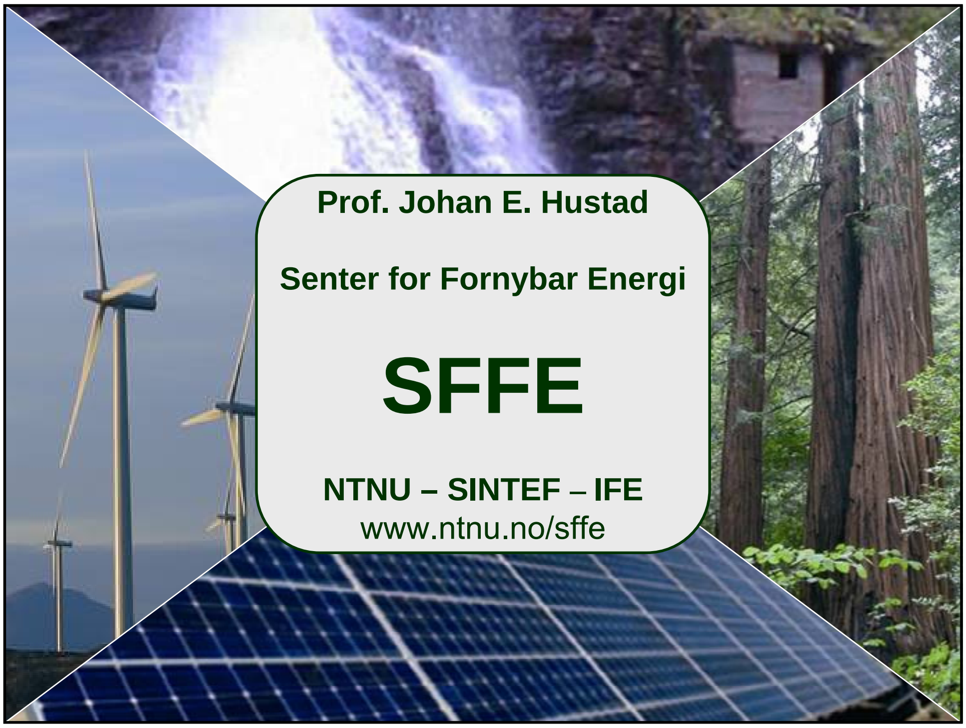

Prof. Johan E. Hustad
Senter for Fornybar Energi
SFFE
NTNU – SINTEF – IFE
www.ntnu.no/sffe

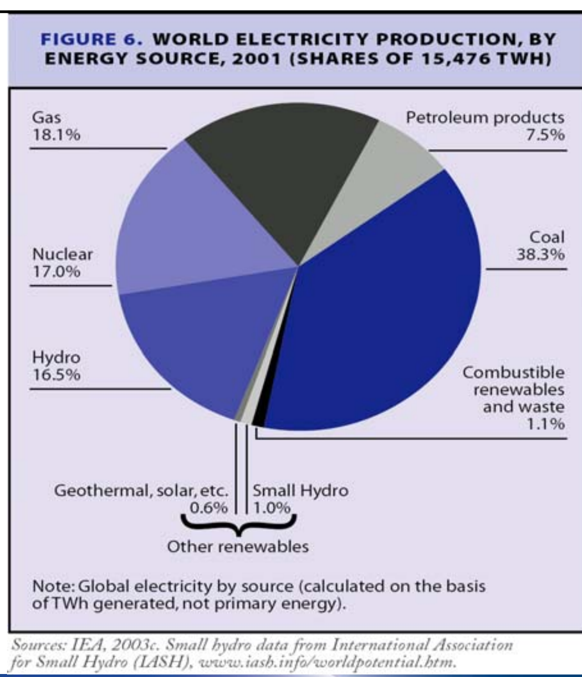
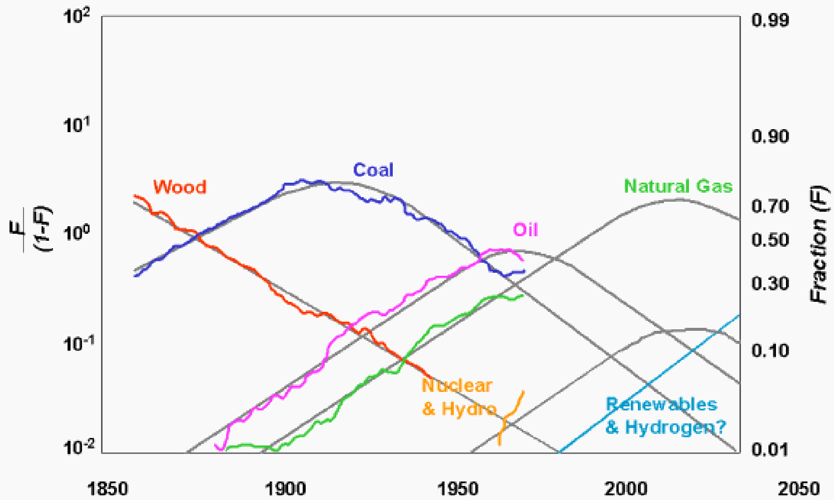


