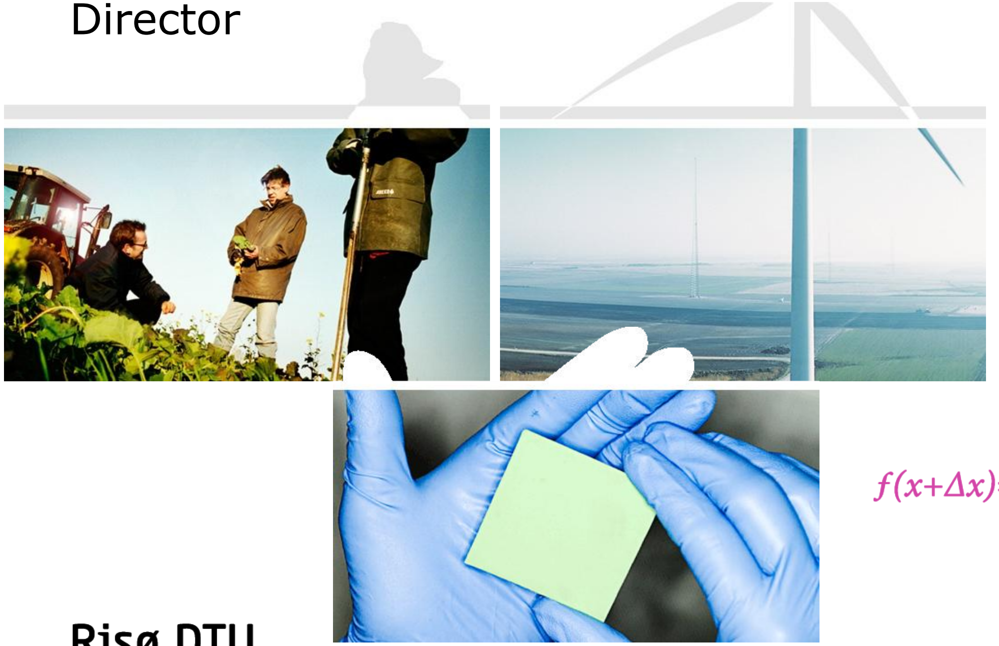
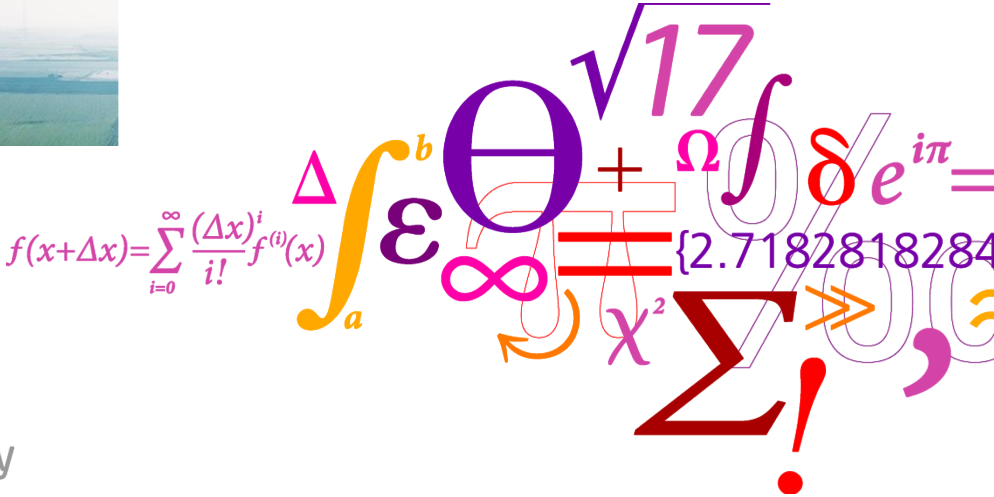
Sustainable energy generation, storage and distribution

Scope, Challenges and Limitations of New Technologies

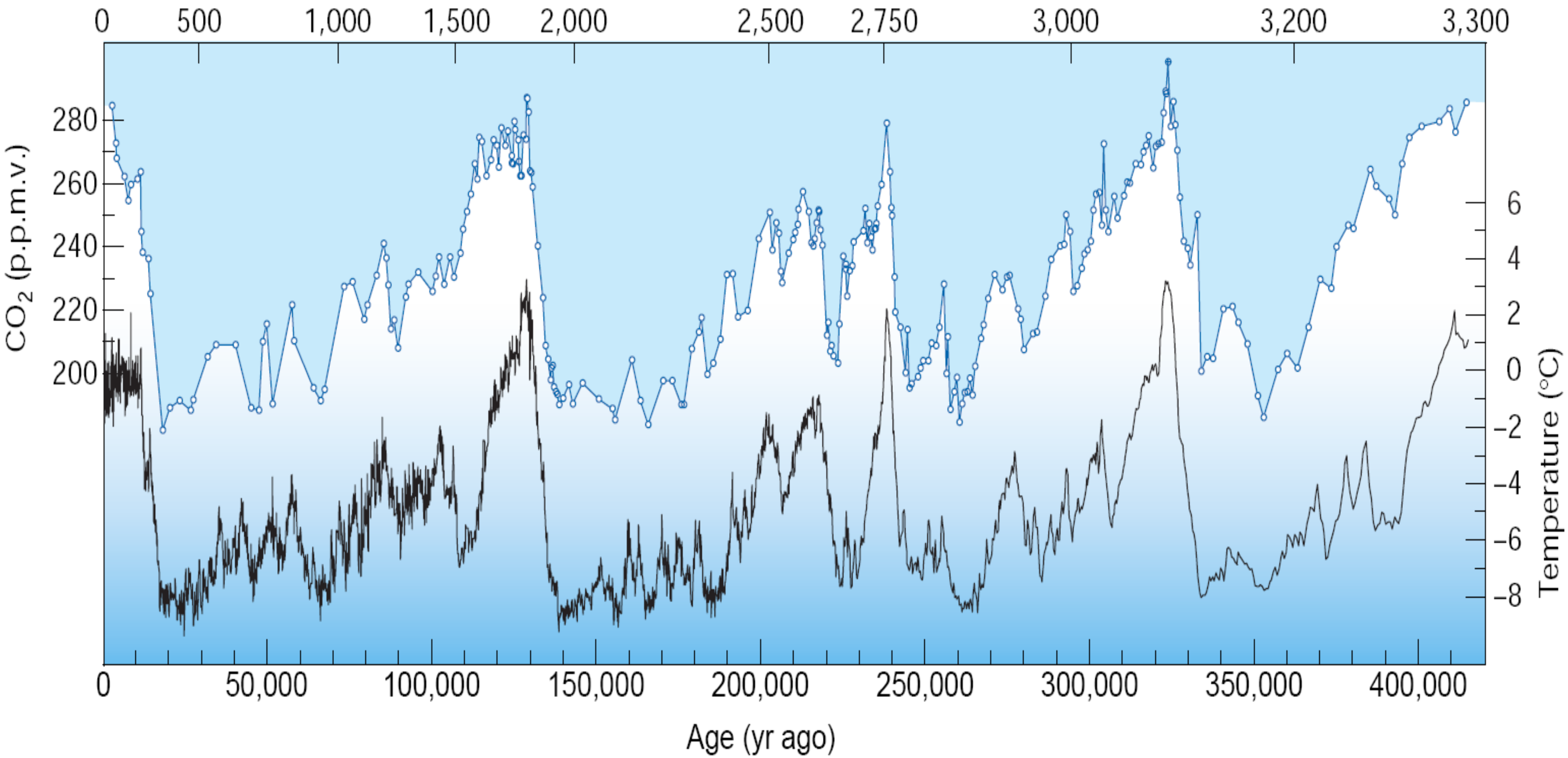
Henrik Bindslev
Director





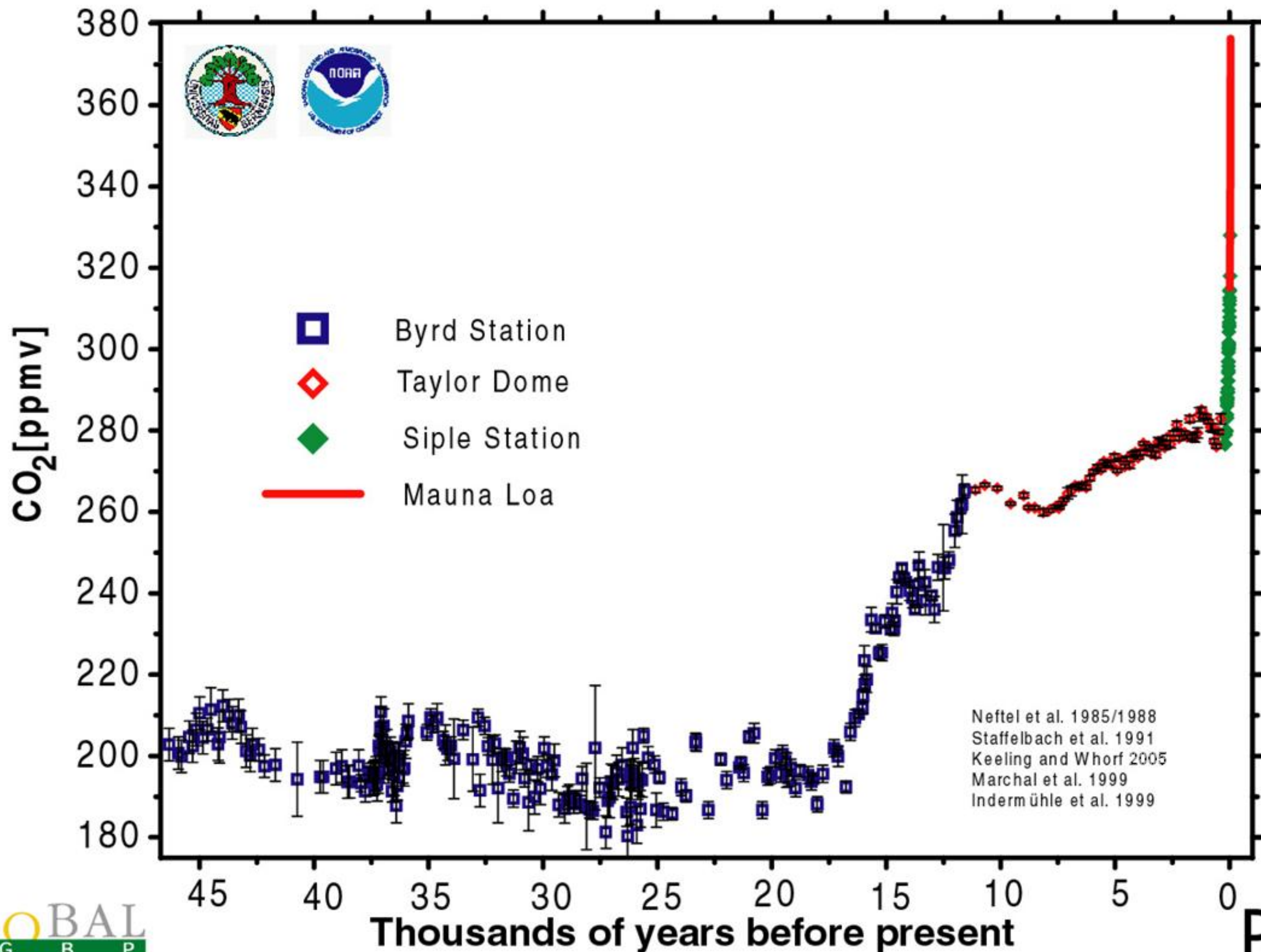
Risø DTU
National Laboratory for Sustainable Energy

CO_2 concentration and temperature the last 400,000 years



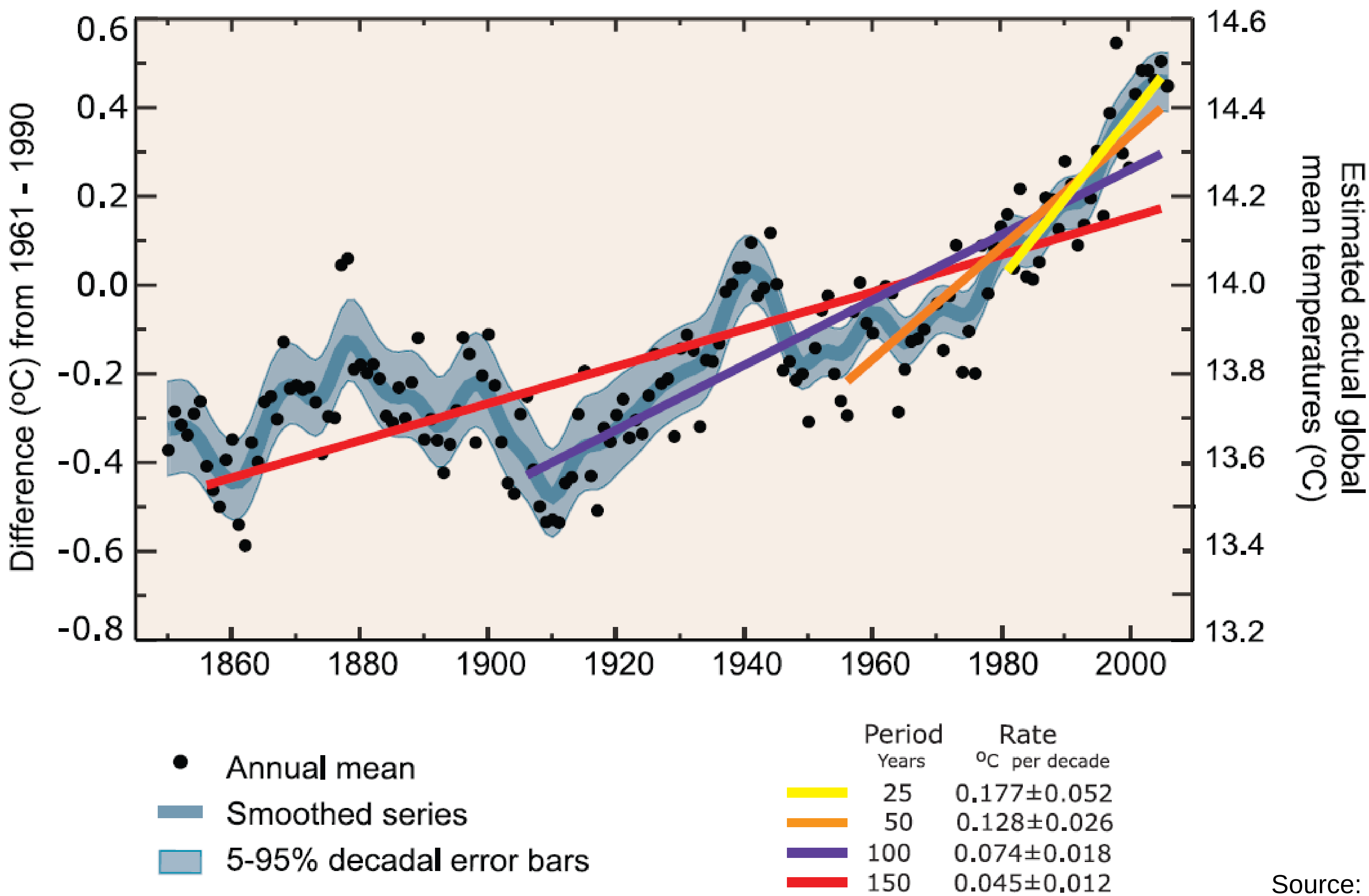
Source: Klump, Nature 419, 2002

CO_2 concentration the last 45,000 years



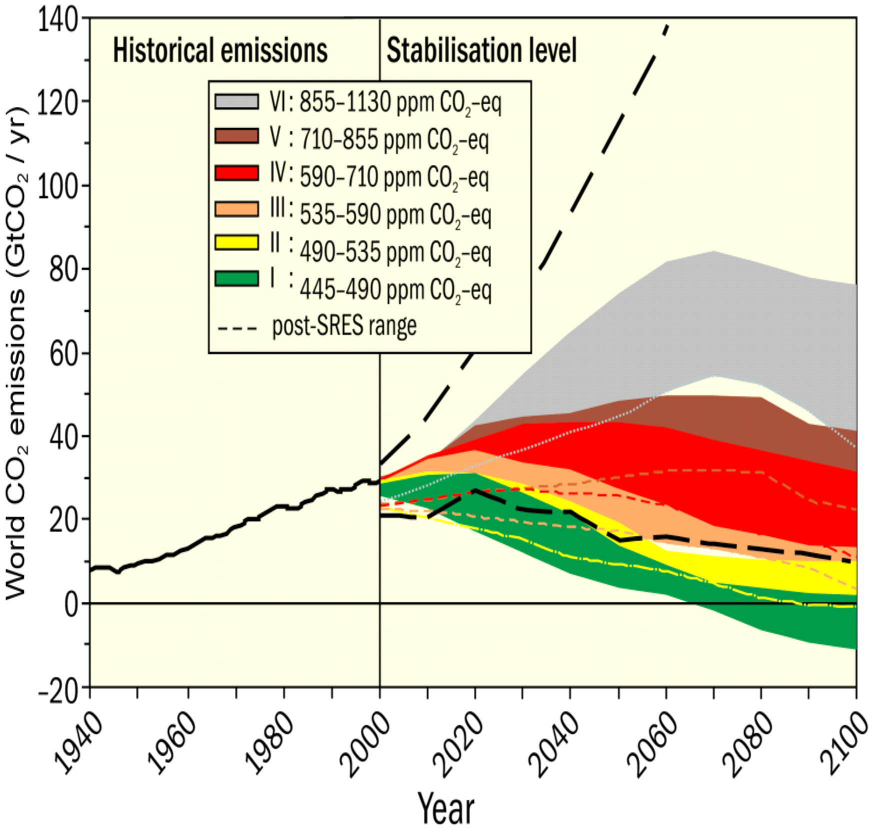
Adapted from: http://www.climate.unibe.ch/gallery_co2.html

