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Energy research Centre of the Netherlands

Intelligent Energy Europe

Overview and Perspectives of Fuel Cell Technologies and Regional Market Developments

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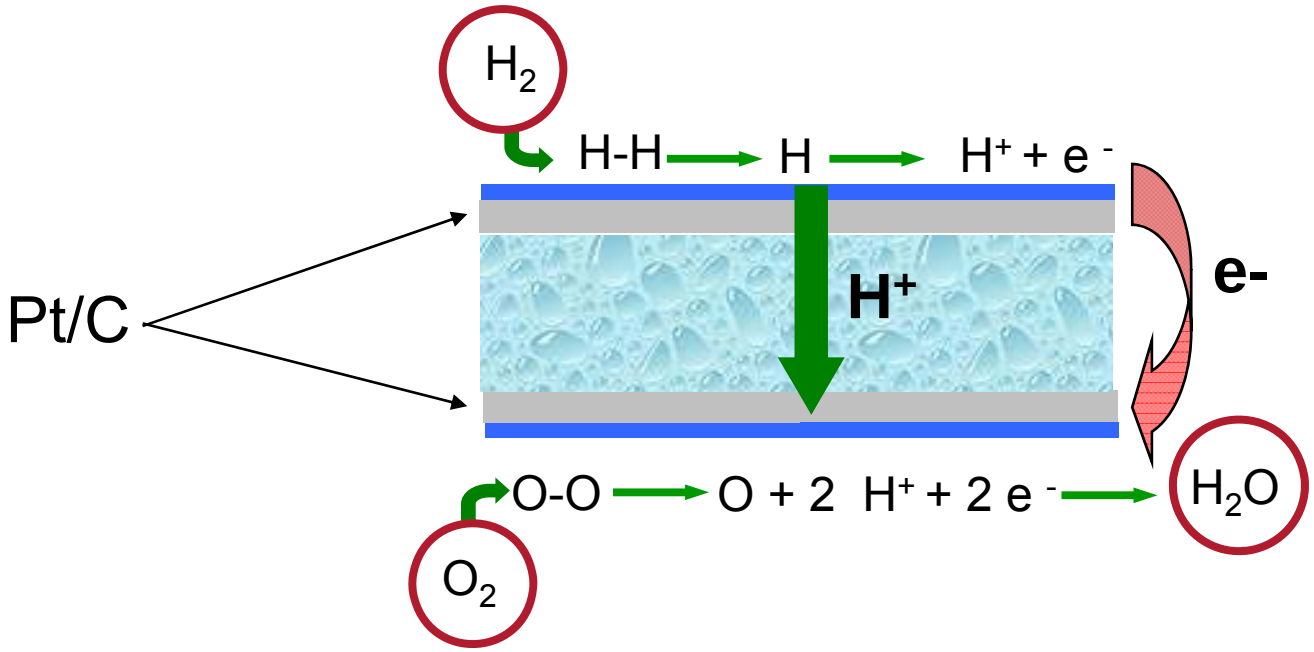
Outline

- Hydrogen and fuel cells
- Regional markets
- RES-FC household systems

Basics on hydrogen and fuel cells

- Hydrogen is an energy carrier
  - Needs to be produced (from hydrocarbons or water, using heat and/or electricity)
  - Needs to be converted (fuel cell, internal combustion engine, gasturbine, burner)
- Fuel Cell is a conversion technology
  - Needs a fuel (hydrogen, syngas or hydrocarbon)
  - Produces electricity and heat
- Several types of fuel cells exist. Not all fuel cells need hydrogen, and to use hydrogen you do not necessarily need a fuel cell
- Fuel cells: most efficient way to convert hydrogen into electricity at small scale
- Efficiency of fuel cells is independent of scale and fuel cells have high part load efficiency (unlike ICE and gasturbine)