FIGURE 6. WORLD ELECTRICITY PRODUCTION, BY ENERGY SOURCE, 2001 (SHARES OF 15,476 TWH)
Gas 18.1%
Petroleum products 7.5%
Nuclear 17.0%
Coal 38.3%
Hydro 16.5%
Combustible renewables and waste 1.1%
Geothermal, solar, etc. 0.6%
Small Hydro 1.0%
Other renewables
Note: Global electricity by source (calculated on the basis of TWh generated, not primary energy).
Sources: IEA, 2003c. Small hydro data from International Association for Small Hydro (IASH), www.iash.info/worldpotential.htm.

Global Primary Energy Substitution



Source: IIASA, Nakicenovic

EU-Politics, regulations

•RES increase from 6% (1997) to 12% (2010)

RES-E incr. from 14% (1997) to 22% (2010)

Energy Performance Certificate in Buildings (Savings, Space Heat., DH, reduce FF)

Solid Biofuel Standardisation – CEN TC-335

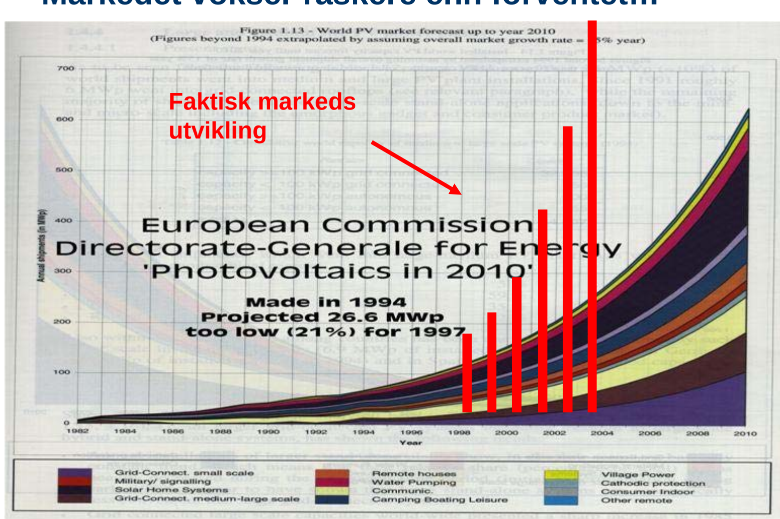
Biofuels Directive to replace gasoline and diesel by 2% in 2005, 5.75% in 2010 and 20% in 2020

Bidrag fra fornybar energi

	2001	2010	2020	2030	2040
World Primary Energy Consumption (IIASA)	10038.3	10549	11425	12352	13310
Biomass	1080	1313	1791	2483	3271
Large Hydro	222.7	266	309	341	358
Small Hydro	9.5	19	49	106	189
Wind	4.7	44	266	542	688
PV	0.2	2	24	221	784
Solar Thermal	4.1	15	66	244	480
Solar Thermal Electricity	0.1	0.4	3	16	68
Geothermal	43.2	86	186	333	493
Marine (tidal/wave/ocean)	0.05	0.1	0.4	3	20
TOTAL RES	1364.5	1745.5	2694.4	4289	6351
RES Contribution	13.6%	16.6%	23.6%	34.7%	47.7%