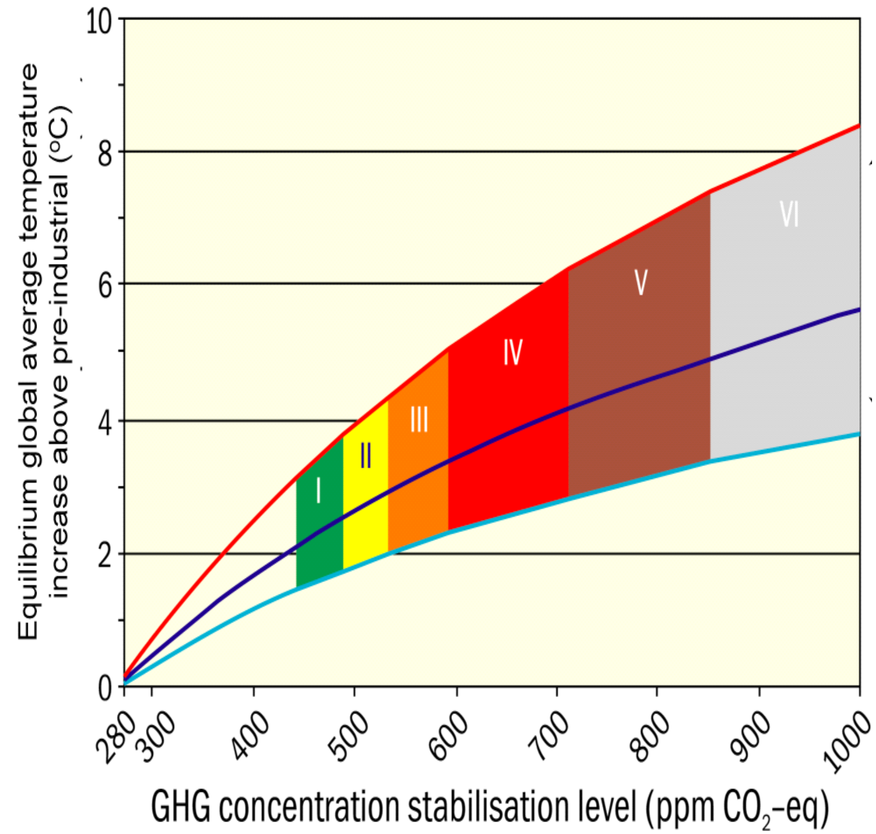
Rising temperature



Source: IPCC

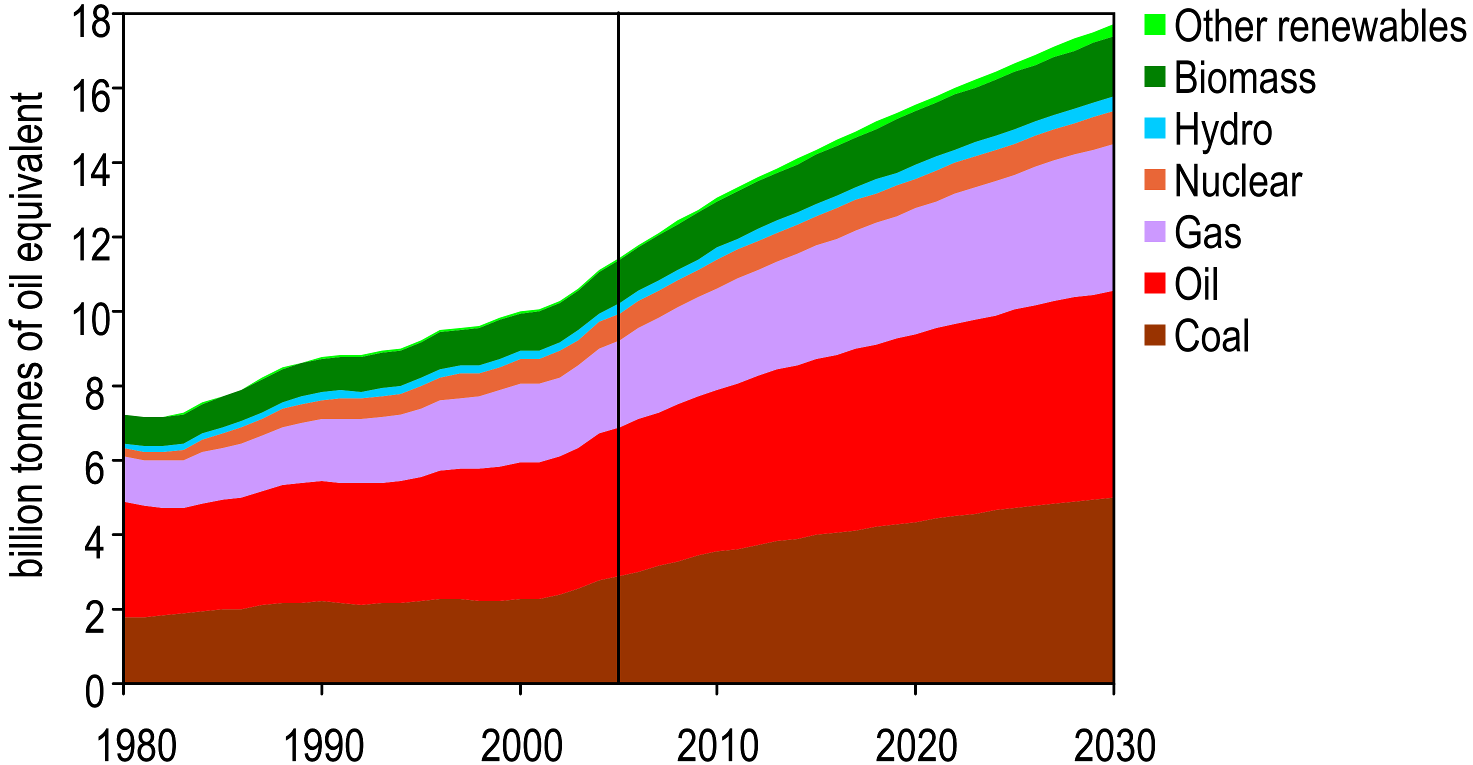
CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels





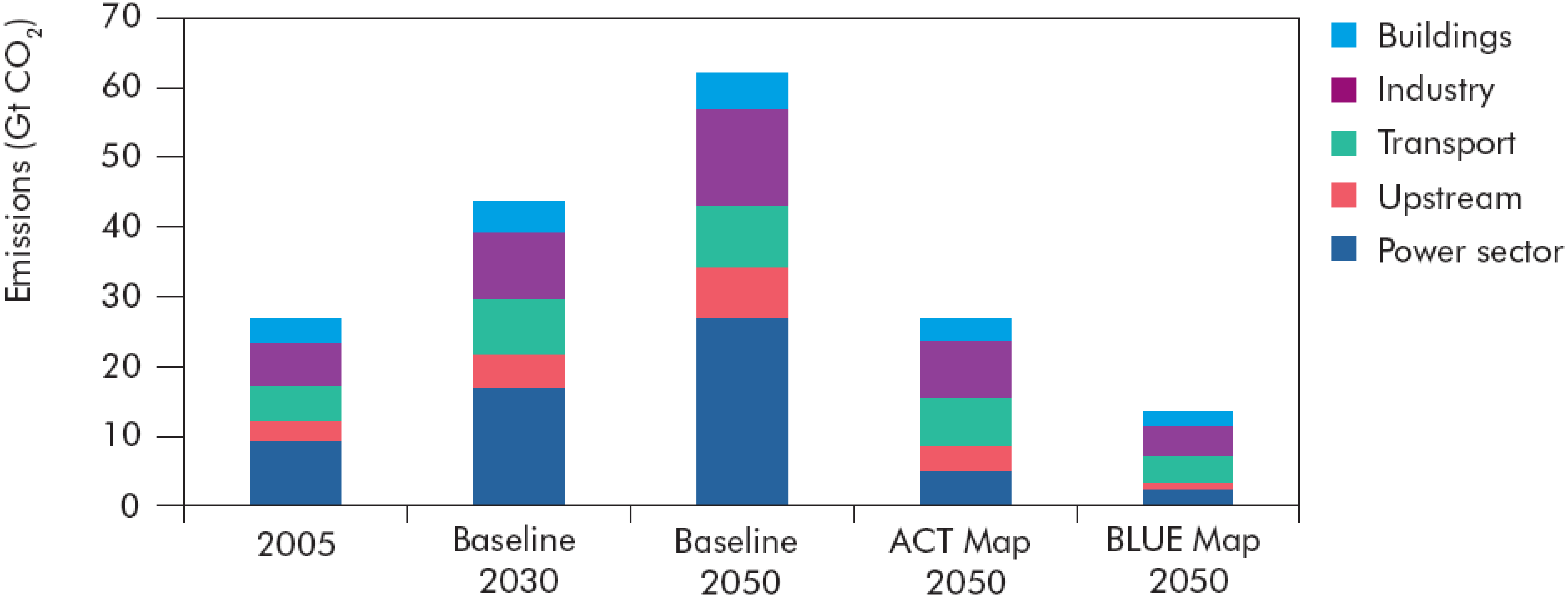
Source: IPCC

World energy consumption, historical and IEA WEO reference scenario



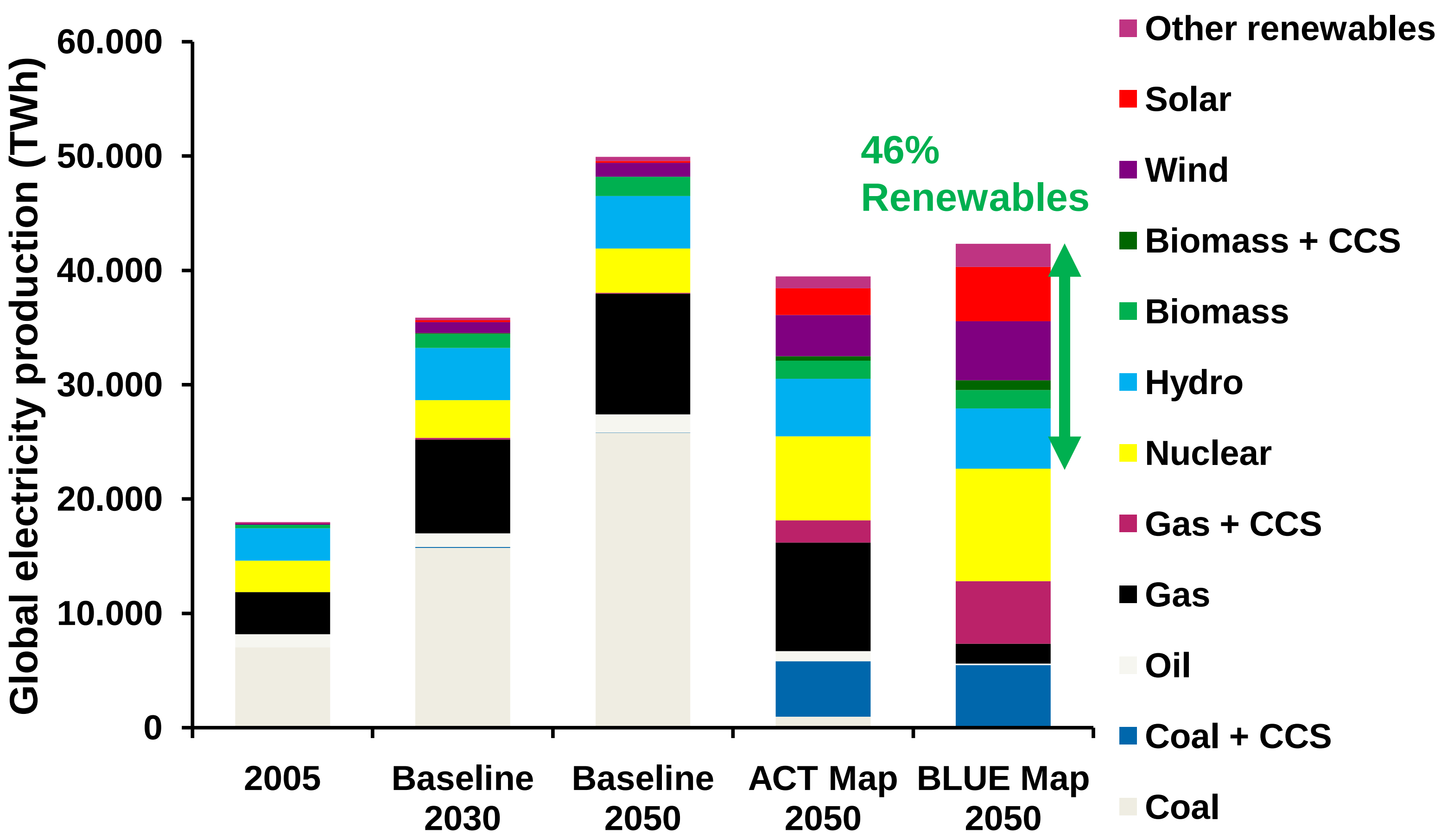
Source: IEA WEO 2007

International Energy Agency, Energy Technology Perspectives 2008, CO_2 emission projections