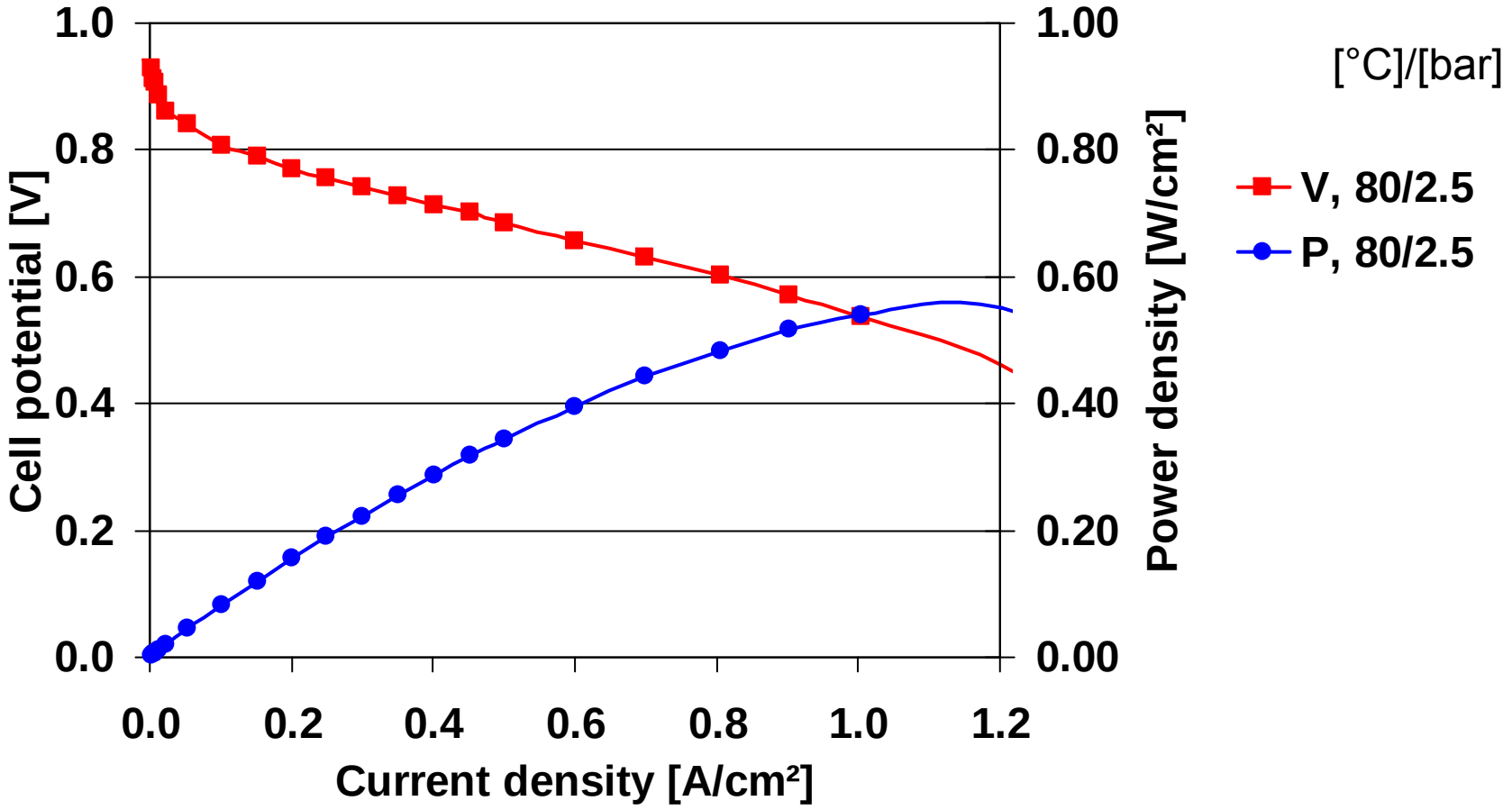
Fuel cell: Basic principles



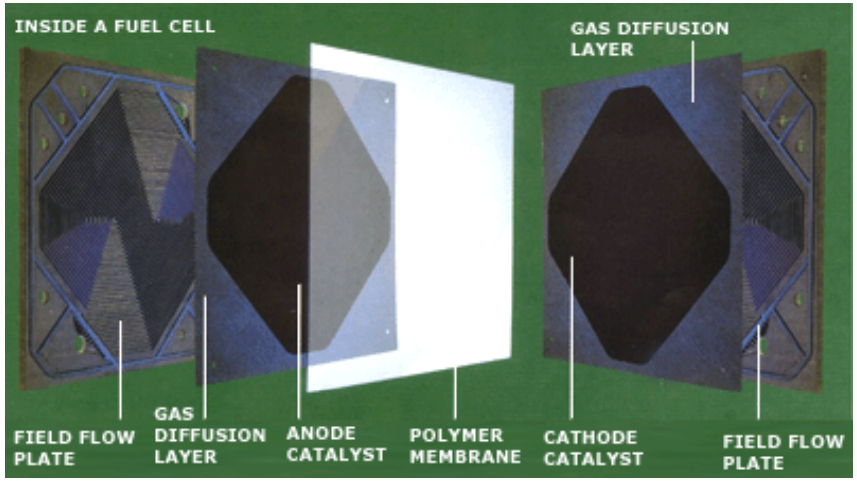
Overall reaction: $2\ H_2 + O_2 \rightarrow 2\ H_2O$ + electricitity + heat

Typical fuel cell characteristics

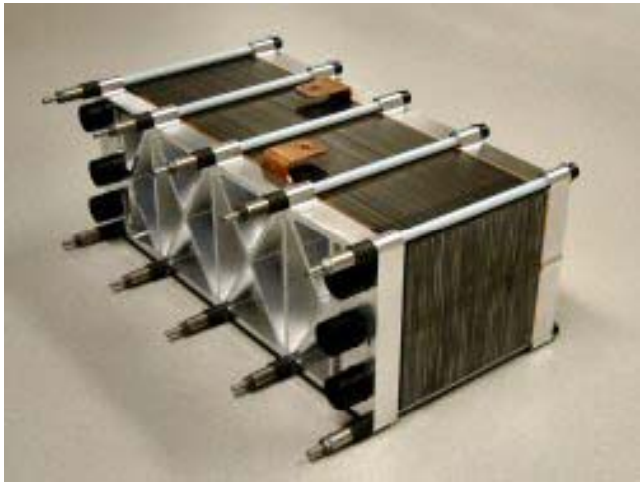
Efficiency = cell voltage / 1.23 V (LHV)
cell voltage / 1.48 V (HHV)