Solceller

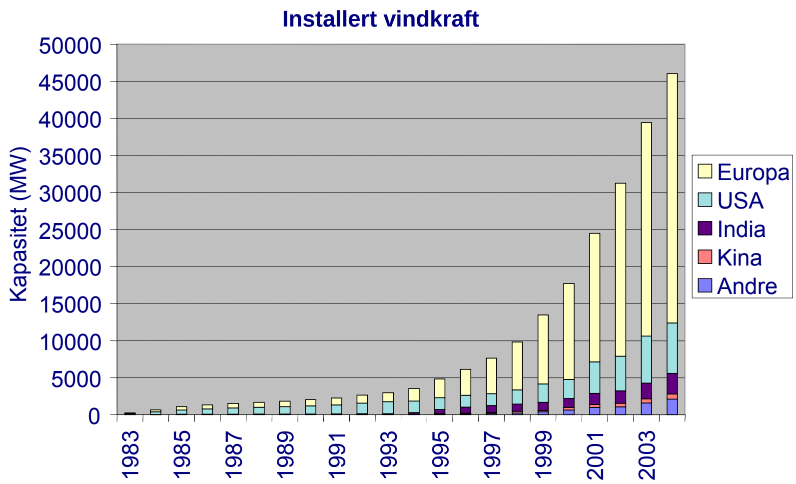
– Markedet vokser raskere enn forventet…

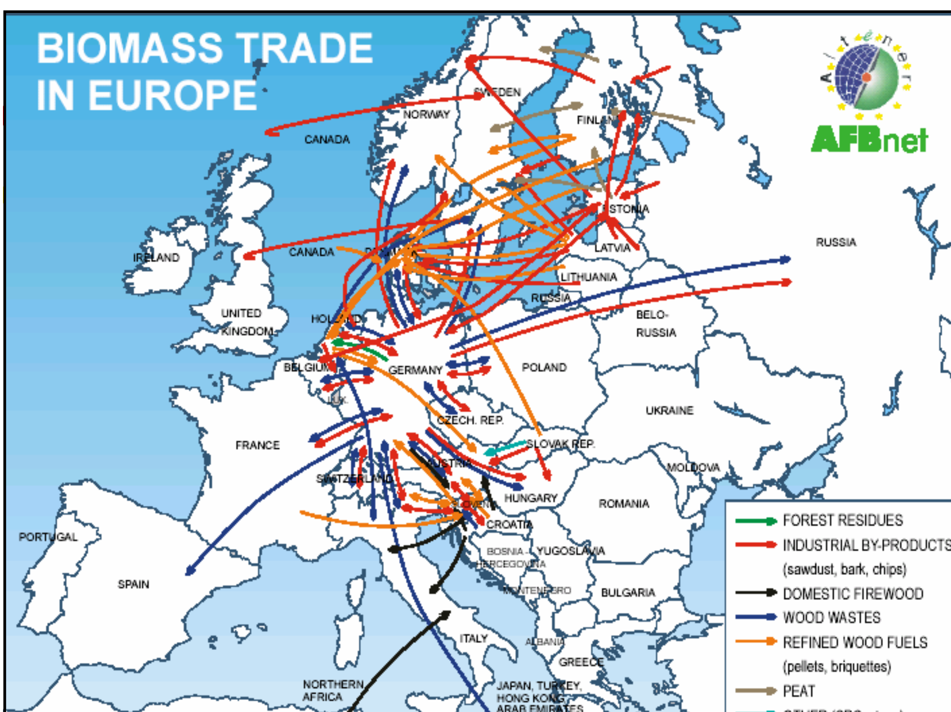


NTNU SINTEF

Vindkraft

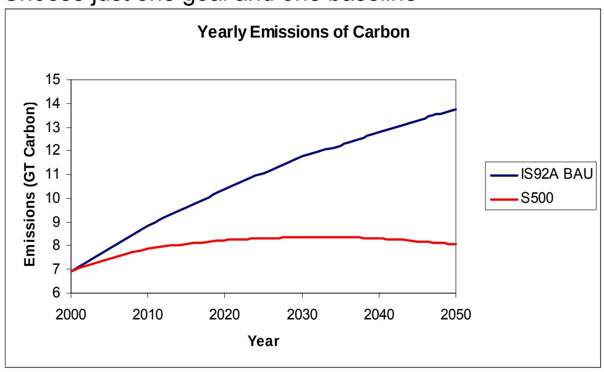
– den raskest voksende energiteknologien





