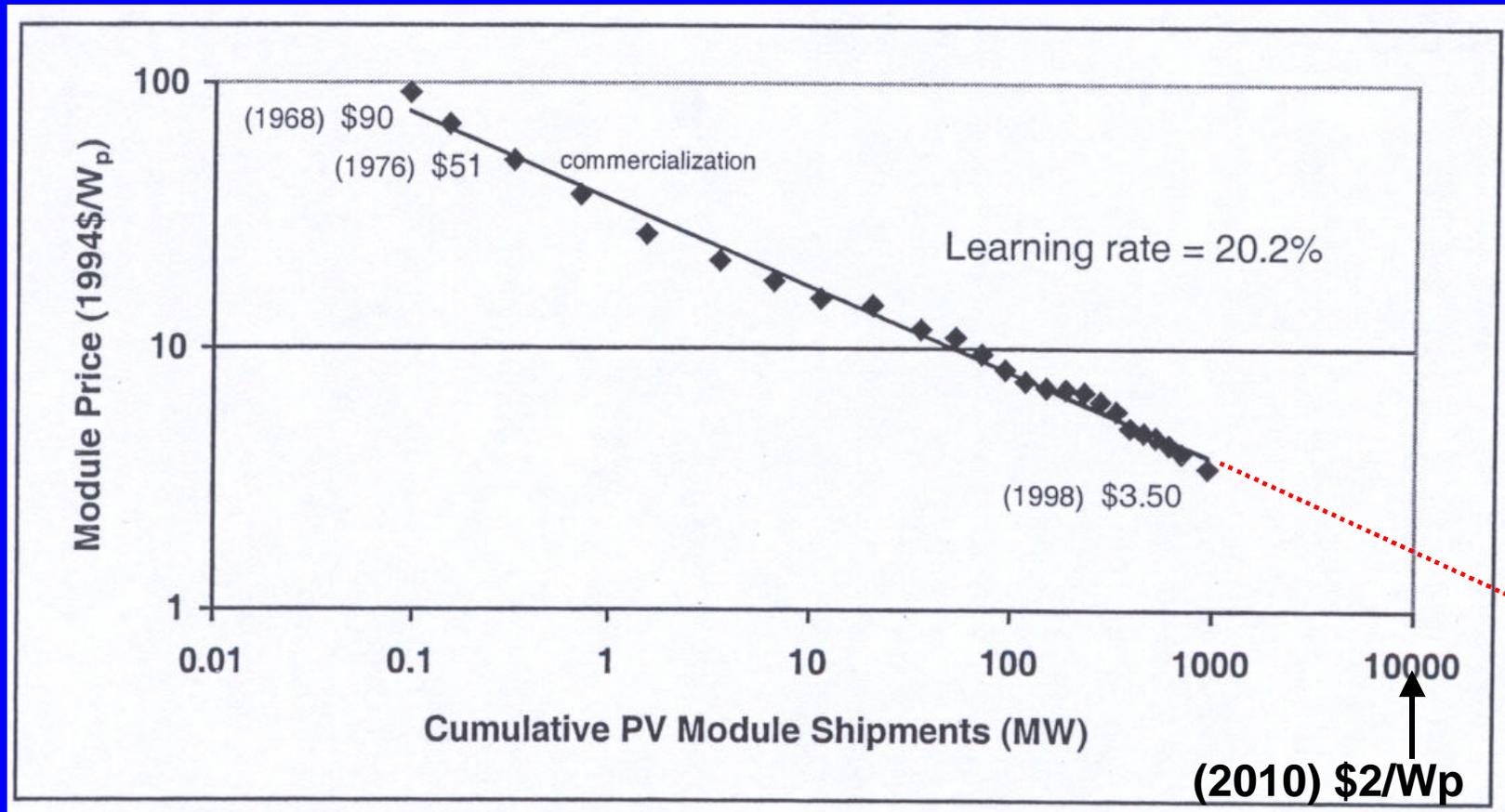


The economics of PV (year 2000)

- Module price $\$ 3 \sim 4 / \text{Wp}$
Balance-of-System price $\$ 2 \sim 3 / \text{Wp}$
→ System price (grid-connected) $\$ 5 \sim 7 / \text{Wp}$
- equivalent electricity price is $0.30 \sim 1.70 \text{ \$ / kWh}$
[depending on electricity yield (
economic lifetime of the system, and interest rate)].