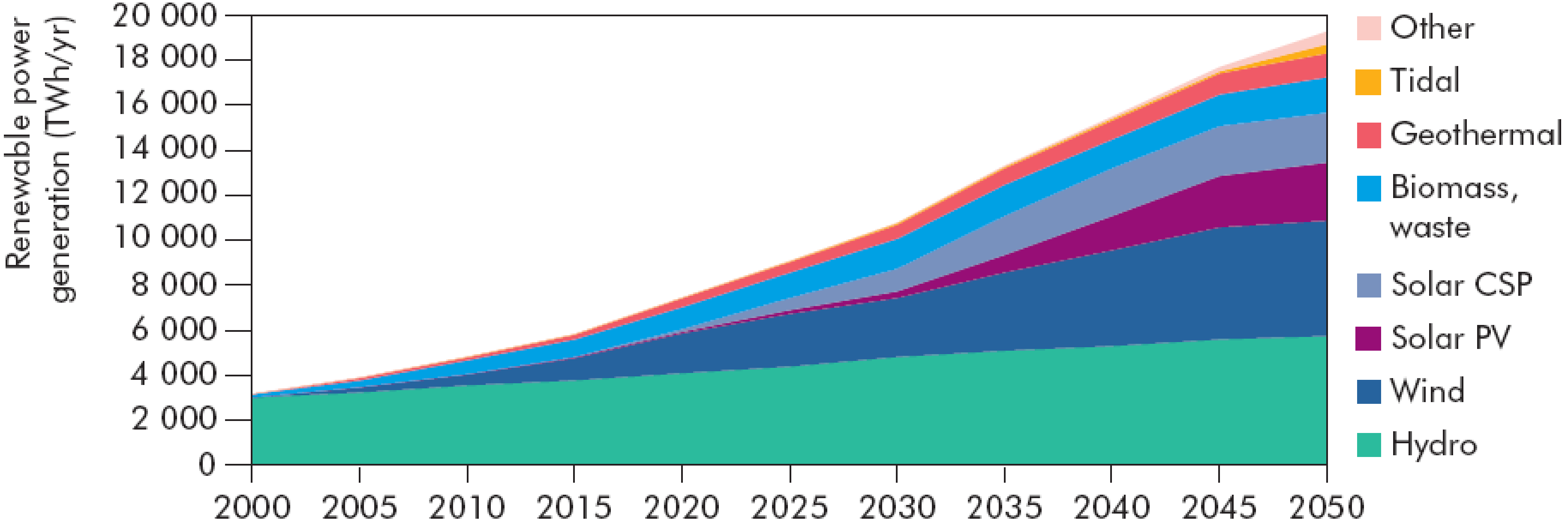


Baseline: current policies
ACT: emissions in 2050 equal today's
BLUE: emissions in 2050 half of today's

Electricity Production



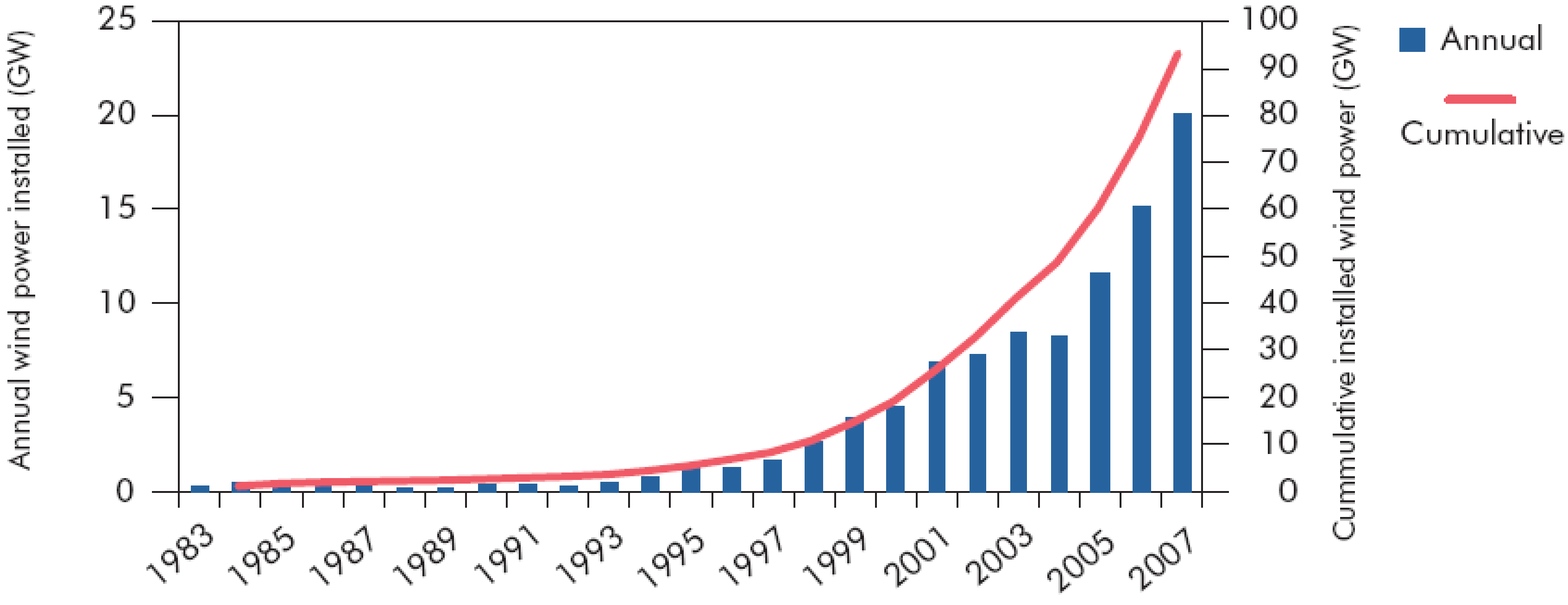
Blue: Renewable Power evolution




Wind
Middelgrunden 20X2 MW

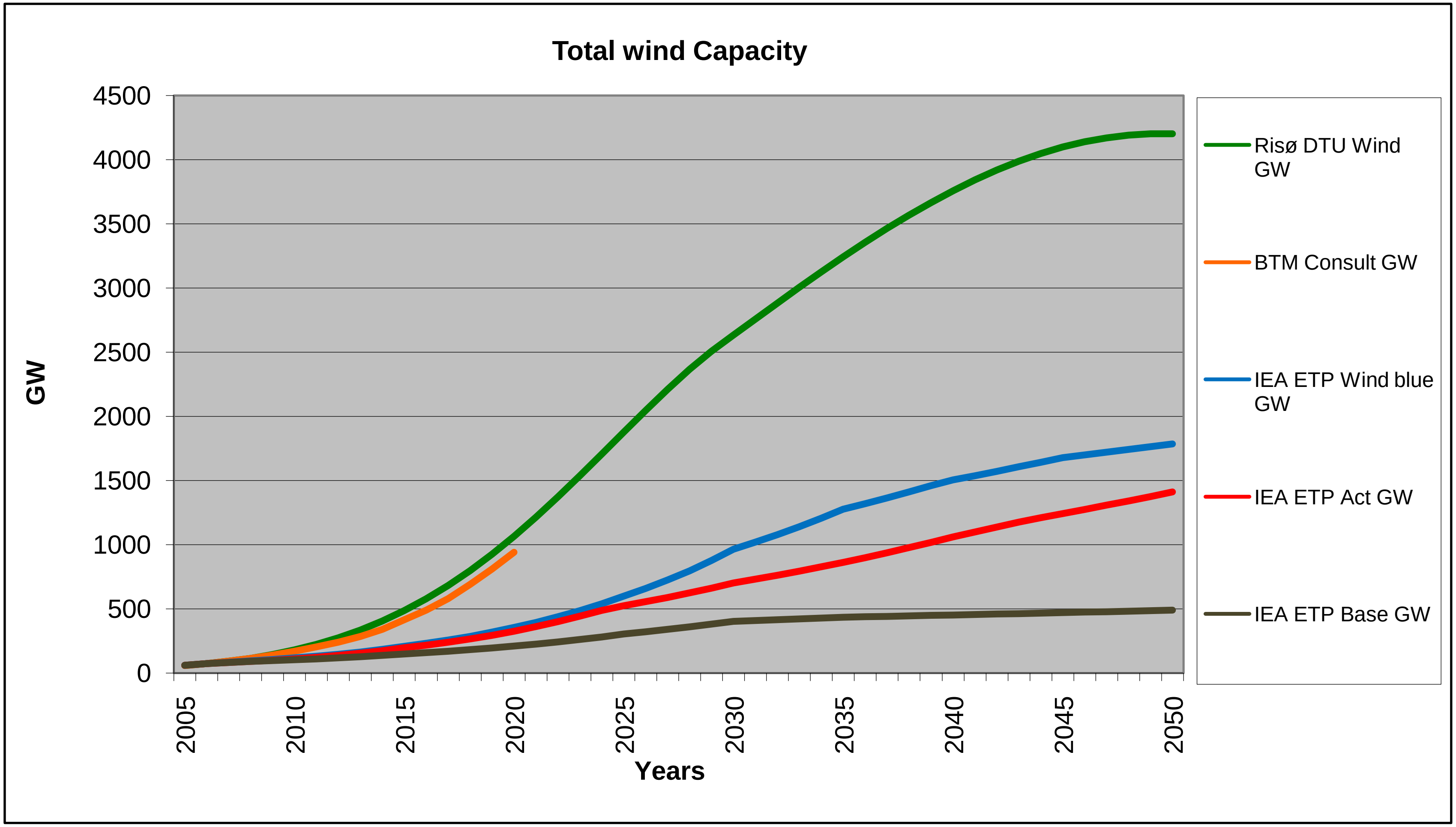
Installed wind capacity

- Capacity doubles every 3-4 years
- 100 GW installed in world
- 1 GW off shore
- 1 % of world electricity
- 20 % in Denmark



Sources: BTM Consult, 2008; Global Wind Energy Council, 2008.

Wind: Scope



Total wind Capacity
GW
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Years
Risø DTU Wind GW
BTM Consult GW
IEA ETP Wind blue GW
IEA ETP Act GW
IEA ETP Base GW


IEA BLUE: 4 per hour
Risø DTU: 10 per hour
Nysted
72 x 2.3 MW
- on a nice day

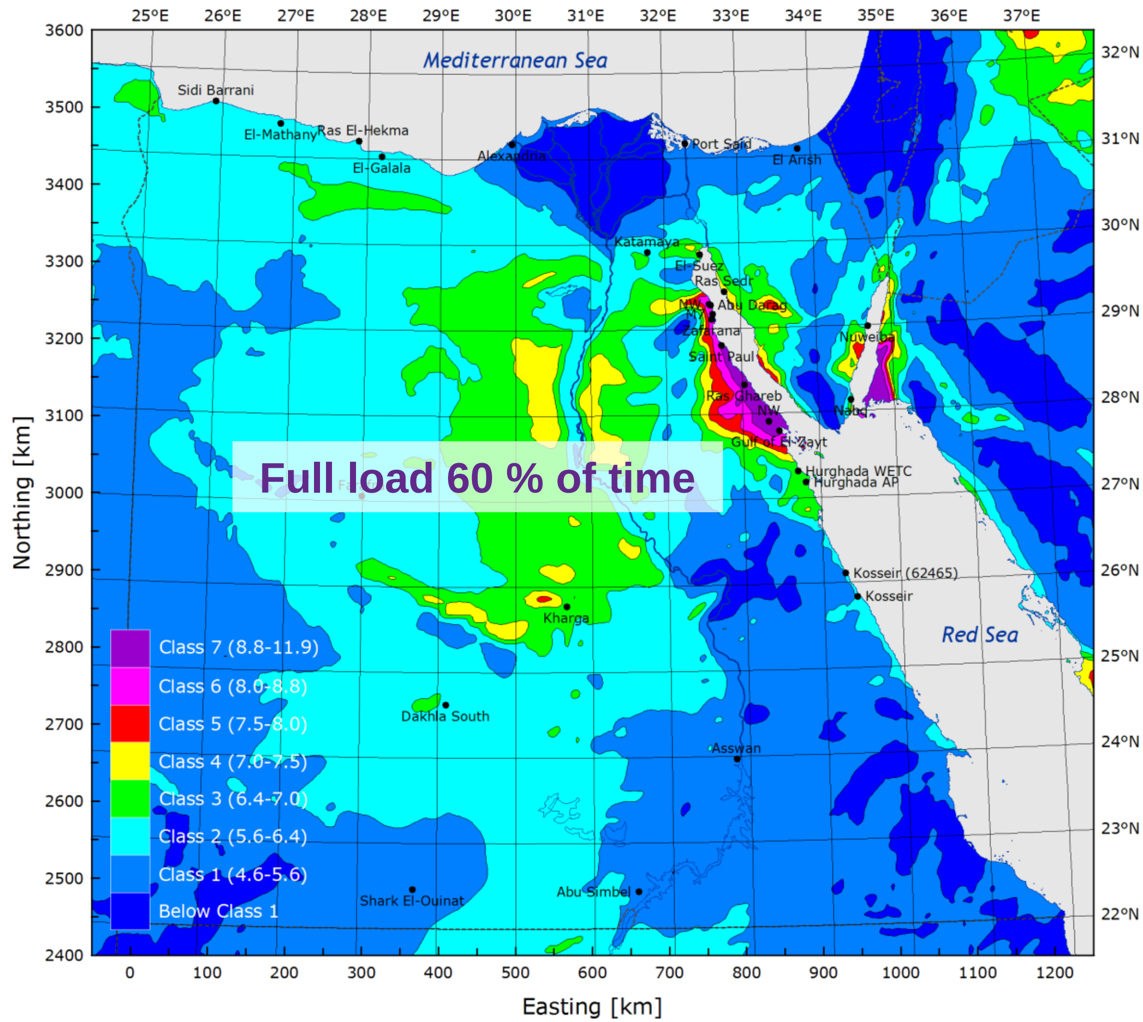
Wind farm area to cover World electricity consumption 2008

World electricity consumption, P_{We} = *2 TW*
Wind power density ≈ 2 GW/km^2
Area of wind farm to cover P_{We} = (1000 km)^2

Strategic Research Agenda
Wind Conditions

- Siting
- design
- forecasting

- **Resources**
- Extreme wind
- Vertical profile
- Turbulence
- Complex terrain
- Wakes
- Offshore



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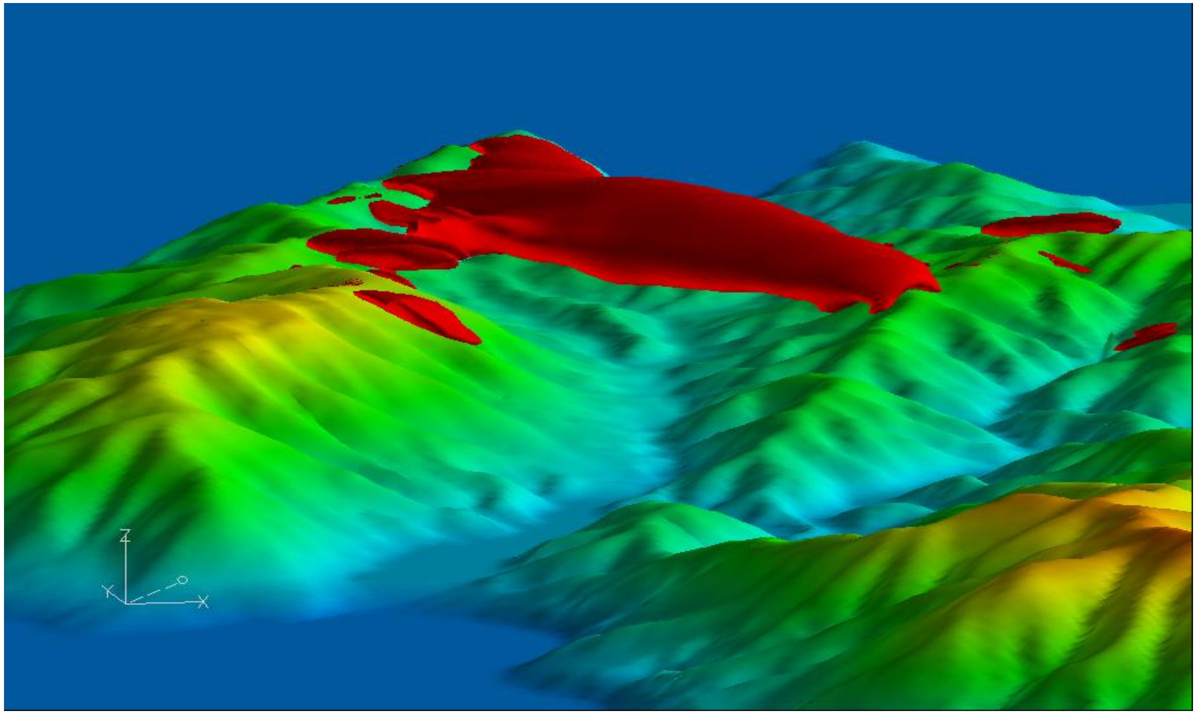