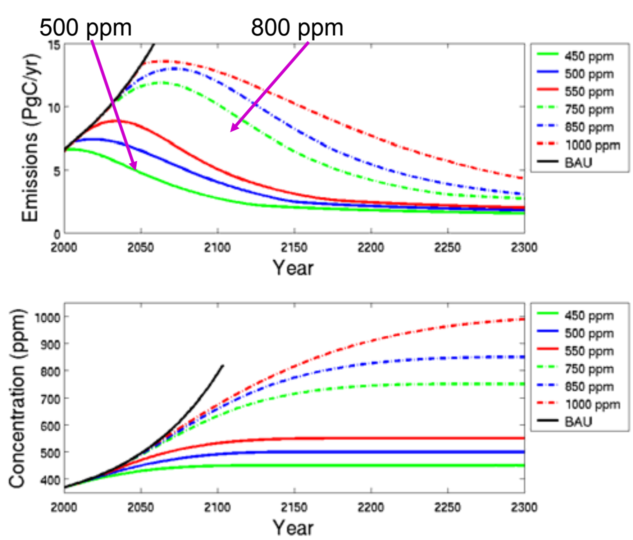
From Multiple Targets and Baselines to The Stabilization Wedge in Three Steps

Step One: Restrict attention to 50 years
Step Two: Choose just one goal and one baseline

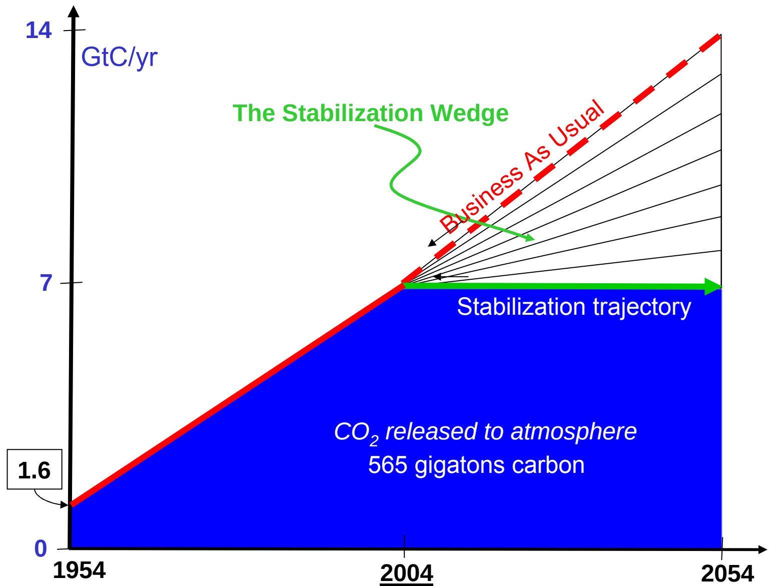


Step Three: Abstracting further, take the goal to be flat emissions and the baseline to be doubling linearly in 50 years.

Flat now: ≈ 500 ppm; BAU till 2054: ≈800 ppm



50 Years Back, 50 Years Forward



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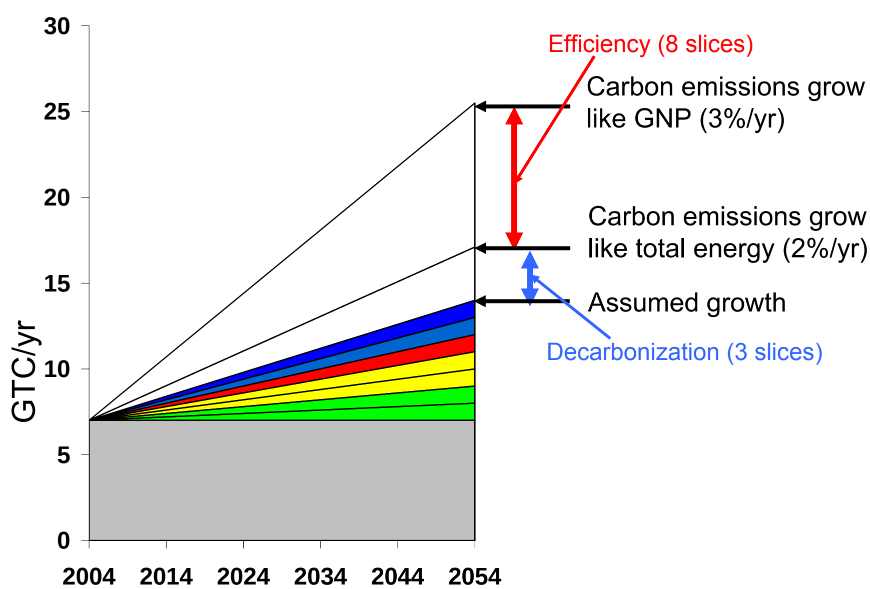
Efficiency and Decarbonization