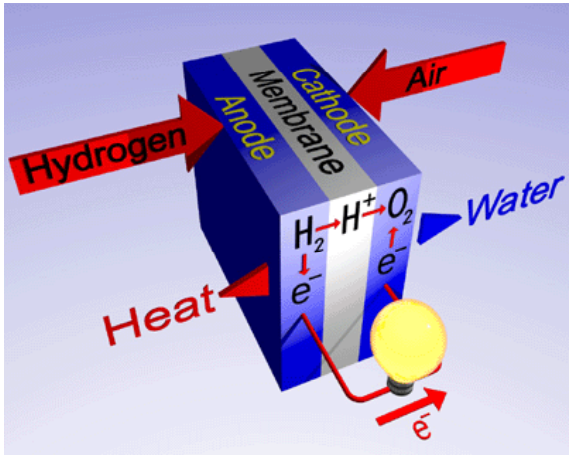
Basics of a (PEM) fuel cell



Fuel cell and flow or separator plates



Stack of fuel cells



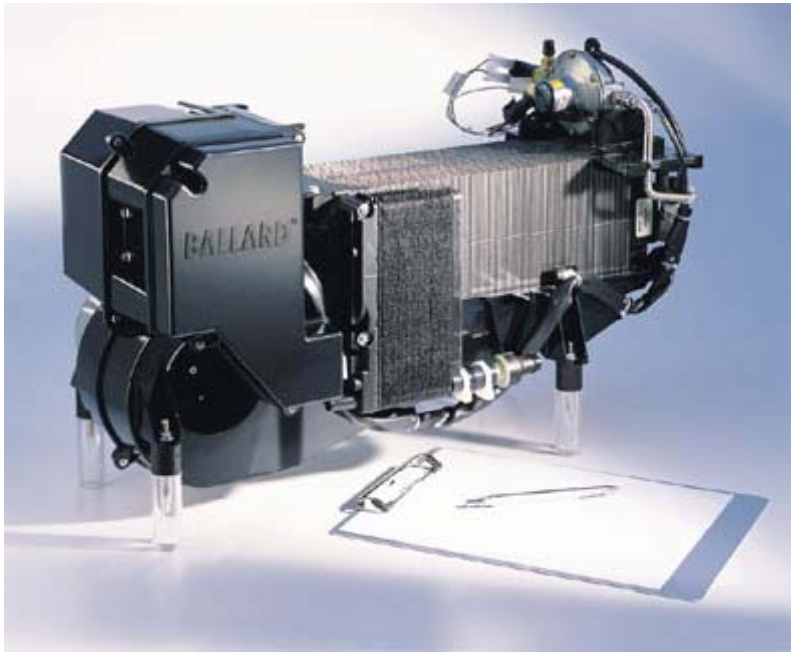
Anode: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode: $O_2 + 4e^- \rightarrow 2O^{2-}$