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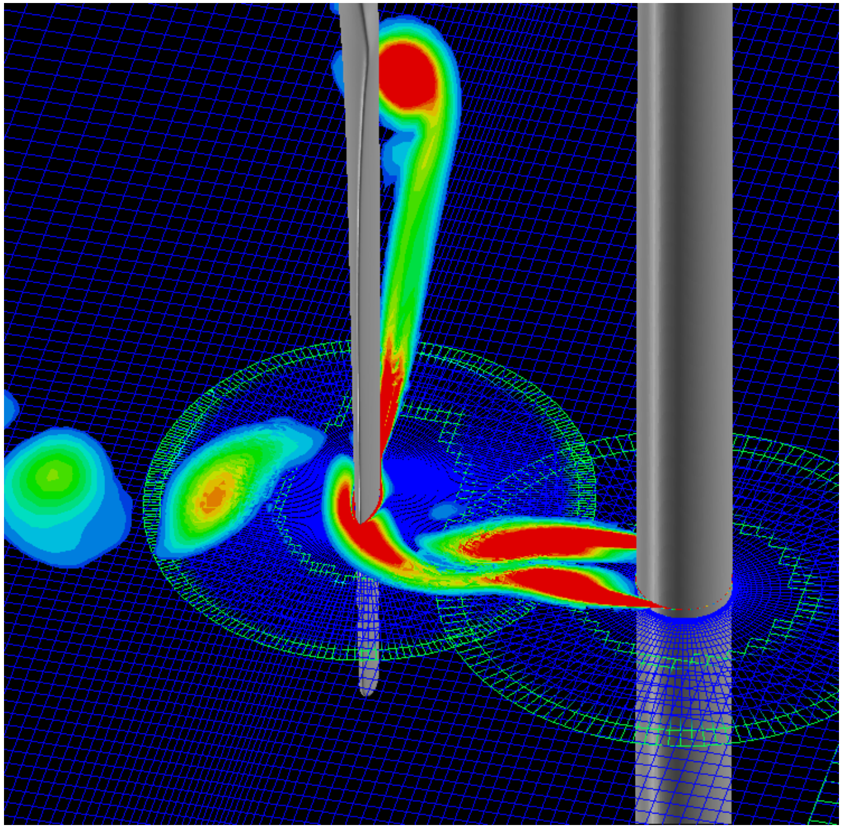
Strategic Research Agenda
Turbine design

- **Aerodynamics**
- **Aeroelastics**
- Stability
- Control
- Materials
- Structures
- Electrical
- Hydrodynamics



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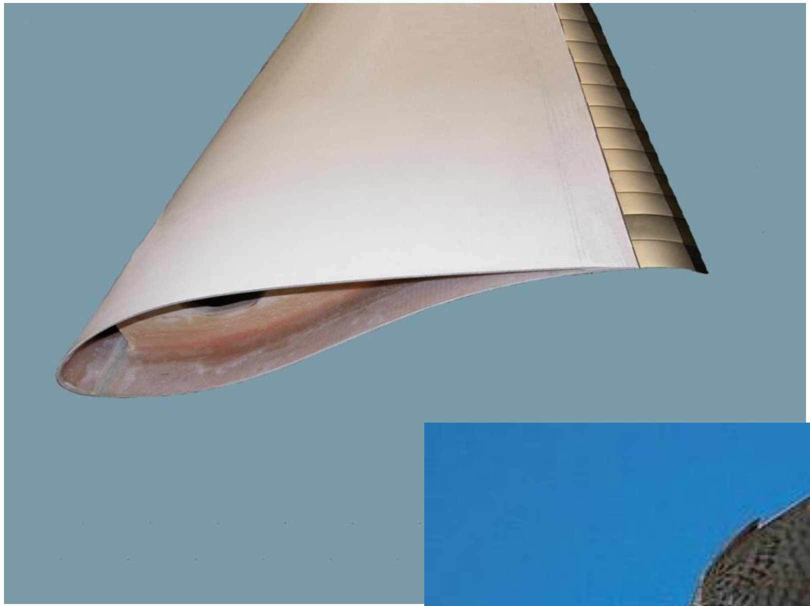

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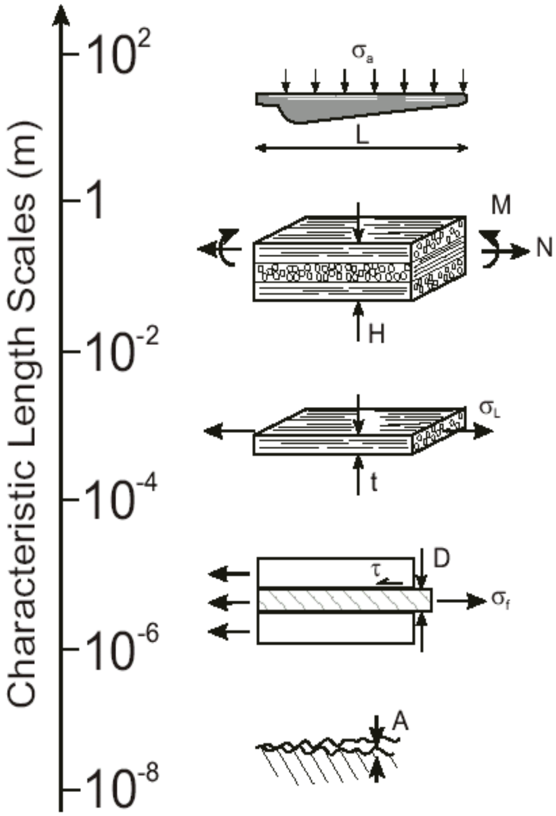

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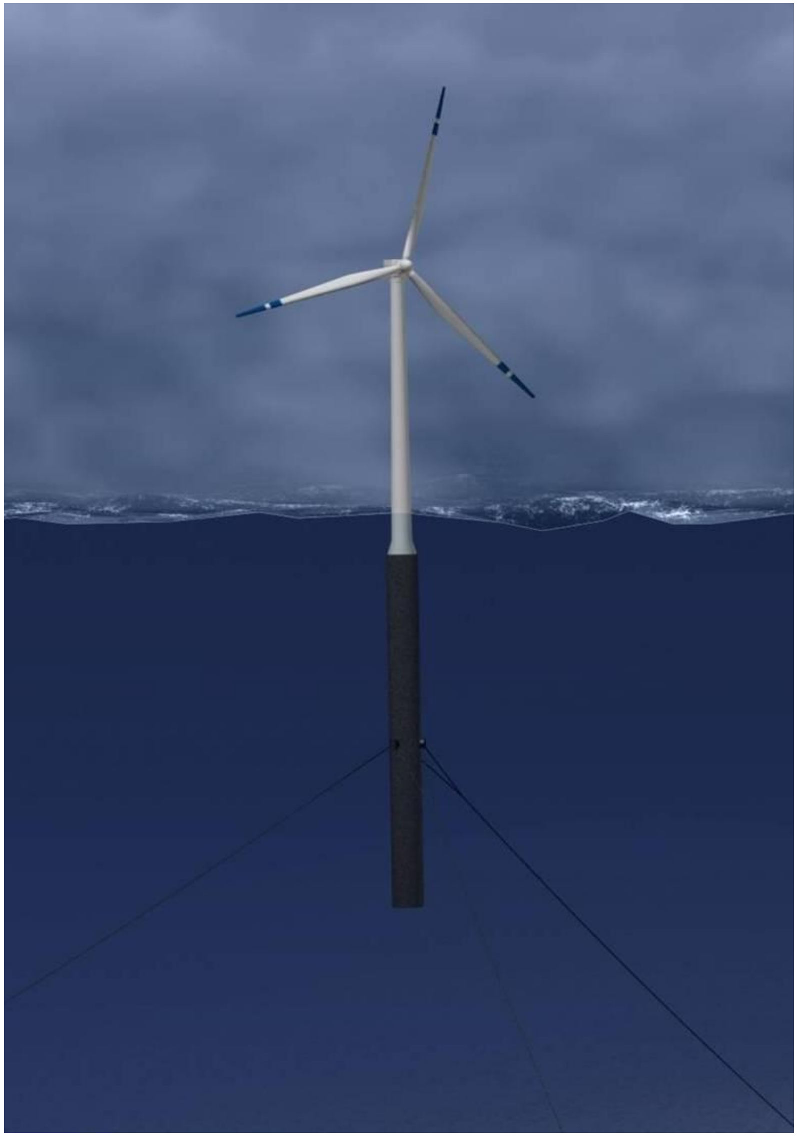
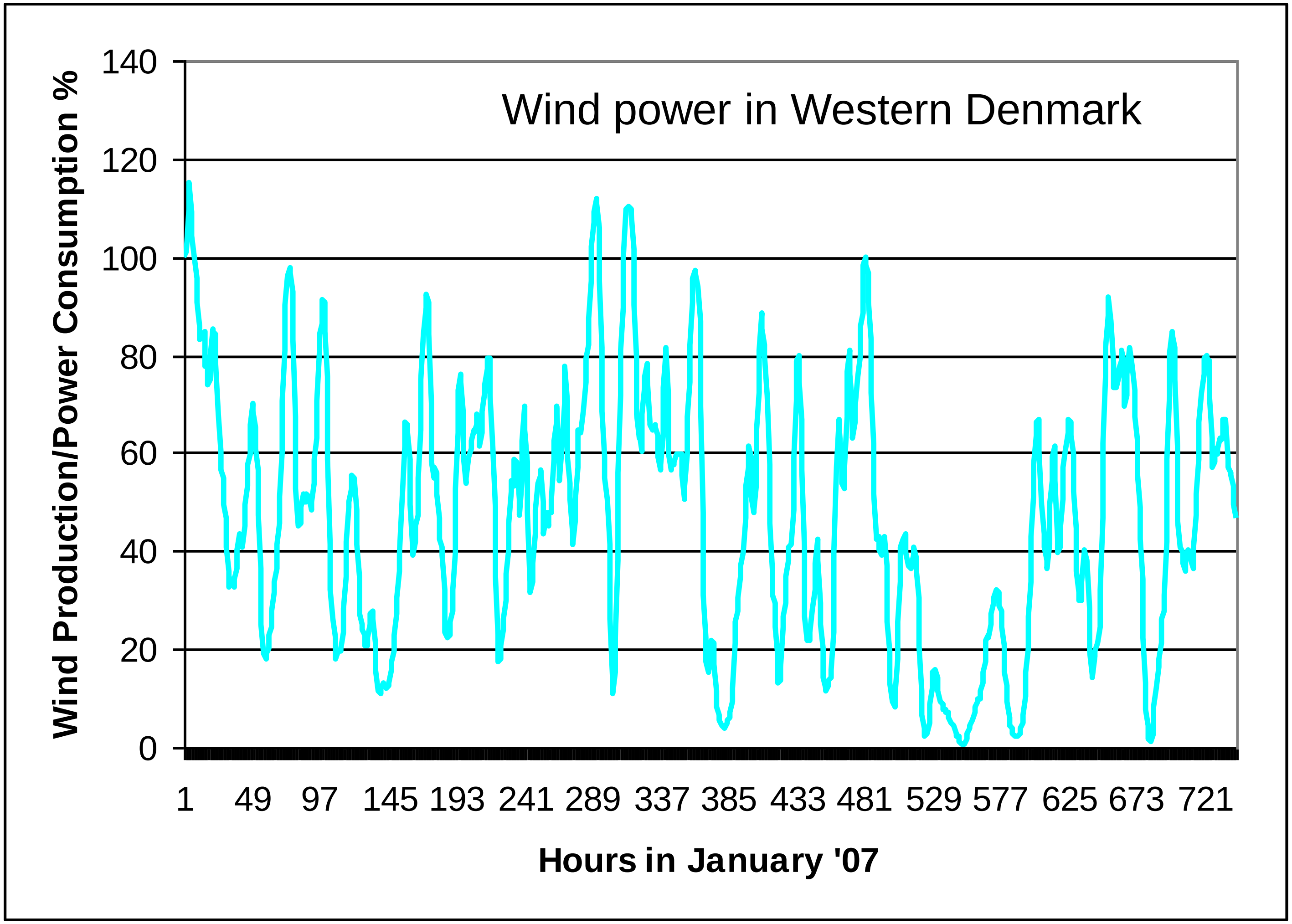