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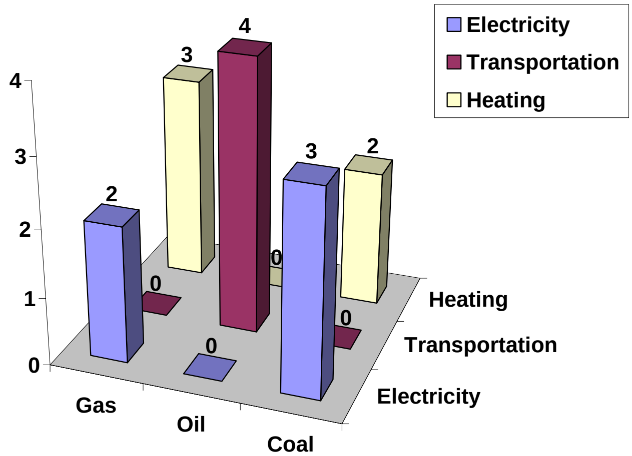
Fuel Sources for 14 GtC/y in 2054



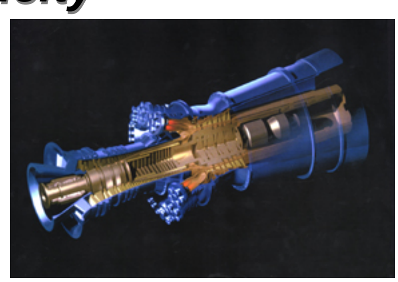
Coal to Gas for Electricity

Effort needed for 1 slice:

700 1-GW baseload coal plants (5400 TWh/y) emit 1 GtC/y.

Natural gas emits ~1/2 as much CO_2 as coal, per kWh.

So: by 2054, build 1400 GW baseload (10,800 TWh/y) fueled by gas, not coal.



Cross-section of the GE MS9001H Advanced Gas Turbine
Photo courtesy of DOE

Yr 2000 electricity:

Coal : 6000 TWh/y;
Natural gas: 2700 TWh/y.

Potential Pitfalls:

Natural gas geopolitics

Efficiency in transport

Effort needed for 1 slice:
2 billion gasoline and diesel cars (10,000 miles/car-yr) at 60 mpg instead of 30 mpg

500 million cars now.

Potential Pitfall:

Suburban sprawl

Photos courtesy of Ford, WMATA, Washington State Ridesharing Organization

Biofuels

Effort needed for 1 slice:

Annually, plant and sustain 4 million new hectares of high-yield (15 t/ha-yr) crops, back out gasoline and diesel

By 2050, have planted area equal to U.S. cropland (200 million hectares)

Photos courtesy of NREL

Potential Pitfalls:

Competing land use, biodiversity

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Wind Electricity

Prototype of 80 m tall Nordex 2,5 MW wind turbine located in Grevenbroich, Germany
(Danish Wind Industry Association)

Effort needed for 1 slice:

Install 40,000 1 MW_{peak} windmills each year

30,000 MW_{peak} in place today, +30%/yr

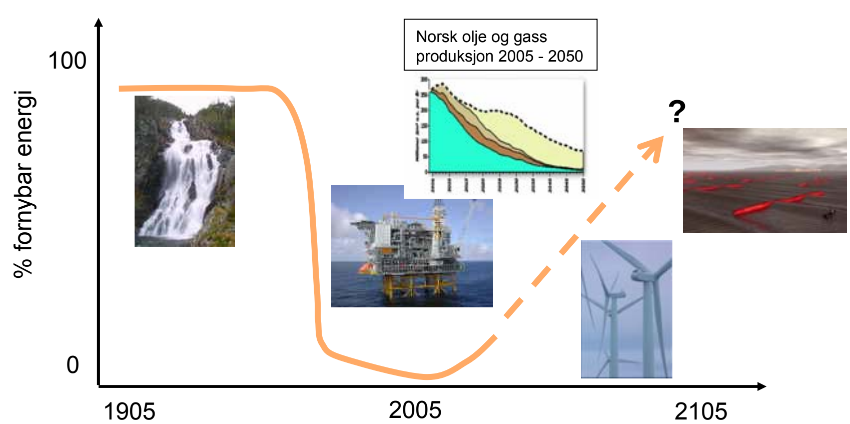
60 million hectares (7% of U.S.): multiple use

Potential Pitfalls:
NIMBY
Changes in regional climate?