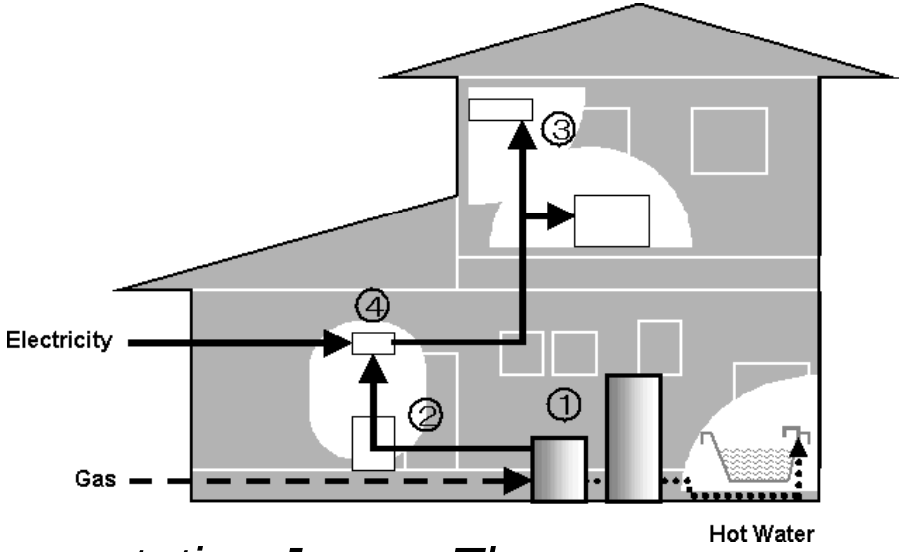
$4H^+ + 2O^{2-} \rightarrow 2H_2O$

Overall: $2H_2 + O_2 \rightarrow 2H_2O$

Fuel cell system and residential application

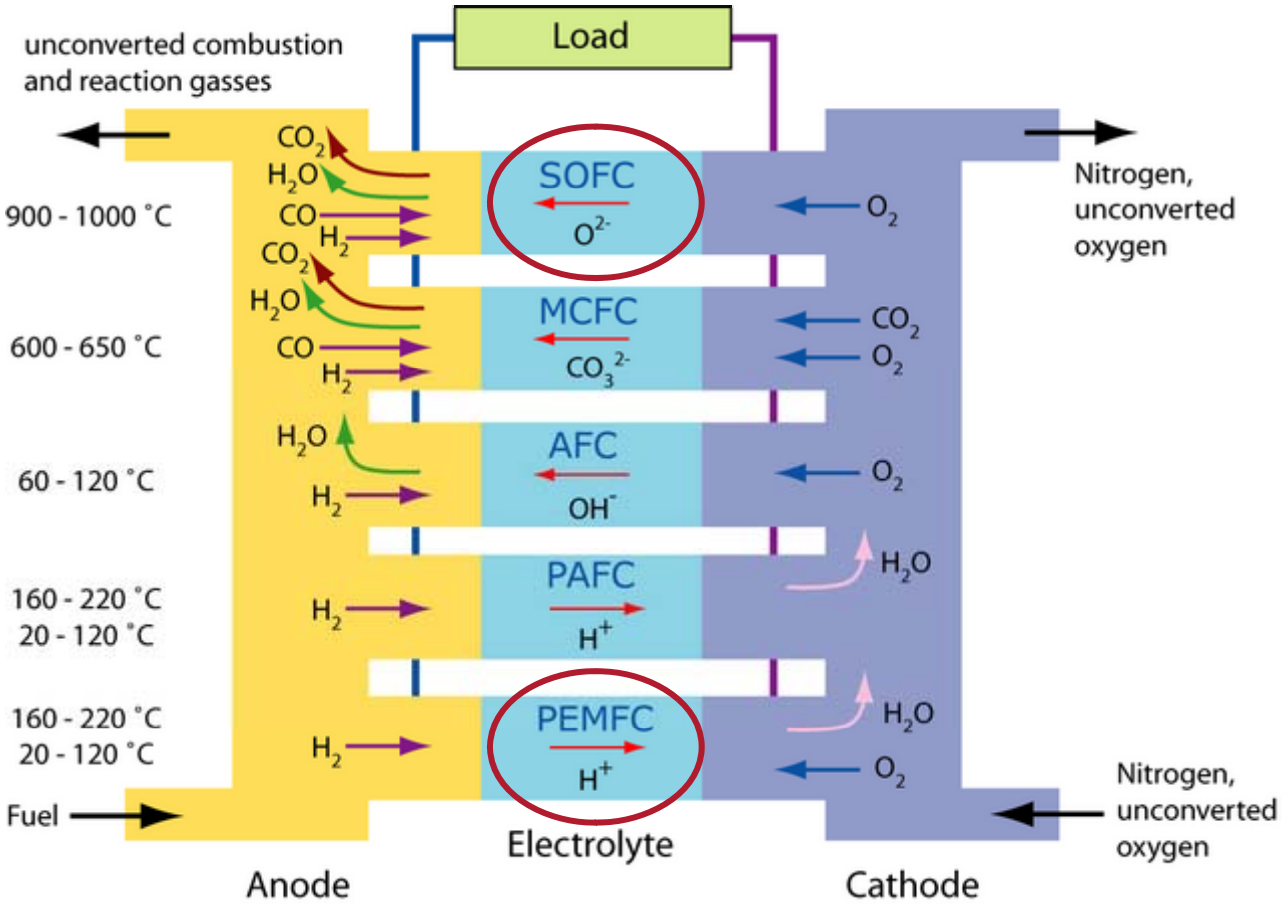


Aggregated market:
- PEM fuel cell
- Operating on H_2
- 0.5-1 kW_{el}
- New houses