Challenge
Integration



Low correlation in wind power over large distances

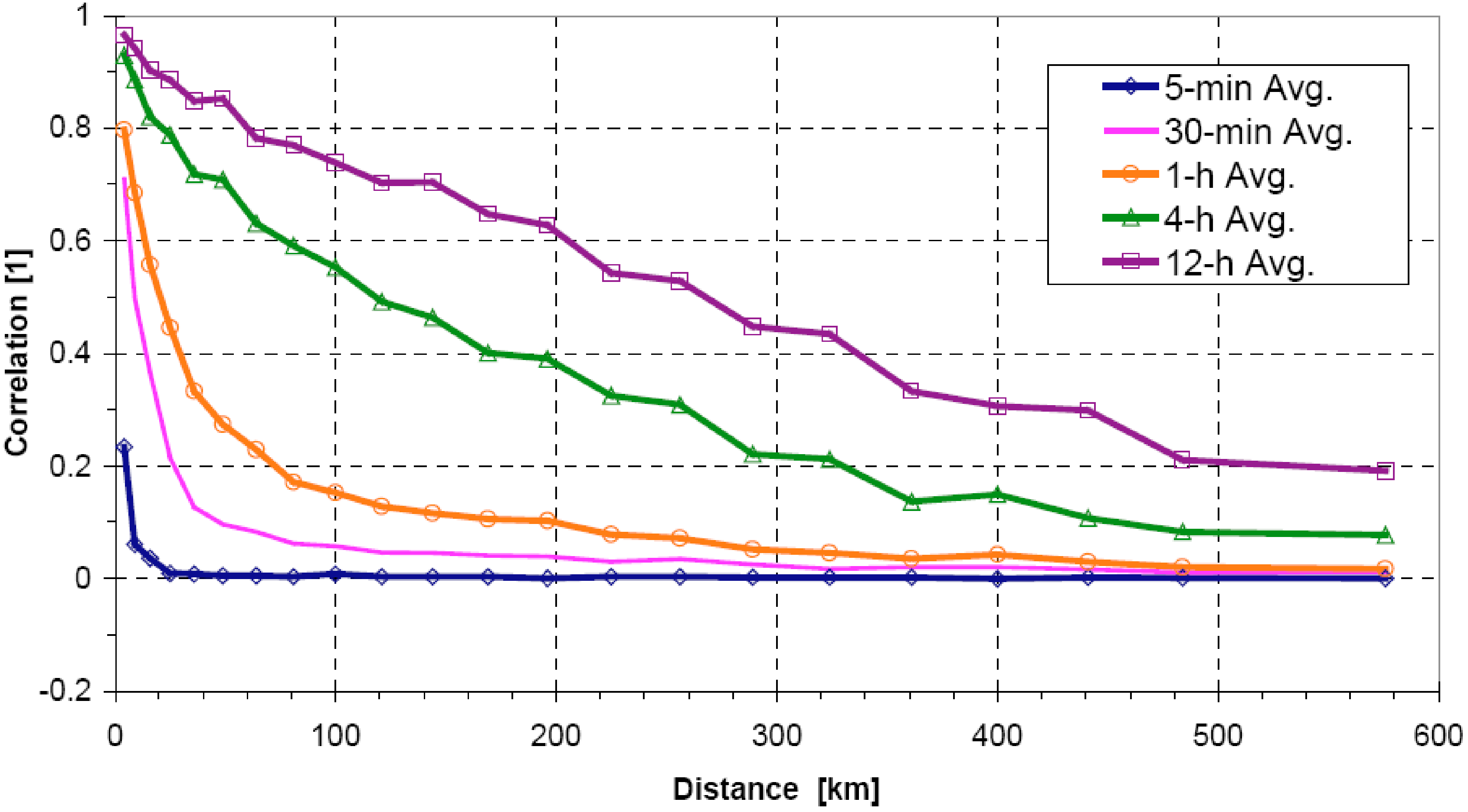
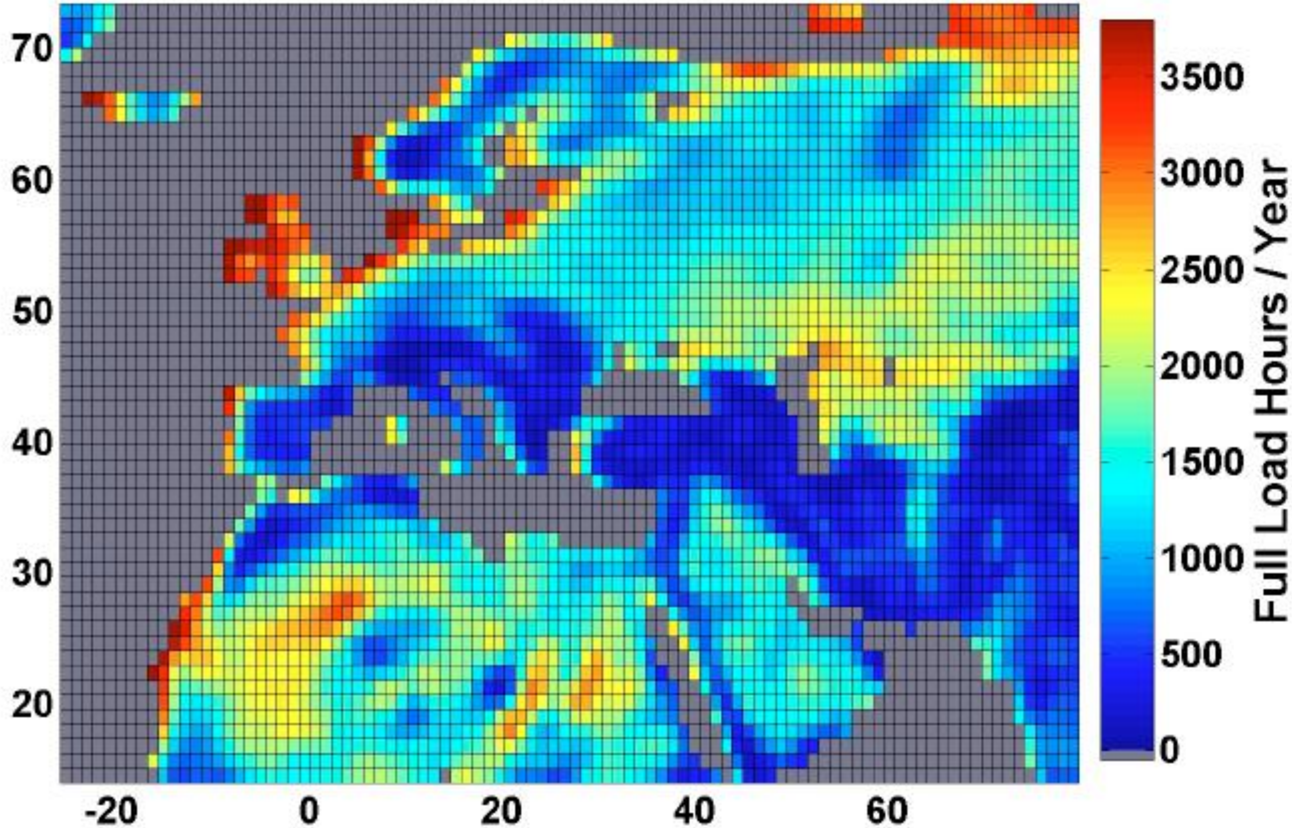


Figure 3: MEAN CORRELATION OF THE CHANGE OF WIND POWER (ΔP) VERSUS DISTANCE AT DIFFERENT AVERAGING TIME SPANS VERSUS DISTANCE DERIVED FROM MEASURED WMEP-DATA OF 176 TURBINES.

www.iset.uni-kassel.de/abt/w3-w/projekte/awea_2001_czisch_ernst.pdf

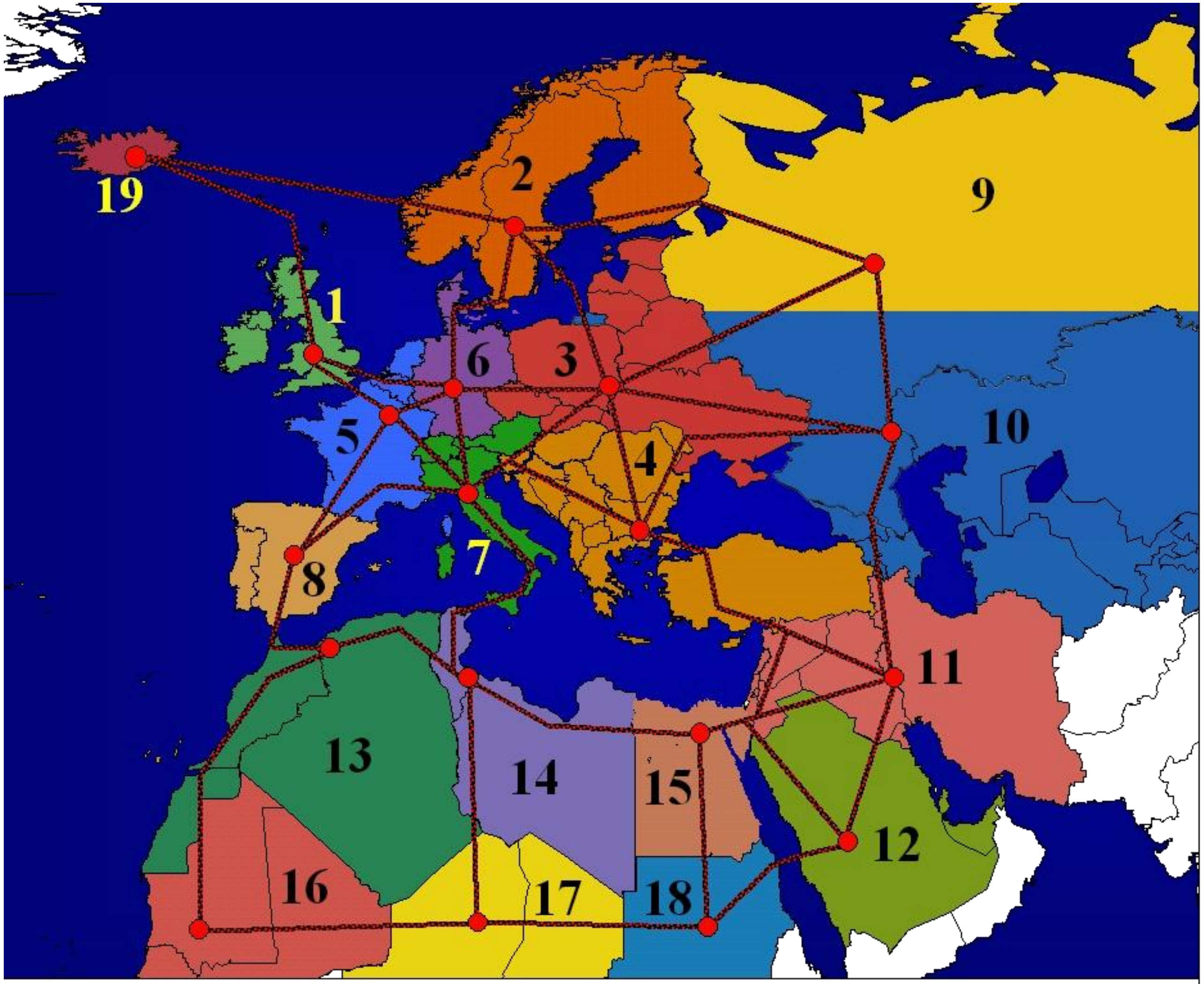
High wind penetration with large catchment areas

- HVDC
- Storage, e.g. Pumped hydro



www.iset.uni-kassel.de/abt/w3-w/projekte/awea_2001_czisch_ernst.pdf

HVDC grid

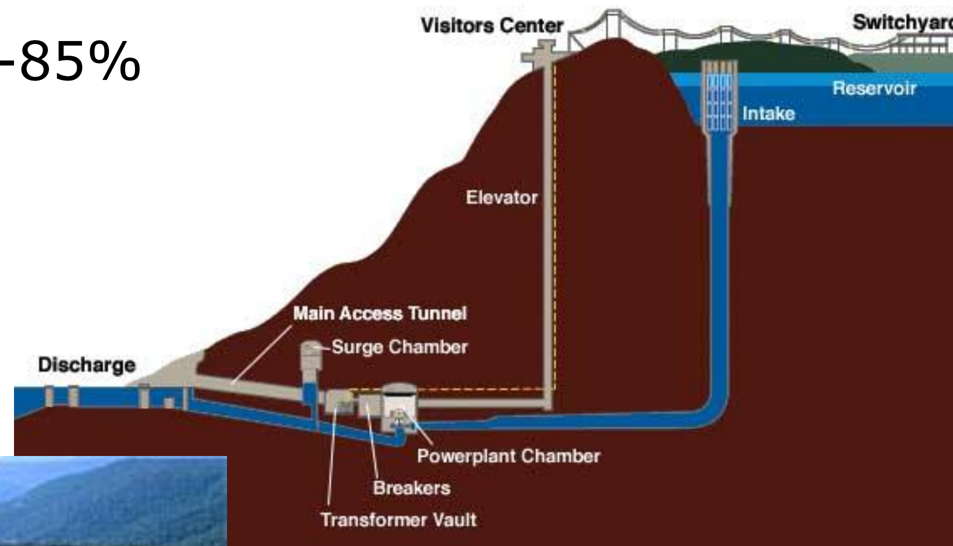


Source: G. Czisch, G. Giebel, May 2007

HVDC Sea cable Norway to Holland

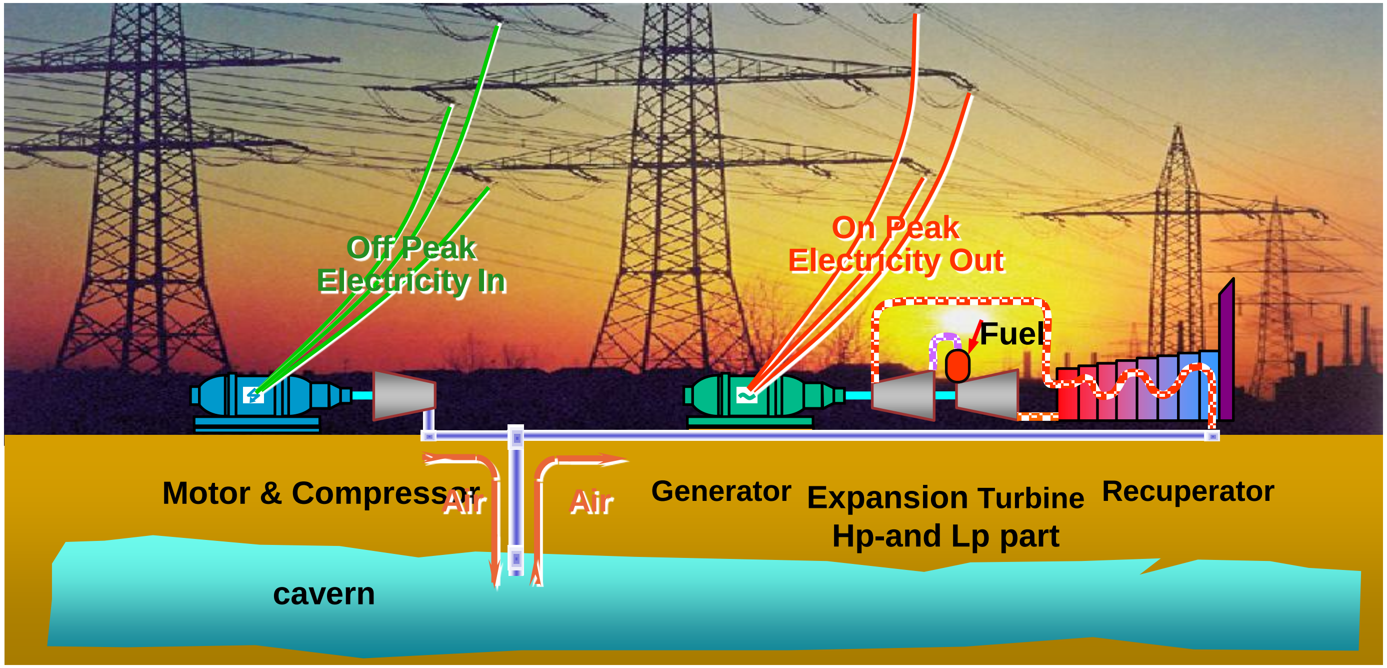
Pumped storage

- Widely used, EU 40 GW, US 25 GW
- Round Cycle Efficiency 70-85%
- Ramping time: 1-1.5 min



Compressed Air Energy Storage

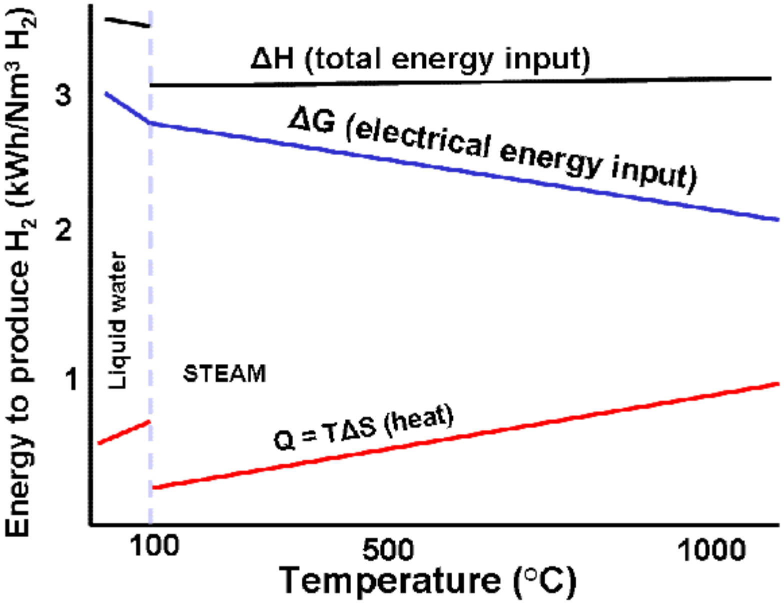
– Fast start-up times (minutes)
– Daily basis
– Efficiency: CAES 45% - AA-CAES 70%
– Expensive technology
– Huntorf installation: 290 MW



Electrolysis and Fuel cells

- Electrolysis 70 % efficiency state of art
- Higher electric efficiency at
  Higher Temp (solid oxides)
- High Temp electrolysis slow start-up

- Fuel cell 50- 60 %



Batteries

- Capacity decreasing with time depending on use
- Low energy density (weight and volume)
- Relatively high electric efficiency (70-85 %)
- Stationary and mobile applications
- Very fast response time