(prices incl. VAT)

PV experience curve



Source: IIASA, 2000

Major options to reduce costs

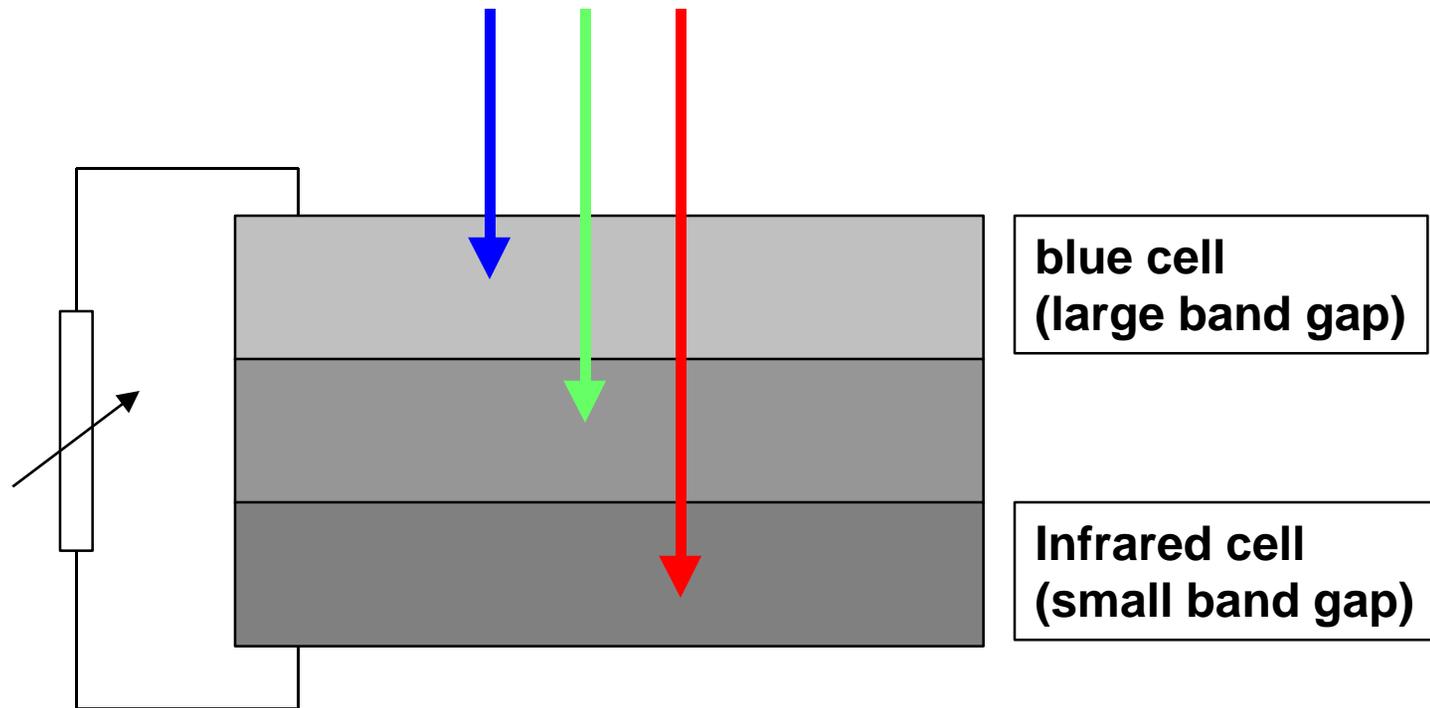
- Increase conversion efficiency (reduction of energy losses in the cell, the module and the

Strong reduction in material use (thin film solar cell development).

Mass production of PV components (module plants of 50-100

Reduction Balance-of-System costs (e.g. multi-functional use of PV area).

Working of multiple layer (tandem) cell



Long term targets for solar PV

- module efficiencies of 30 ~ 40%
→ cell efficiencies of 40 ~ 60% needed
(multiple layer / concentrated light cell)
- no use of hazardous or scarce materials
stable operation ~ 40 yrs
- module cost < 0.5 \$ / Wp
- system cost < 1 \$ / Wp

PV: conclusions (1)

- PV technically sufficiently mature for large-

Powerful option in rural electrification.

ranging from 6-9% (a-

Shipments in 2000:

Annual increase shipments:

Cumulative shipments in 2000:

Solar PV: conclusions (2)

- Continuous reduction investment costs

cost grid-connected PV-systems
may come down from 5-

Electricity production cost may come down
\$/kWh \rightarrow 0.05-0.25 \$/kWh.