NTNU IFE SINTEF

Fornybar Energi

– Vår primære energikilde i fortiden – også i fremtiden?



HYDRO

Senter for Fornybar Energi (SFFE)

- Senteret er **virtuelt**, **koordinerende** og **rådgivende** organ for undervisnings- og forskningsmiljøene ved NTNU, SINTEF og IFE innen fornybar energi

- SFFEs Styre kommer fra NTNU, SINTEF, IFE og industri

- Senteret rapporterer til NTNUs, SINTEFs og IFEs ledelse

SFFEs formål

Øke kvalitet, effektivitet og omfang av undervisning, forskning, utvikling og innovasjon innen fornybar energi i Norge

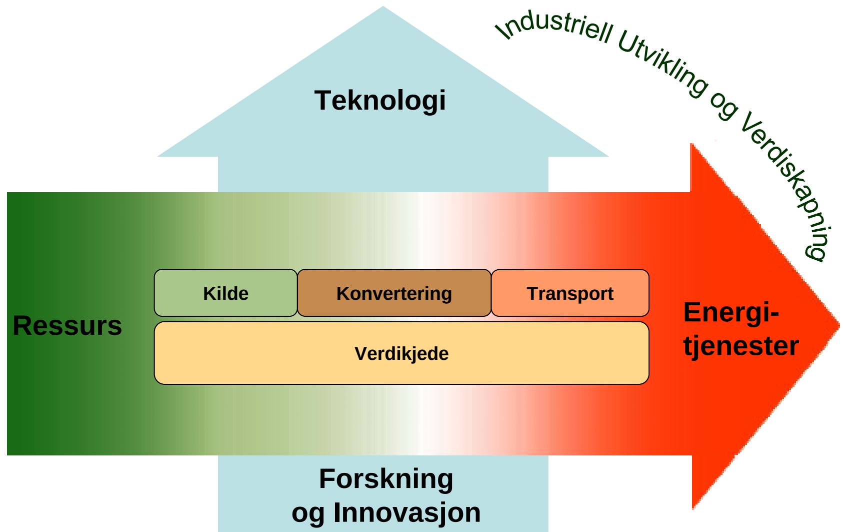
– ved å samordne eksisterende aktiviteter og etablere nye aktiviteter ved NTNU, SINTEF og IFE knyttet til kunnskapsutvikling, implementering og utnyttelse av fornybare energikilder og energiteknologier

Visjon:

”Fornybar energi for et bedre miljø og økt verdiskaping”

Fornybar Energi

- Fra forskning og utvikling til innovasjon og nyskaping



Aktiviteter - prosjekter

- SEEWEC
  - Sustainable Economically Efficient Wave Energy Converter
- FOXY
  - Development of solar-grade silicon feedstock for X wafers and cells, by purification and crystallisation
- WAVESSG
  - Full-scale demonstration of robust and high-efficiency wave energy converter
- EMINENT
  - Early Market Introduction of New Energy Technologies by the OPET Network in Liaison with Science and Technology
- DGFACTS
  - Improvement of the Quality of Supply in Distributed Generation networks through the integrated application of power electronic techniques
- WILMAR
  - Wind Power Integration in Liberalized Electricity Markets
- RELIANCE (TSO-Research)
- Nextgen BIOWASTE
  - Innovative demonstrations for the next generation of biomass and waste combustion plants for renewable electricity production