Risø DTU, Technical University of Denmark

Stationary vanadium flow battery at SYSlab, Risø DTU

15 kW – 120 kWh

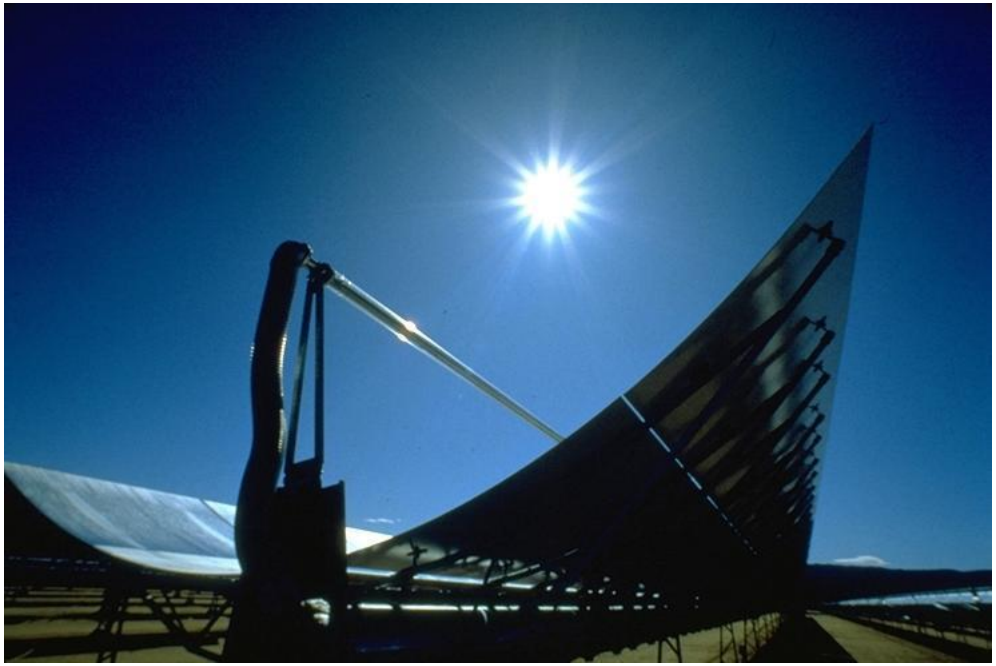
Storing energy
Energy density of storage technologies

Energy carrier	kJ/ml	kJ/g
Gasoline (Octane)	33.4	47.6
$LiBH_4$	14.3	21.7
Magnesium Hydride	14.4	10.9
$Mg(NH_3)_6Cl_2$	14.3	11.4
Liquid Hydrogen	10.0	141.0
Hydrogen at 200 bar	2.4	141.0
Lead-Acid Battery	0.3	0.2
Advanced Battery	1.2	0.7
Fly Wheel		0.5
Methanol	18.0	22.7
Liquid Ammonia	17.9	25.2

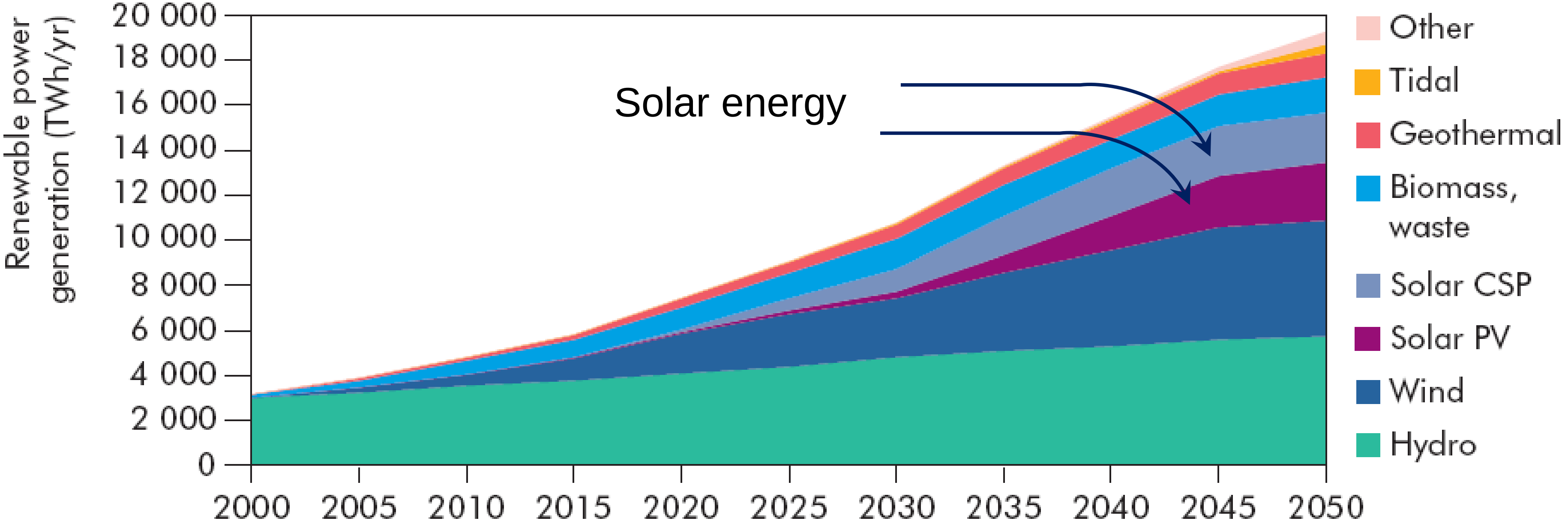
Numbers do not include containers and system components

Smart grids

Solar Power
Photo Voltaic and Concentrated Solar Power



Blue: Renewable Power evolution



Solar farm area to cover World electricity and energy consumption 2008

1 square for world electricity consumption.

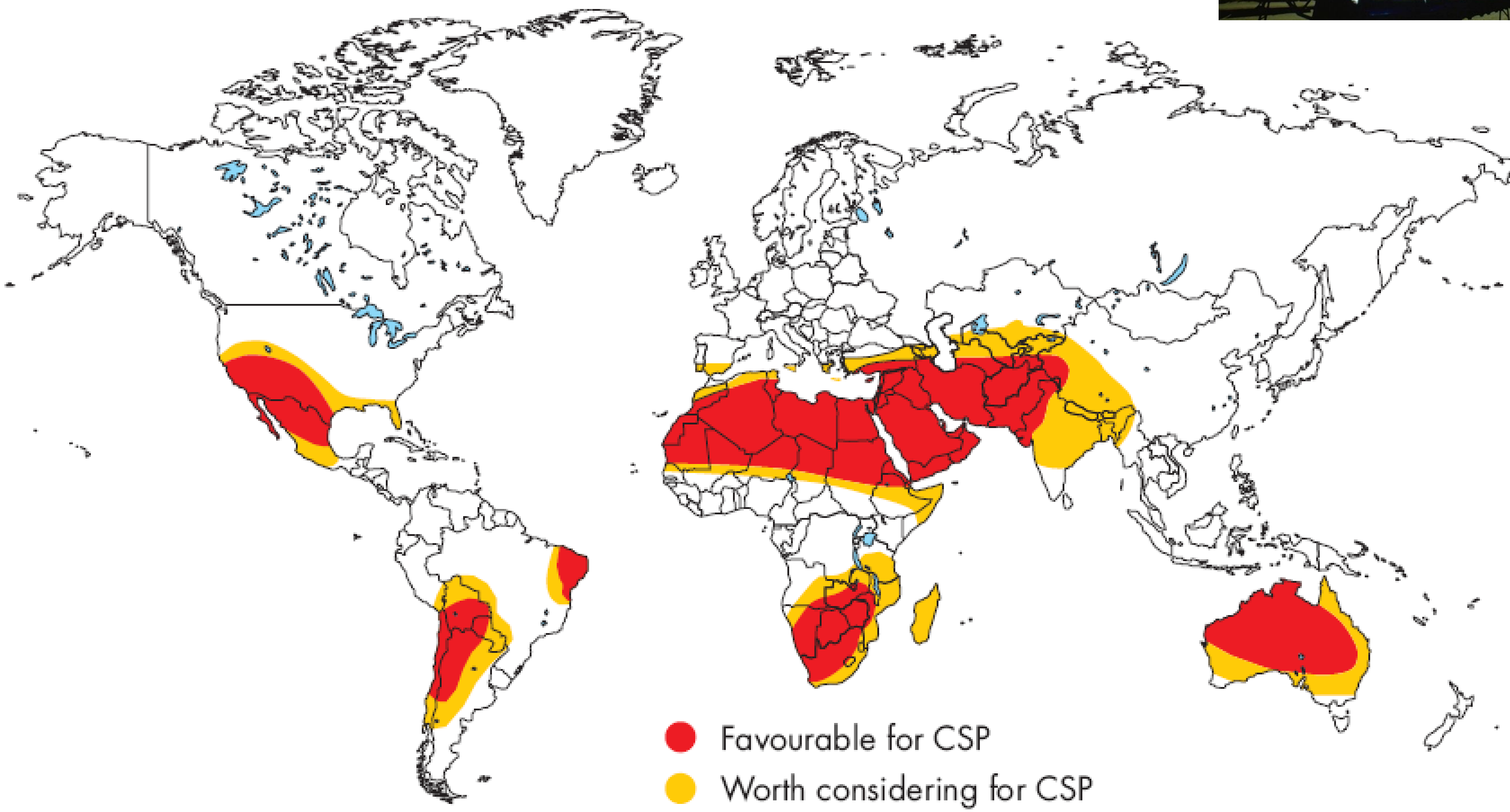
4 squares for world energy consumption

World electricity consumption, $P_{We} = 2\ TW$

Solar power generation density ≈ 40 GW/km^2

Area of solar farm to cover P_{We} = (250 km)^2

CSP potential map



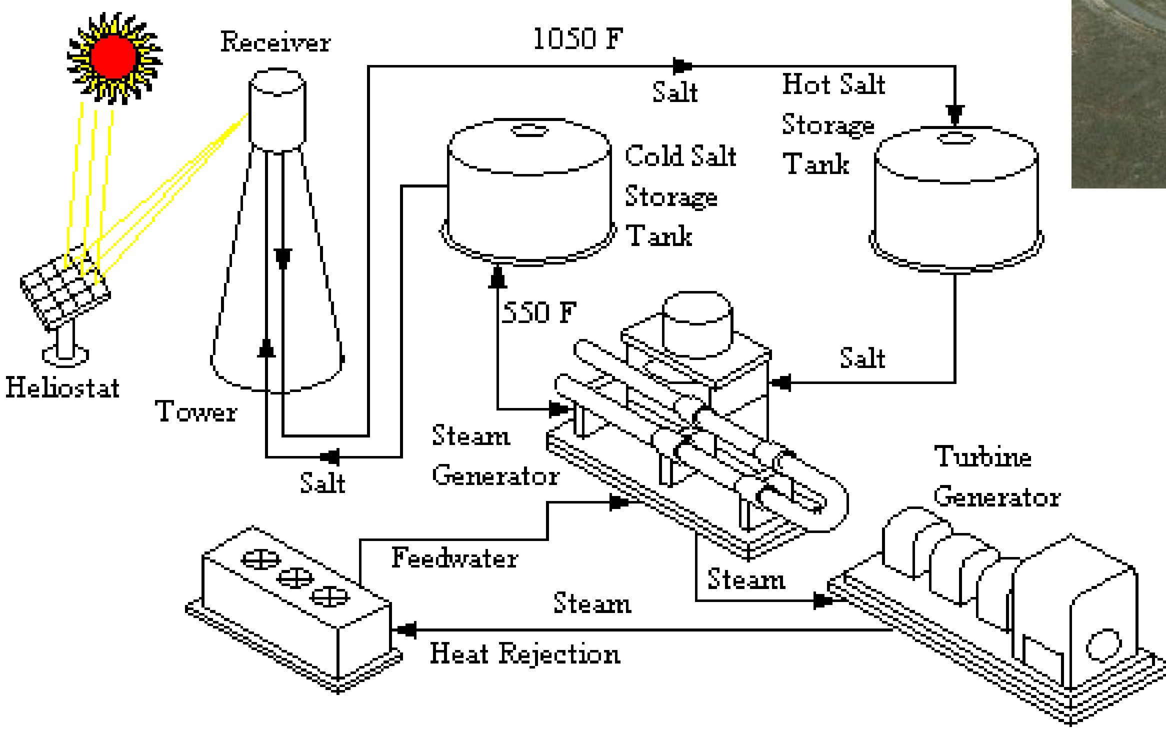
Source: Pharabod and Philibert, 1991.

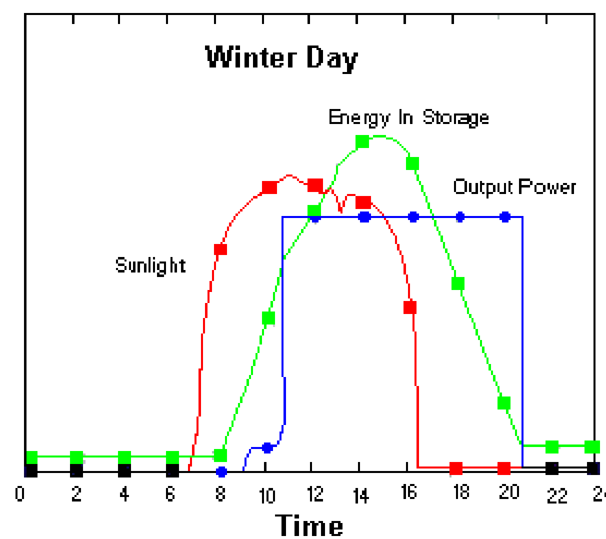
© OECD/IEA, 2008, Energy Technology Perspectives 2008

CSP with Molten Salt Heat Storage

5 MW thermal power, 60 MW test plants

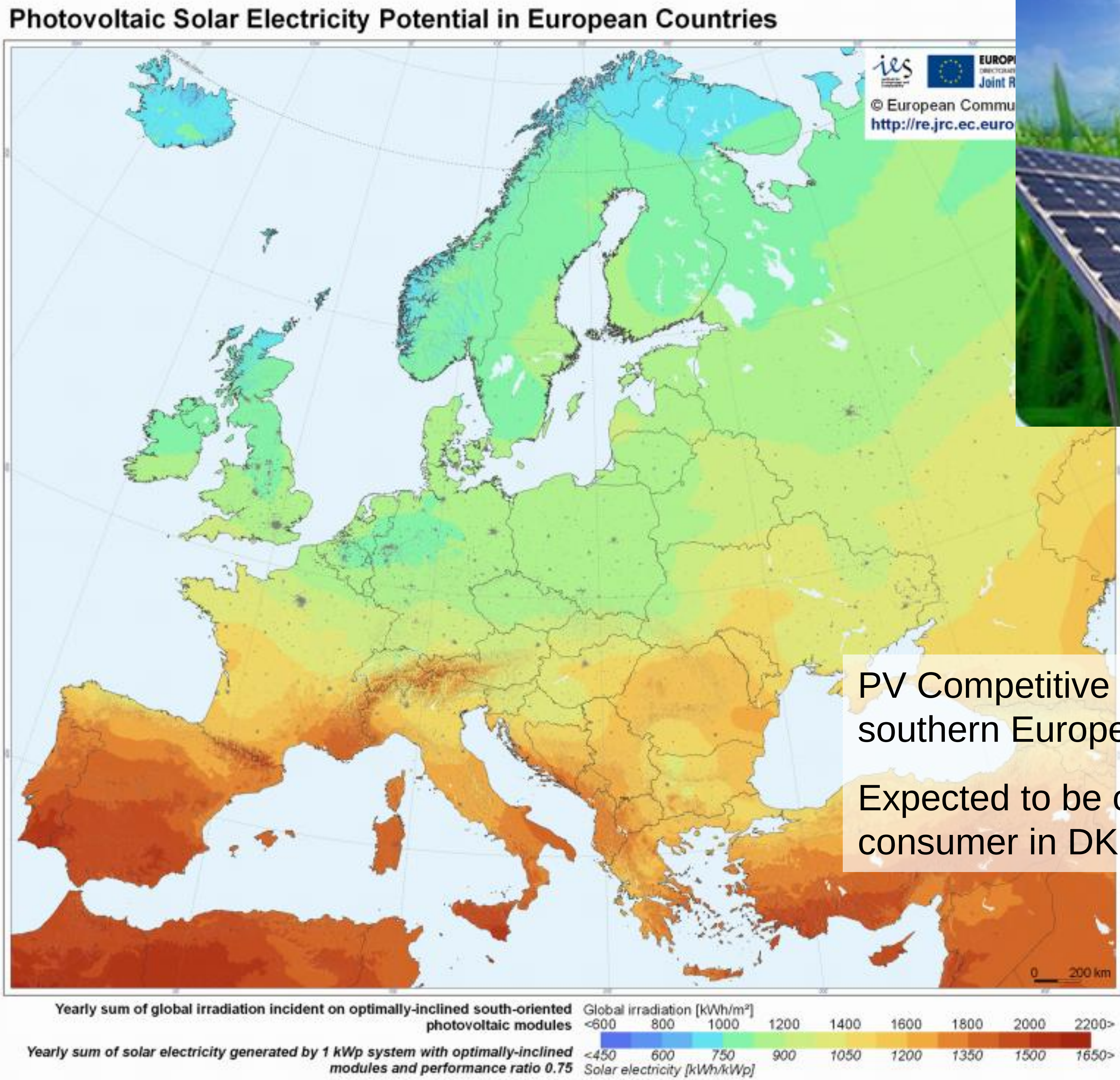
300-500 MW hybrid





Strategic Research Agenda
CSP

- Direct steam
  - Flow
  - Materials
- Thermal Storage
  - Sensible and latent
- High Temp Air (800°C)
  - High temperature materials
- Desalination and power
- Hydrogen and metals production



PV Competitive at consumer in southern Europe now.