Requires a new generation of solar cells.

Wind energy

- **characteristics of modern wind projects**
- **technology trends**
- **market and cost developments**
- **conclusions**



Modern wind energy projects



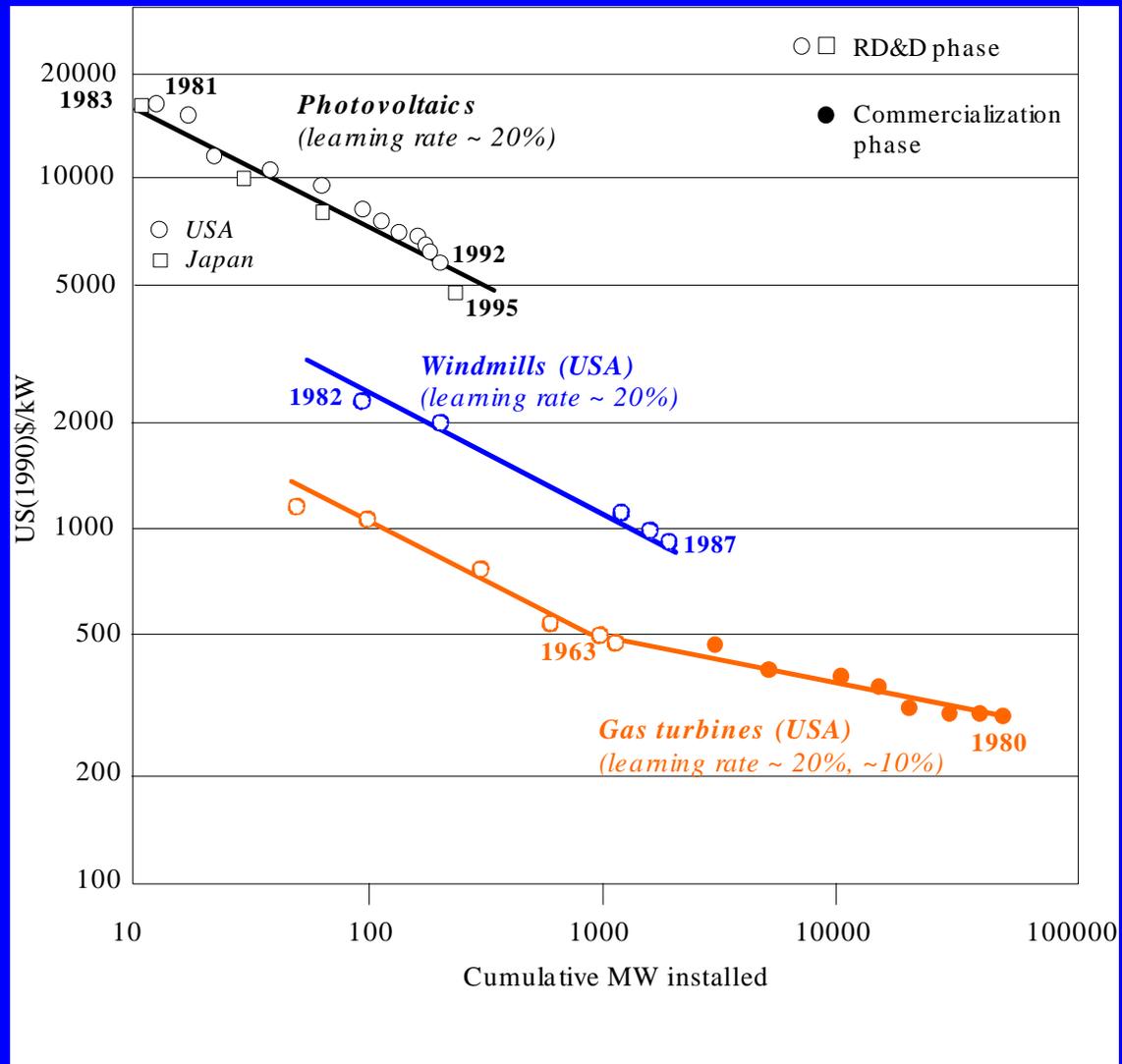
Modern wind farms: some key figures