Presentation Jesper Themsen

Fuel cell types



Residential

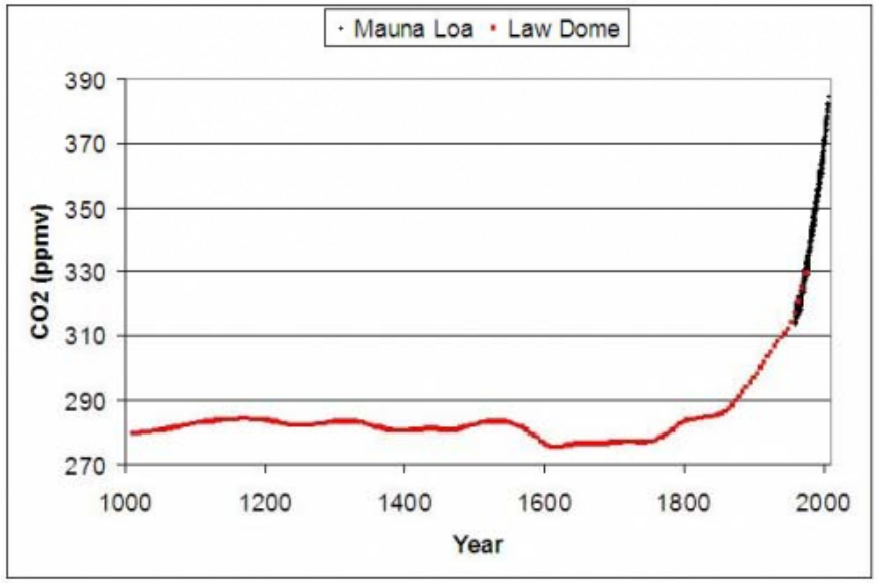
1 kW_{el} Fuel Cooling

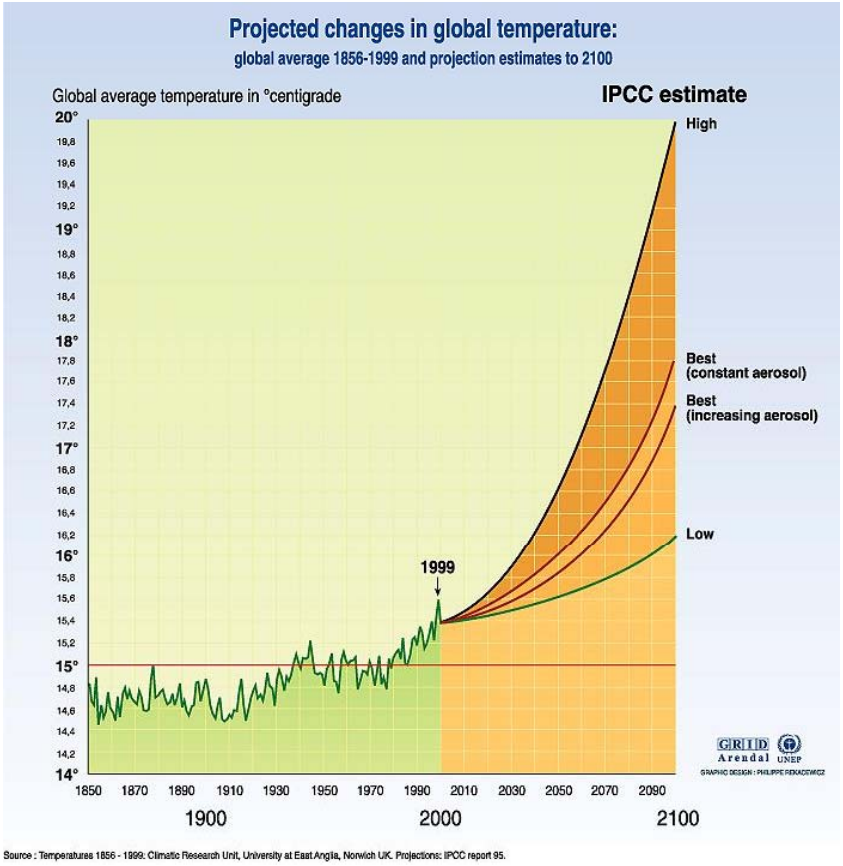
η_e =50% CH_4 Process
η_{th}=40% Gas

η_e =50% H_2 Water
η_{th}=40% NG*
reforming

Why hydrogen with fuel cells

- Reduction of CO_2 emissions
  - Additional way to implement renewables
  - Production from fossil sources with CCS
  - Fuel switch and efficiency improvement





Source : Temperatures 1856 - 1999: Climatic Research Unit, University at East Anglia, Norwich UK. Projections: IPCC report 95.

RES-FCHS and regions considered

Biogas as renewable energy source

- Jutland, Denmark.
- Baden-Württemberg, Germany.

Biomass and Wind as renewable energy source

- Jutland, Denmark.
- Baden-Württemberg, Germany.
- Reykjavik, Iceland.

Wind as renewable energy source

- Jutland, Denmark.
- Schleswig-Holstein, Germany.
- Friesland, the Netherlands.
- Navarra, Spain.
- Coimbra, Portugal.