Expected to be competitive at consumer in DK in 10 years

40MW thin-film CdTe solar field

First Solar and
Juwi Solar.

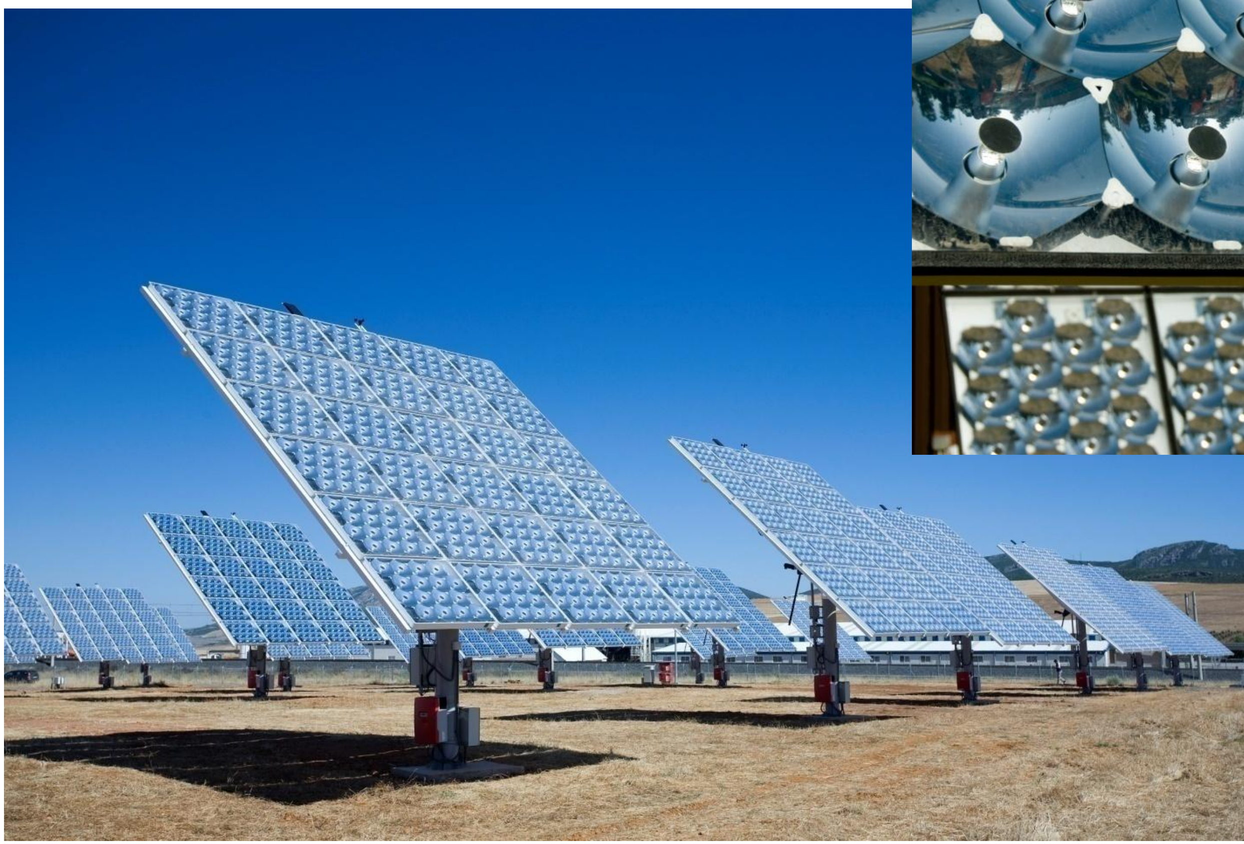
Waldpolenz (Saxony, Germany), military air field

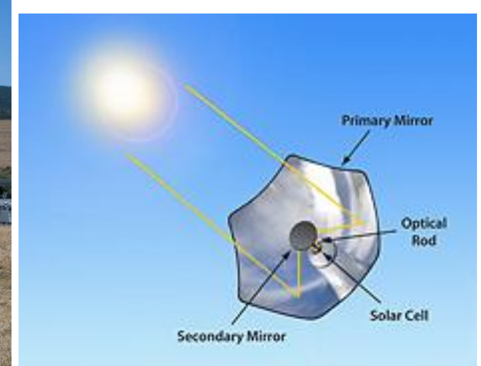
400 000 m² | First Solar | 40 000 kW_{peak} | 40 000 000 kWh | 2007-2009

Completion 2009
Installed system price 3.25$ / Wp

Concentrating PV

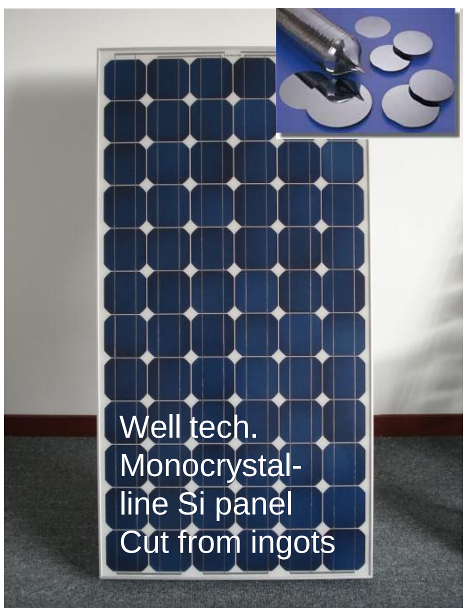
- SolFocus 500 x concentration

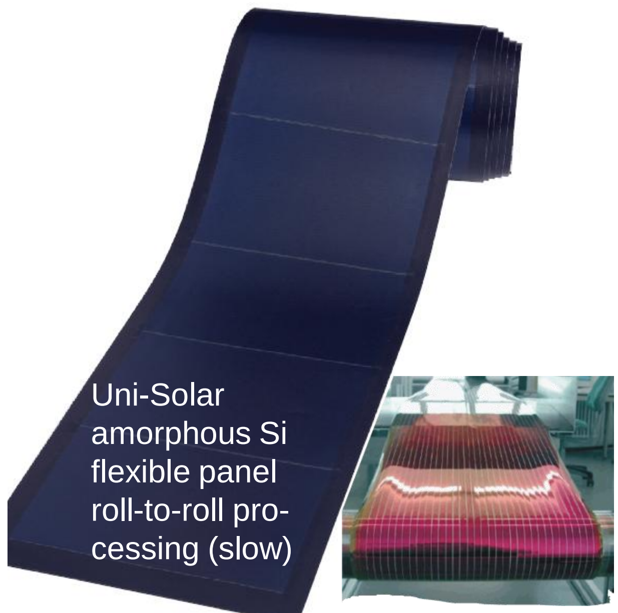




Three generations of solar cells

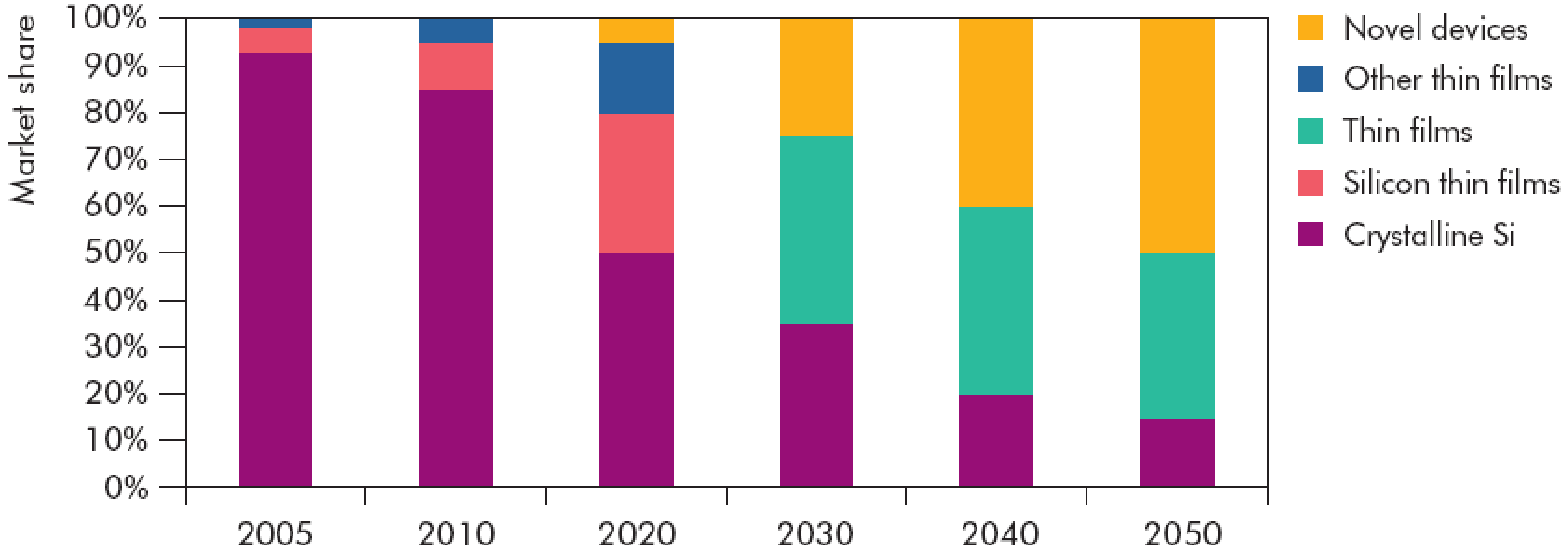
1st:	Crystalline Silicon solar cells	20%	Expensive Low volume
2nd:	Thin film technology (amorphous Si, CdTe, CIGS)	8 (to 20%)	Cheaper Higher volume
3rd:	organic and polymer solar cells	1 (to 5%)	Extremely cheap Extremely high volume





Risø DTU solar cell printed on textile. Screen print (fast)

Shift in Solar PV technology



Source: Frankl, Menichetti and Raugei, 2008.

Strategic Research Agenda
PV

- Substitution of critical materials

C-Si

- **Cheaper feedstock**
- **Wafer manufacturing**

Thin films

- Materials and interfaces
- Multi-junction structures
- Low grade materials
- Stability

Polymer

- Stability (oxygen, light)
- Efficiency
- Cheap production

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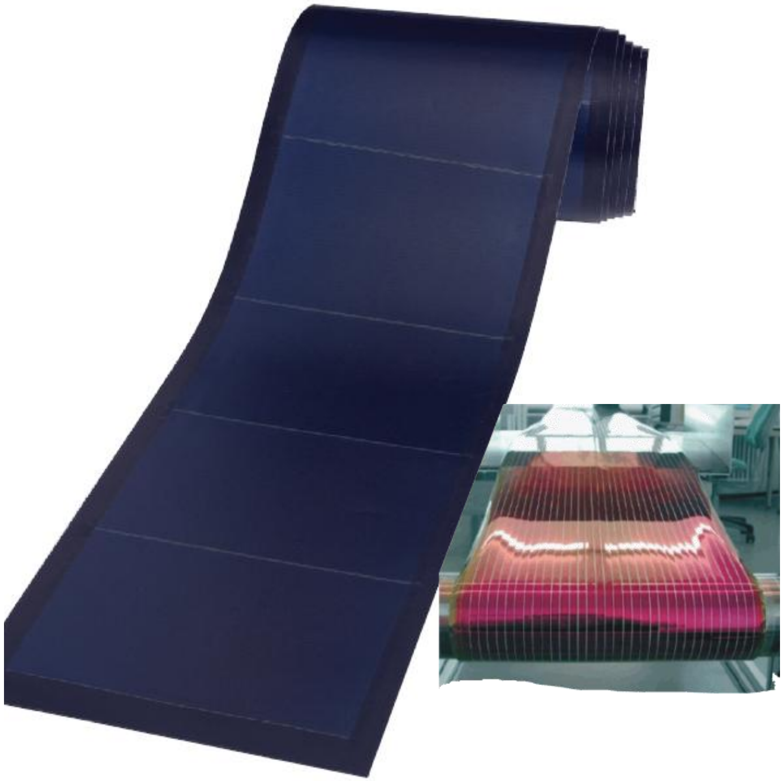
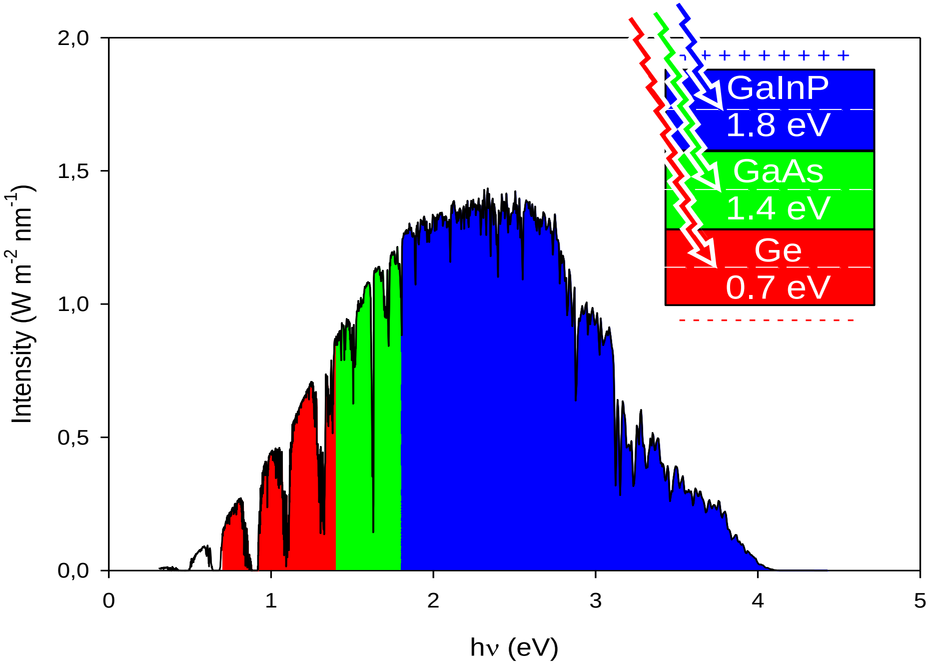


Multijunction - tandem PV

- Triple-junction PV:
  GaInP: >1.8 eV light absorbed
  GaAs: 1.4 eV to 1.8 eV absorbed
  Ge: 0.7 eV to 1.4 eV absorbed
  SpectroLab Inc. η = 41%

- Theoretical limits:
  Single junction cell 31%
  Infinite-junction cell
  + concentration 85%