- On land wind farms: capacity varying from 1 MW

applied turbines

400 per m² rotor swept area

Experience curves (PV, wind,

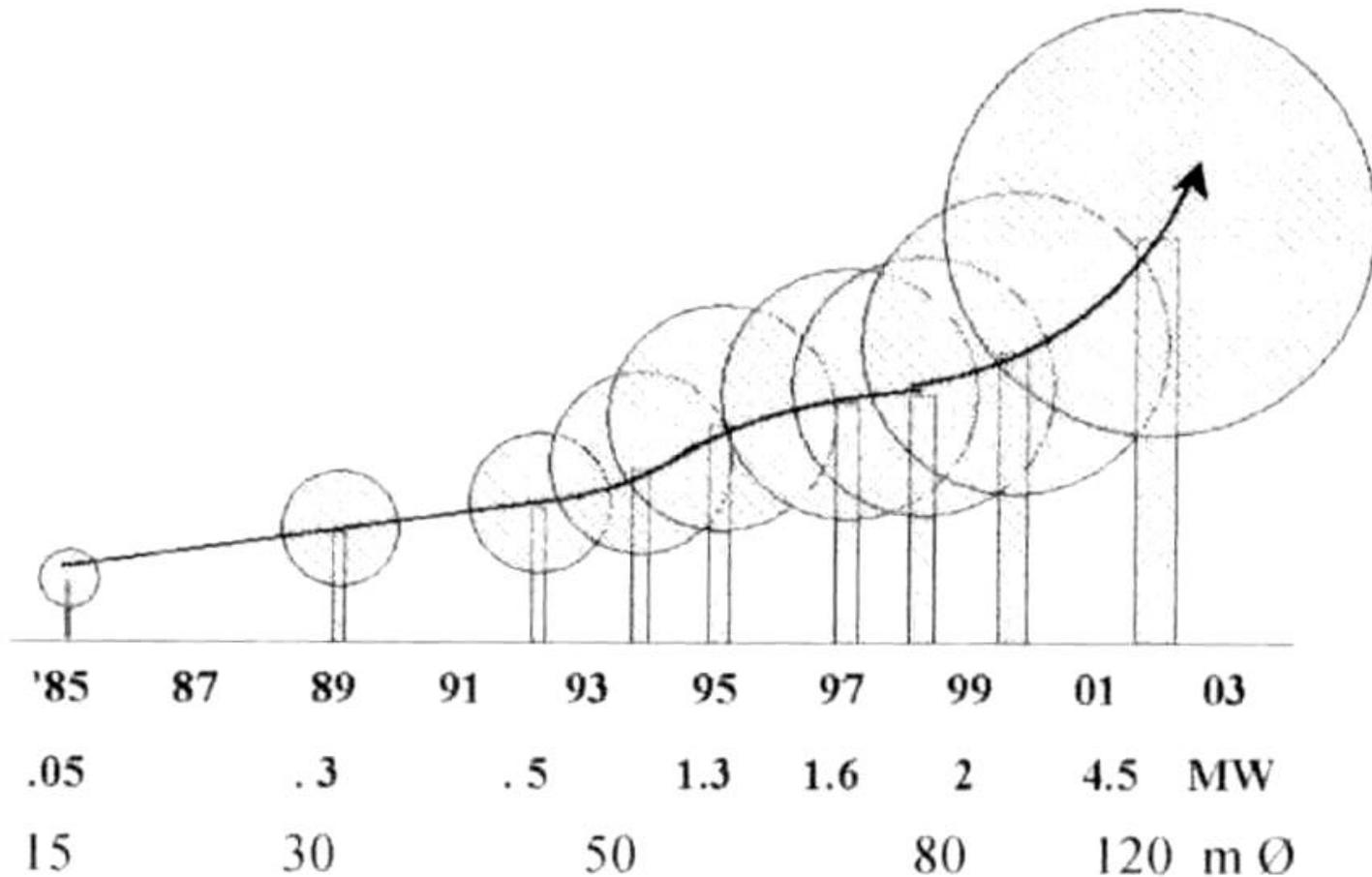


Wind turbine technology trends

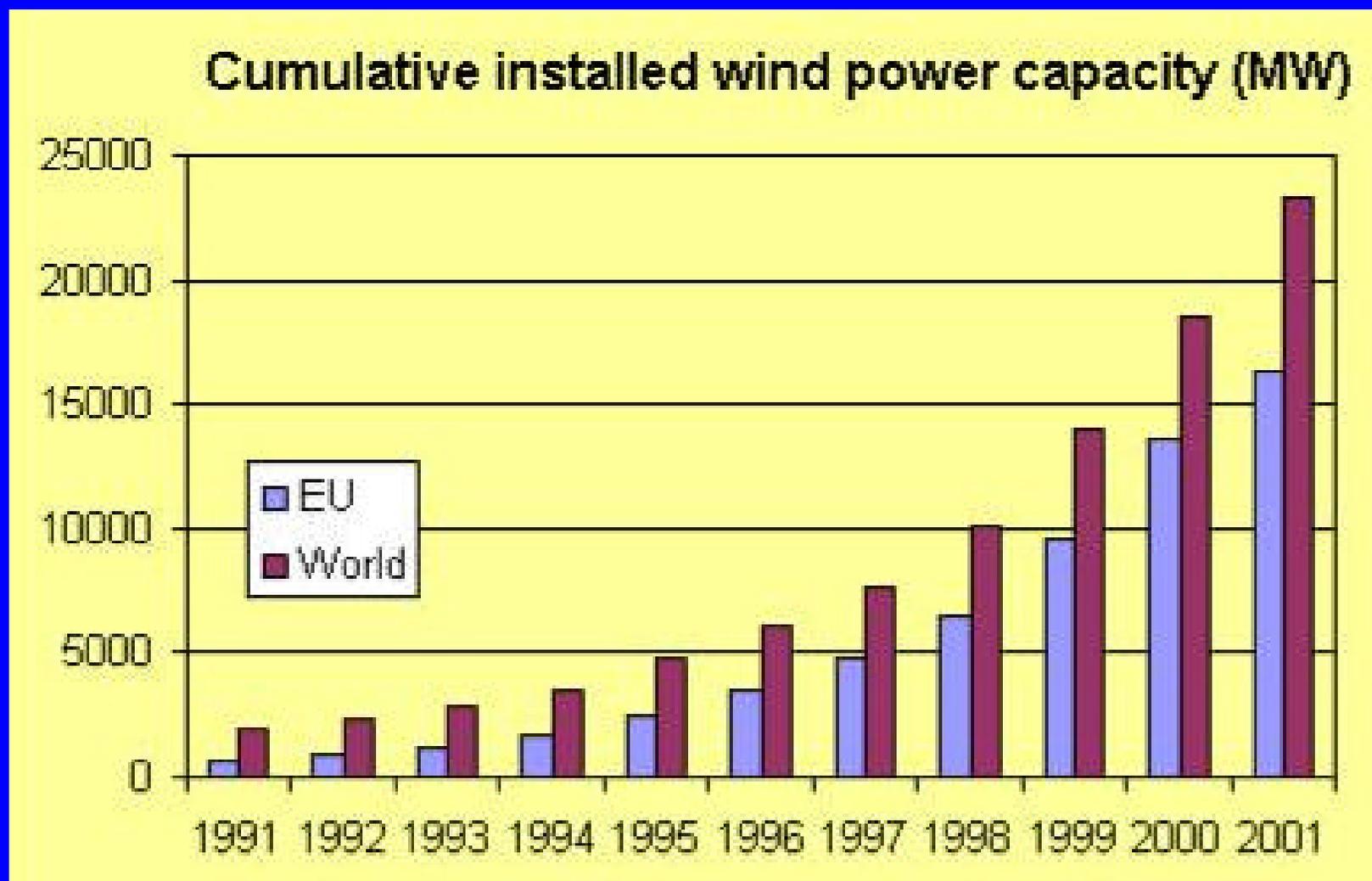


- From 10 m to 120 m \emptyset (1975-now)
- From 30 kW to 5 MW
- Introduction of power electronics
- Variable speed
- Fixed blade angle to variable
- From classical drive trains to direct
- Significant reduction in number of
- Technical lifetime 20 years

Wind turbine technology trends:

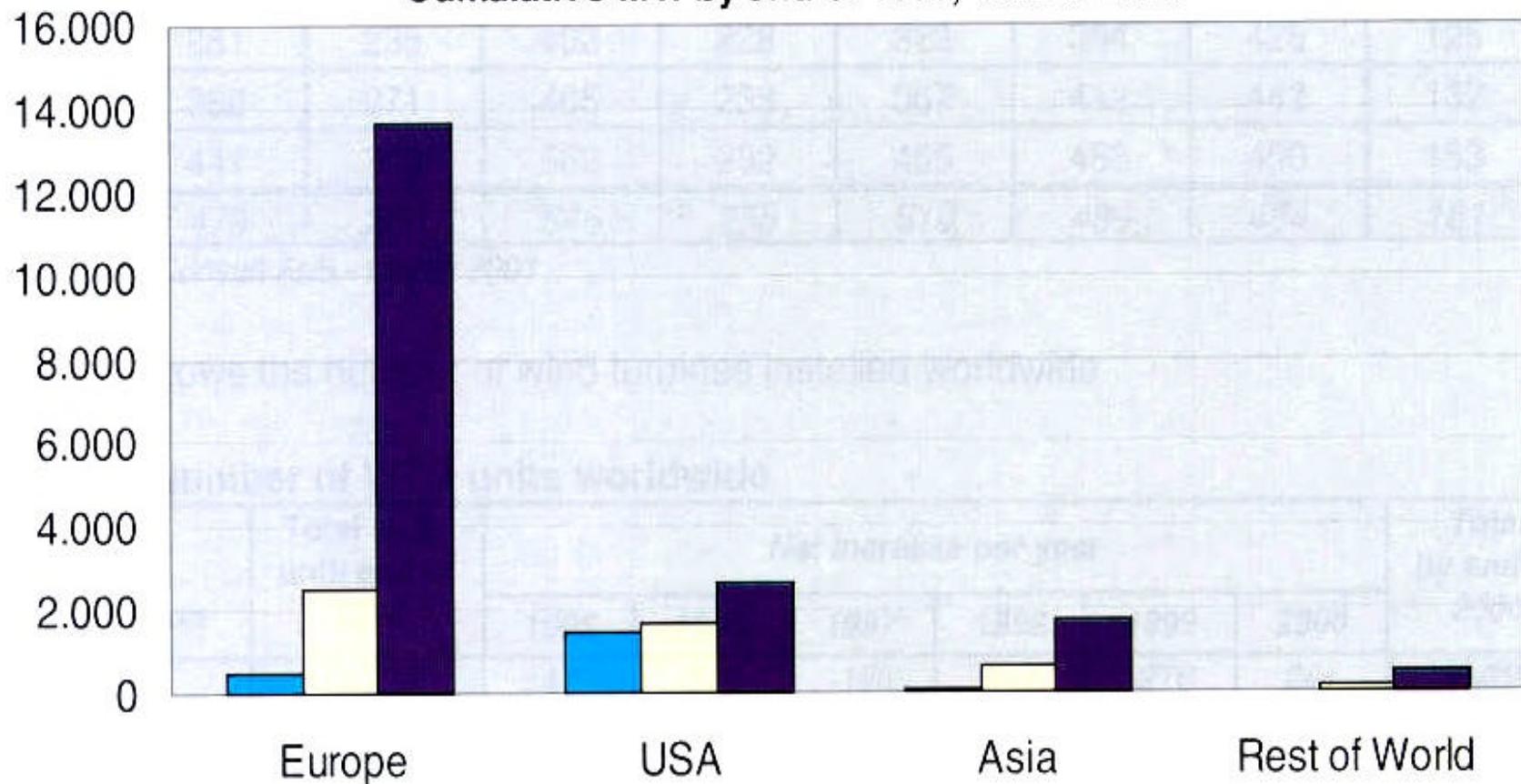


Market development



Global Wind Power Status

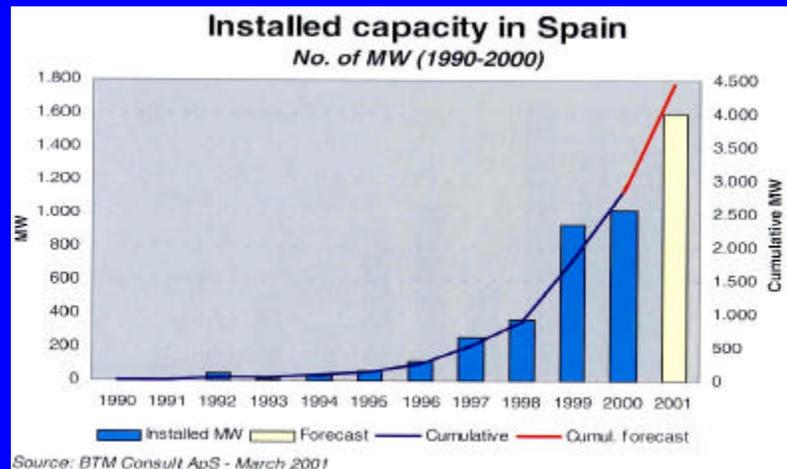