- 2 SFI søknader 2005 Vind og Solceller
- 2 KMB start opp 2006

- *Tysk-Norsk Energiseminar Febr. 2006 - EU-Seminar 17./18. Mars 2006 -> 7 FP*

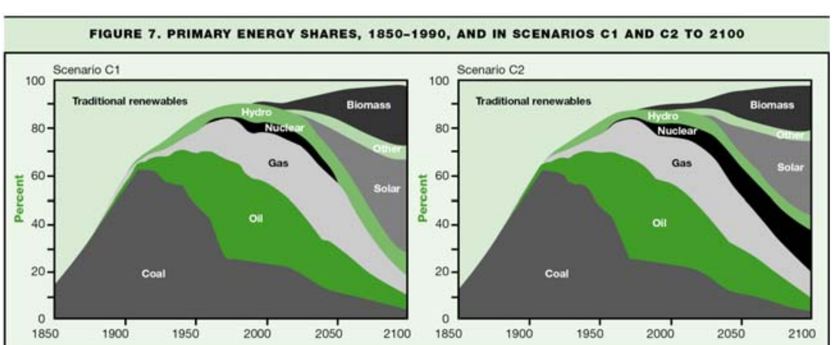
- *KUF på Gløshaugen i DAG!*

Tillegg

Energy scenarios

Ecologically driven energy scenarios

(C1: new renewables, C2: new renewables and new nuclear)



Source: Nakićenović, Grübler, and McDonald, 1998.

TABLE 7. STATUS OF RENEWABLE ENERGY TECHNOLOGIES, END 2001

Technology	Increase in energy production, 1997–2001 (percent per year)	Operating capacity, end 2001	Capacity factor (percent)	Energy production, 2001	Turnkey investment costs (2001 US$ per kilowatt)	Current energy cost	Potential future energy cost
Biomass energy							
Electricity	~ 2.5	~ 40 GWe	25–80	~ 170 TWh (e)	500–6000	3–12 ¢/kWh	4–10 ¢/kWh
Heat[a]	~ 2	~ 210 GWth	25–80	~ 730 TWh (th)	170–1000	1–6 ¢/kWh	1–5 ¢/kWh
Ethanol	~ 2	~ 18 bln litres		~ 450 PJ		(8–25 $/GJ	(6–10 $/GJ
Bio-diesel	~ 1	~ 1.2 bln litres		~ 45 PJ		15-25 $/GJ)	10-15 $/GJ)
Wind electricity	~ 30	23 GWe	20–40	43 TWh (e)	850–1700	4–8 ¢/kWh	3–10 ¢/kWh
Solar photovoltaic electricity	~ 30	1.1 GWe	6–20	1 TWh (e)	5000–18000	25–160 ¢/kWh	5 or 6–25 ¢/kWh
Solar thermal electricity	~ 2	0.4 GWe	20 – 35	0.9 TWh (e)	2500–6000	12–34 ¢/kWh	4–20 ¢/kWh
Low-temperature solar heat	~ 10	57 GWth (95 million m^2)	8–20	57 TWh (th)	300–1700	2–25 ¢/kWh	2–10 ¢/kWh
Hydro energy							
Large	~ 2	690 GWe	35–60	2600 TWh (e)	1000–3500	2–10 ¢/kWh	2–10 ¢/kWh
Small	~ 3	25 GWe	20–90	100 TWh (e)	700–8000	2–12 ¢/kWh	2–10 ¢/kWh
Geothermal energy							
Electricity	~ 3	8 GWe	45–90	53 TWh (e)	800–3000	2–10 ¢/kWh	1 or 2–8 ¢/kWh
Heat	~ 10	11 GWth	20–70	55 TWh (th)	200–2000	0.5–5 ¢/kWh	0.5–5 ¢/kWh
Marine energy							
Tidal	0	0.3 GWe	20–30	0.6 TWh (e)	1700–2500	8–15 ¢/kWh	8–15 ¢/kWh
Wave	–	exp. phase	20–35	0	2000–5000	10–30 ¢/kWh	5–10 ¢/kWh
Tidal stream/Current	–	exp. phase	25–40	0	2000–5000	10–25 ¢/kWh	4–10 ¢/kWh
OTEC	–	exp. phase	70–80	0	8000–20000	15–40 ¢/kWh	7–20 ¢/kWh

a. Heat embodied in steam (or hot water in district heating), often produced by combined heat and power systems using forest residues, black liquor, or bagasse.

Source: W.C. Turkenburg, Utrecht University, Netherlands (March 2003), with contributions from André Faaij (Netherlands), Peter Fraenkel (United Kingdom), Ingvar Fridleifsson (Iceland), Carlo Hamelinck (Netherlands), Geyer (Germany), David Mills (Australia), Jose Roberto Moreira (Brazil), Wim Sinke (Netherlands), Bart van der Ree (Netherlands).