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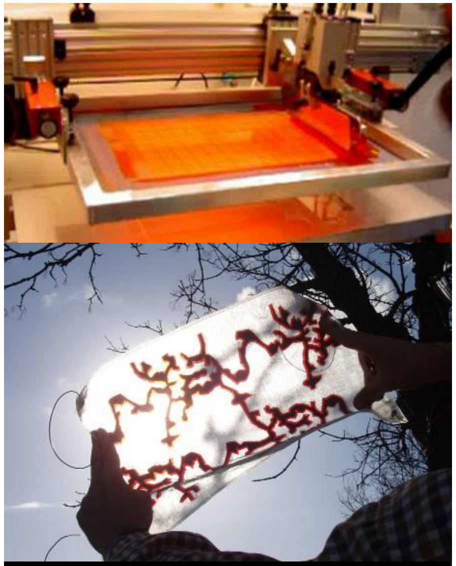
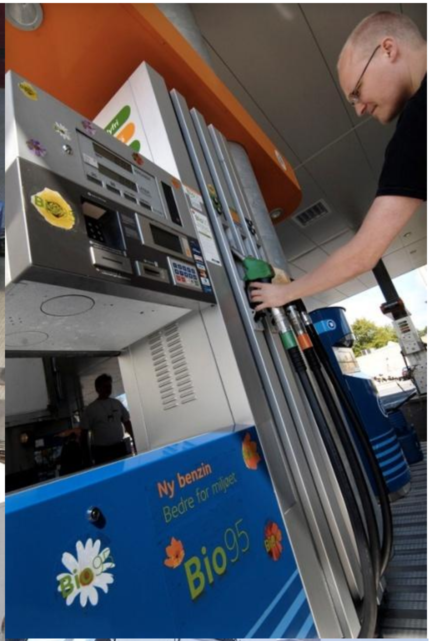


Risø DTU solar cell printed on textile. Screen print (fast)

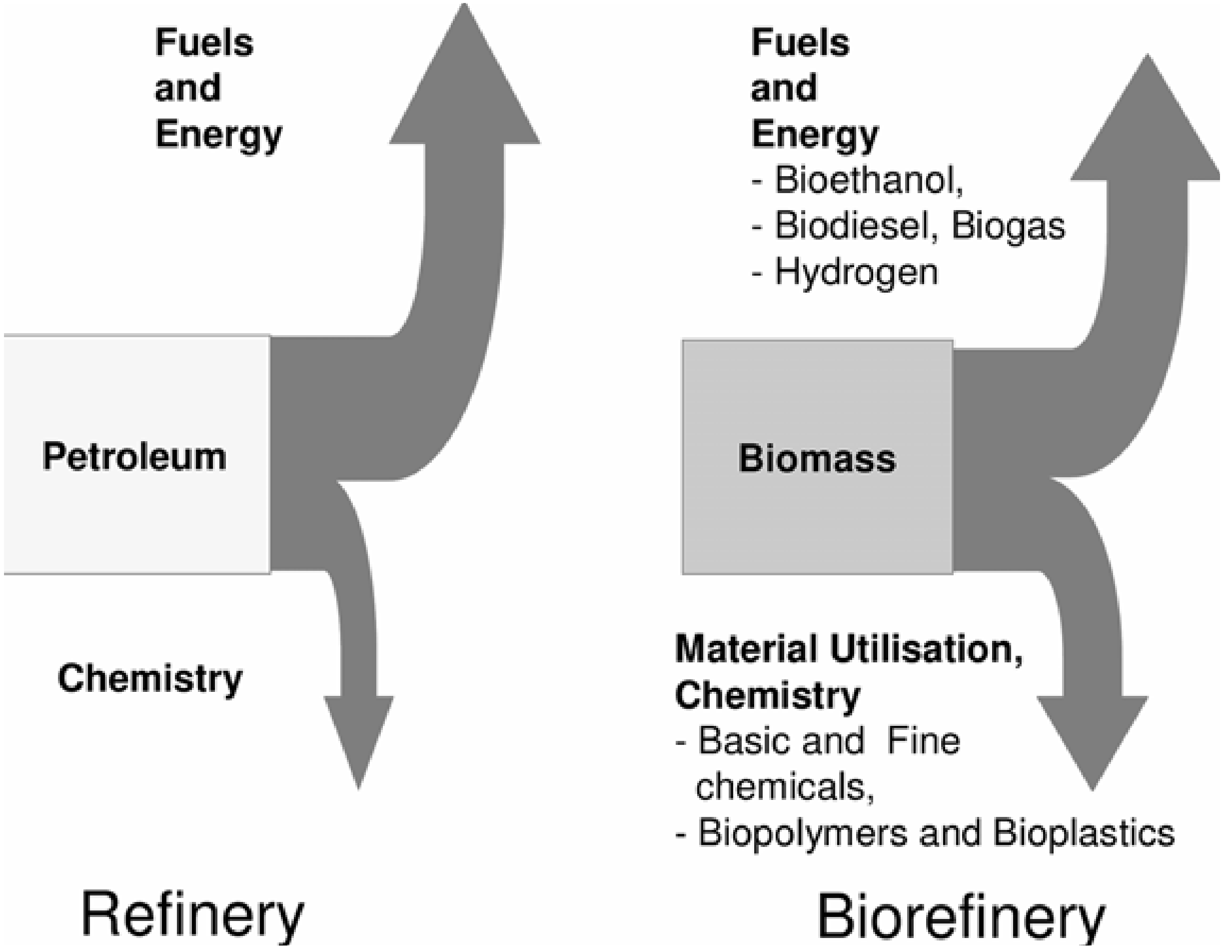
A solar cell made from polymers and produced by printing technology

DTU

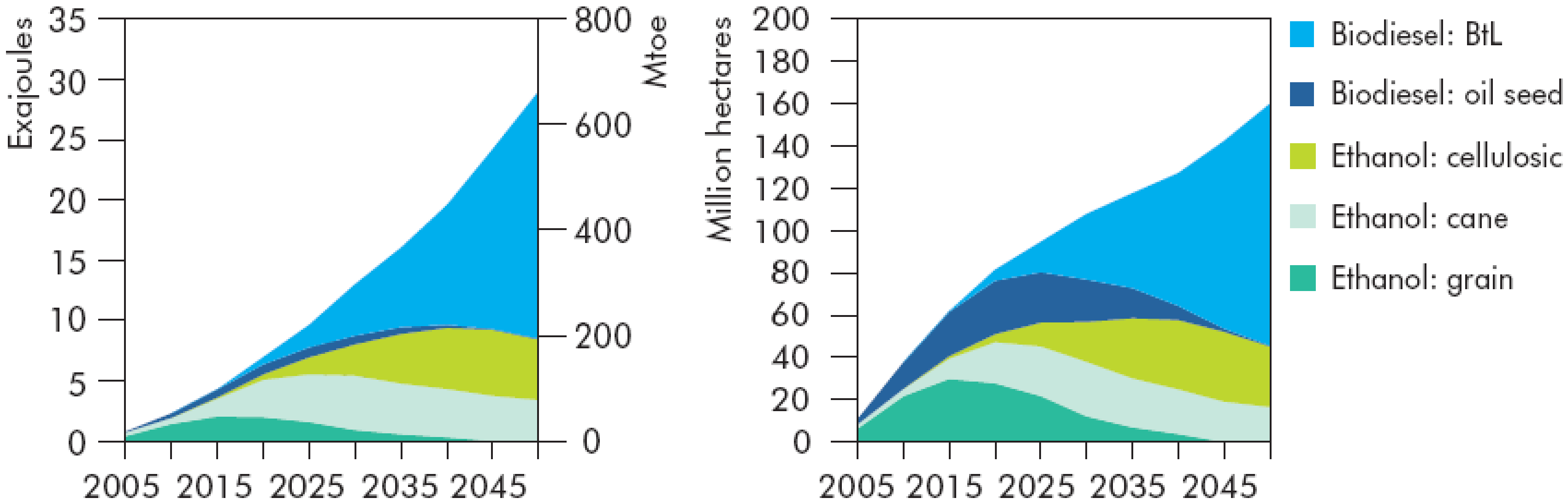
Biomass, bio energy and bio materials



Towards biorefinery

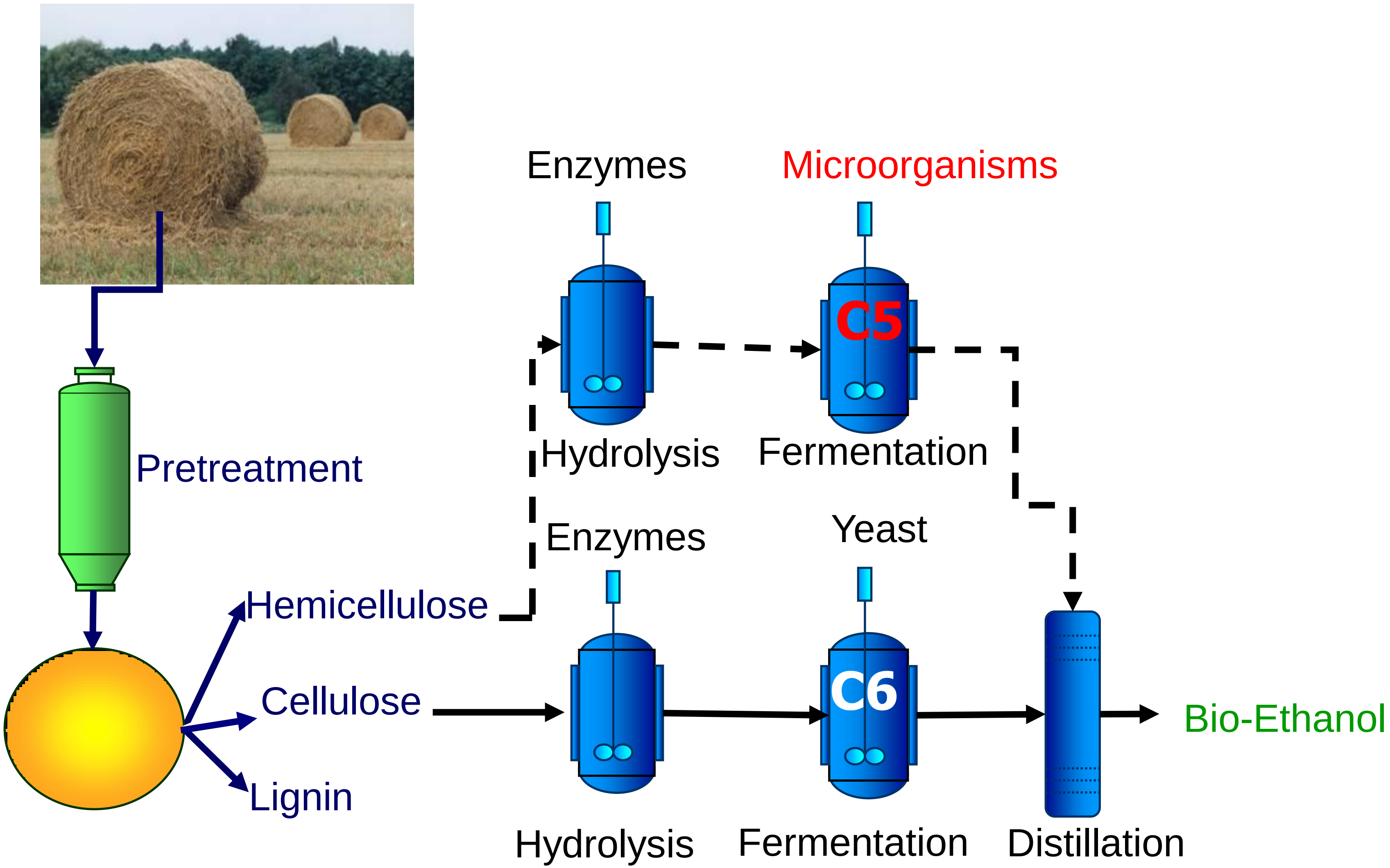


IEA, ETP 2008, Blue: Demand for bio fuels

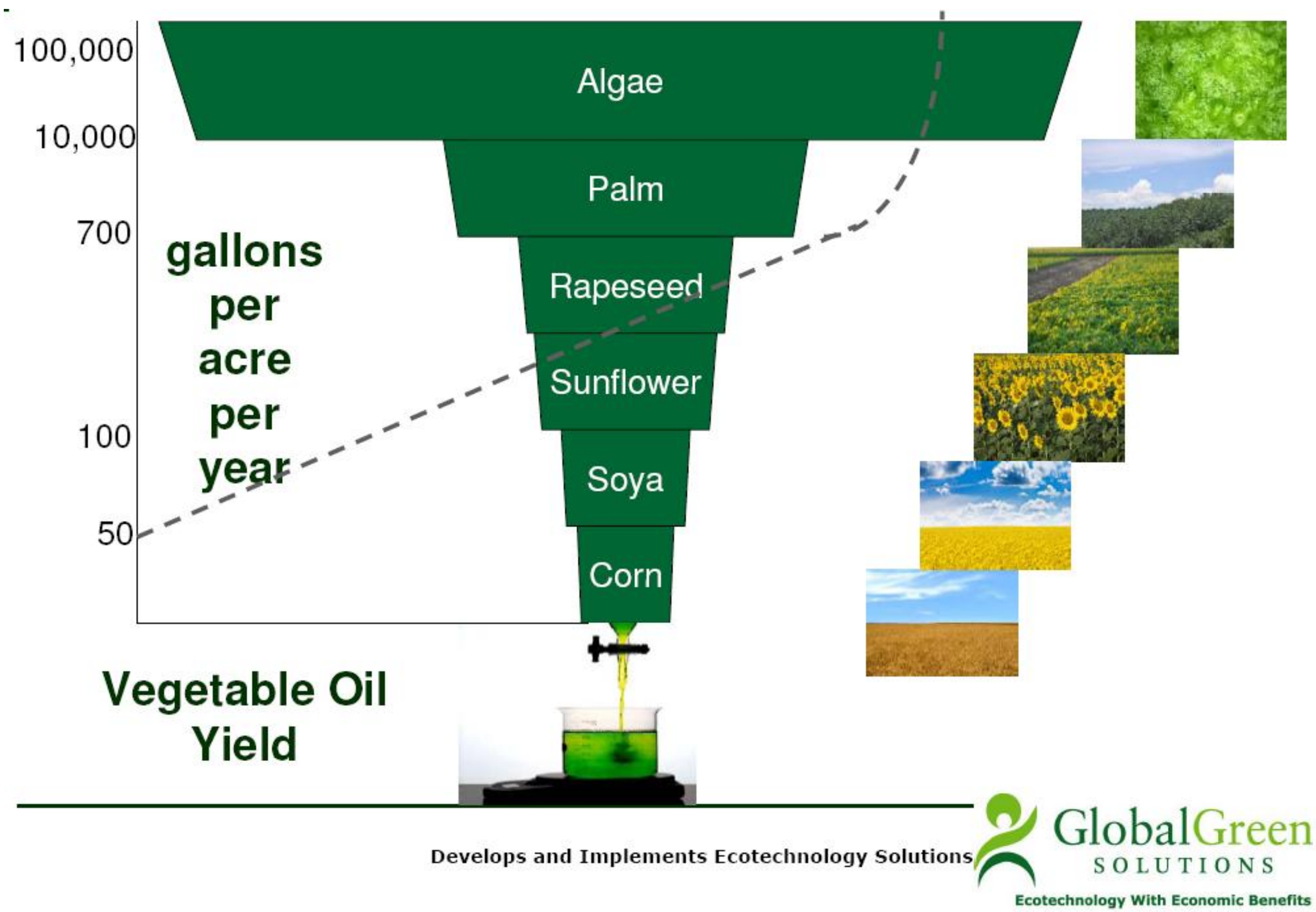


Airplanes
Trucks
Ships

2. generation Bioethanol production



Algae for biodiesel?



Challenges in growth systems for algae

- Reactor design and price
- Use CO_2 from power plants and slurry from animal farming
- Improve methods for harvesting


Geothermal
4G Nuclear
Fusion
Hydro
Wave
Tidal
CCS
Together we will find the energy for the future