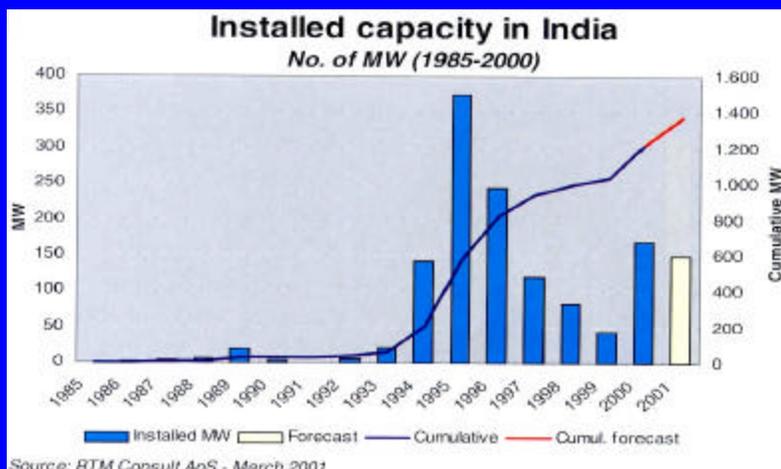
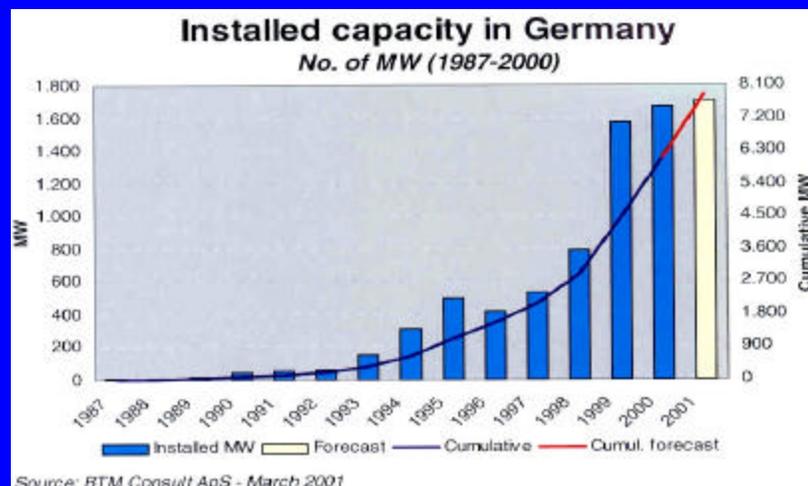
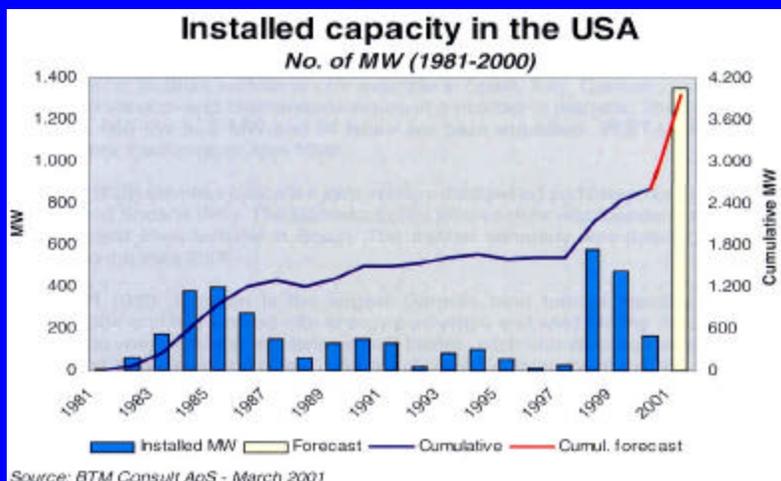
Cumulative MW by end of 1990, 1995 & 2000



Source: BTM Consult ApS - March 2001

■ 1990 (2.013 MW) □ 1995 (4.778 MW) ■ 2000 (18.449 MW)

Market development: country profiles



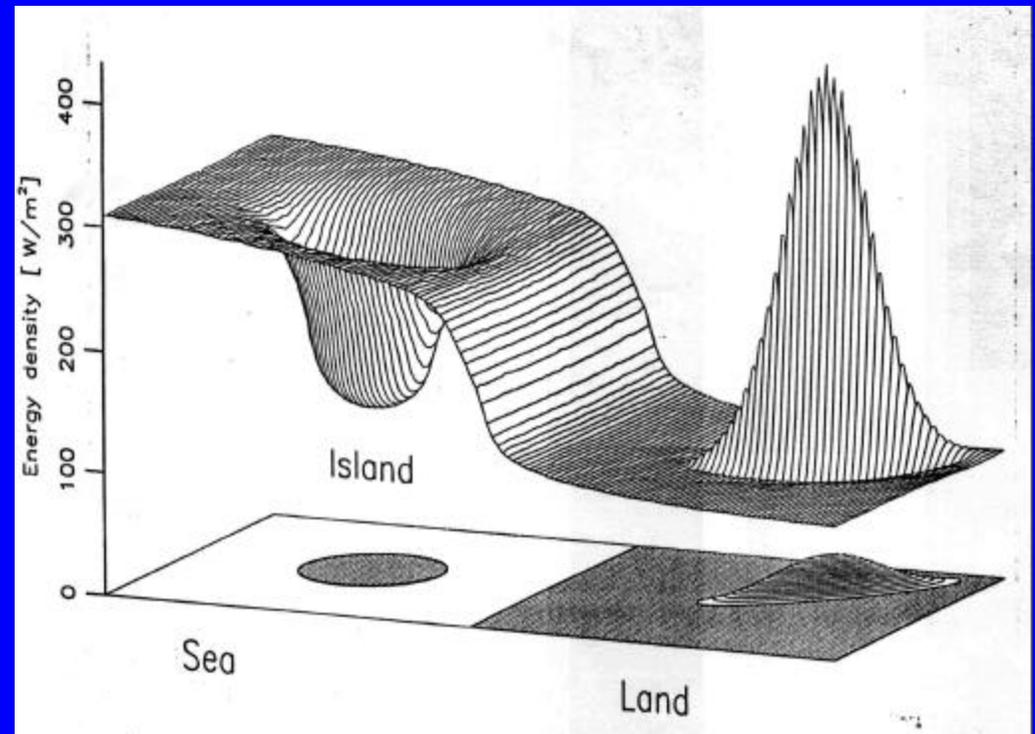
Wind energy: impact on electricity production in 2000

- Denmark: 15 %
(goal: 50% in 2030)
- Schleswig Holstein (D): > 16 %
- Navarra (E): 22 %

Special designs for offshore wind farms

Novell concepts for:

- Installation
- Electricity conversion
- Transport systems
- Corrosion protection
- Integration with external conditions (wind, wave loading)



Energy production costs (1)

- Turnkey cost: \$ 600 per m²
- Interest: 5 percent
- Economic lifetime: 15 years
- Technical availability: 95 percent
- Annual energy output: 3.15 V³ kWh per m²
- O&M costs: \$ 0.005 per kWh

Energy production costs (2)

- Energy cost:
 - \$ 0.05 per kWh ($V = 7.5$ m/sec at hub height)
 - \$ 0.12 per kWh ($V = 5.6$ m/sec at hub height)

Note: Potential cost reduction: 35-45 percent
in next 15-20 years

Wind: conclusions (1)

- Wind turbines become larger (30 kW)
New wind turbines have fewer components.
Special offshore designs.
Total installed power 23,300 MW (end 2001,
82% of power in only 5 countries (D, E, USA,
Growth during last 5 years: > 30 %/year.

Wind: conclusions (2)

- 10 percent grid penetration maybe around 2020.
Installed capacity in 2030 could be 1,000 – 2,000

‘Learning rate’ (cost reduction):

Potential development energy production costs:
\$ 0.05 → \$ 0.03 per kWh

Combined with storage (CAES): base-load
electricity production feasible at \$ 0.04 per kWh.

Thanks!