Regional market information

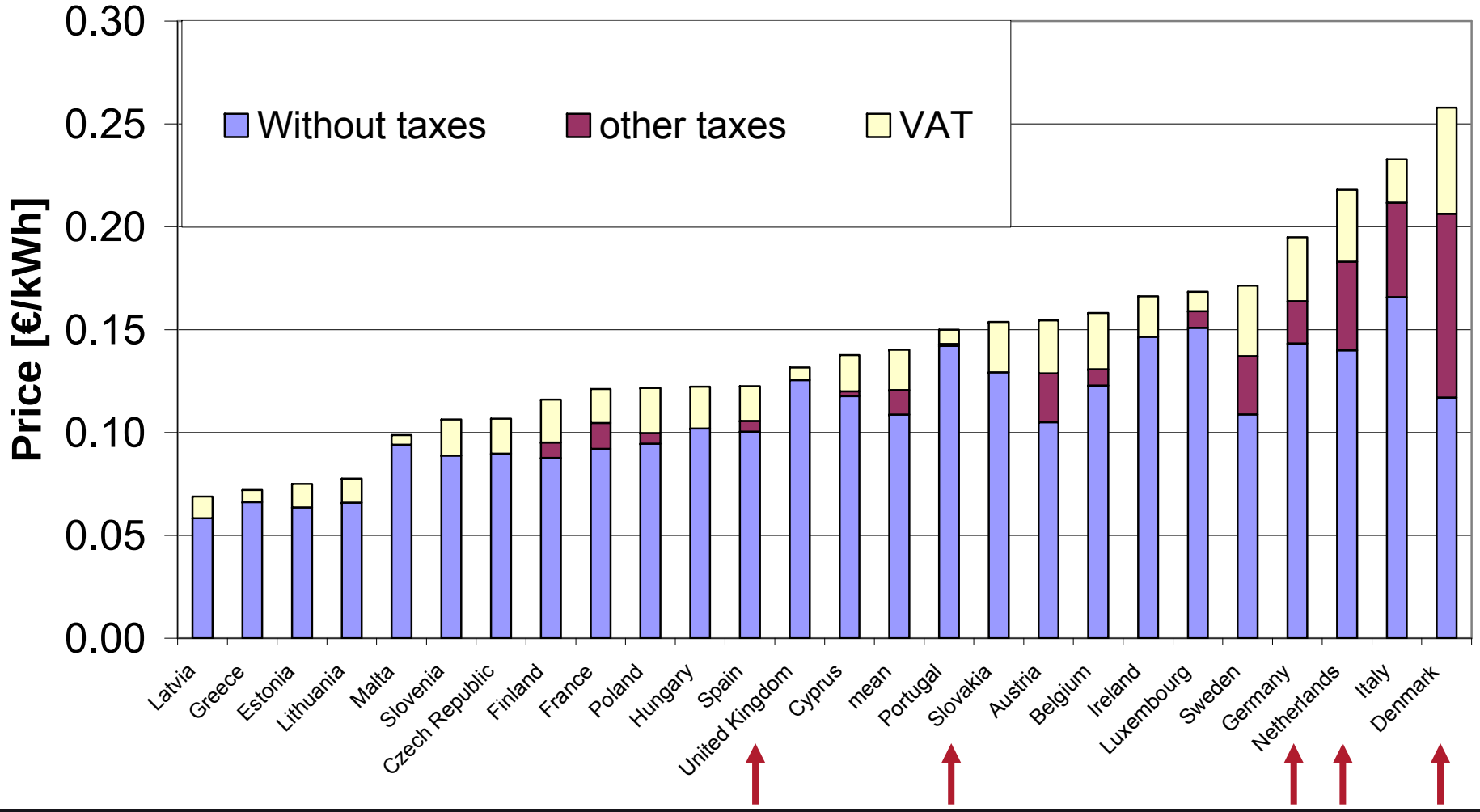
PEMFC = residential CHP system on H_2

Favourable perspectives:

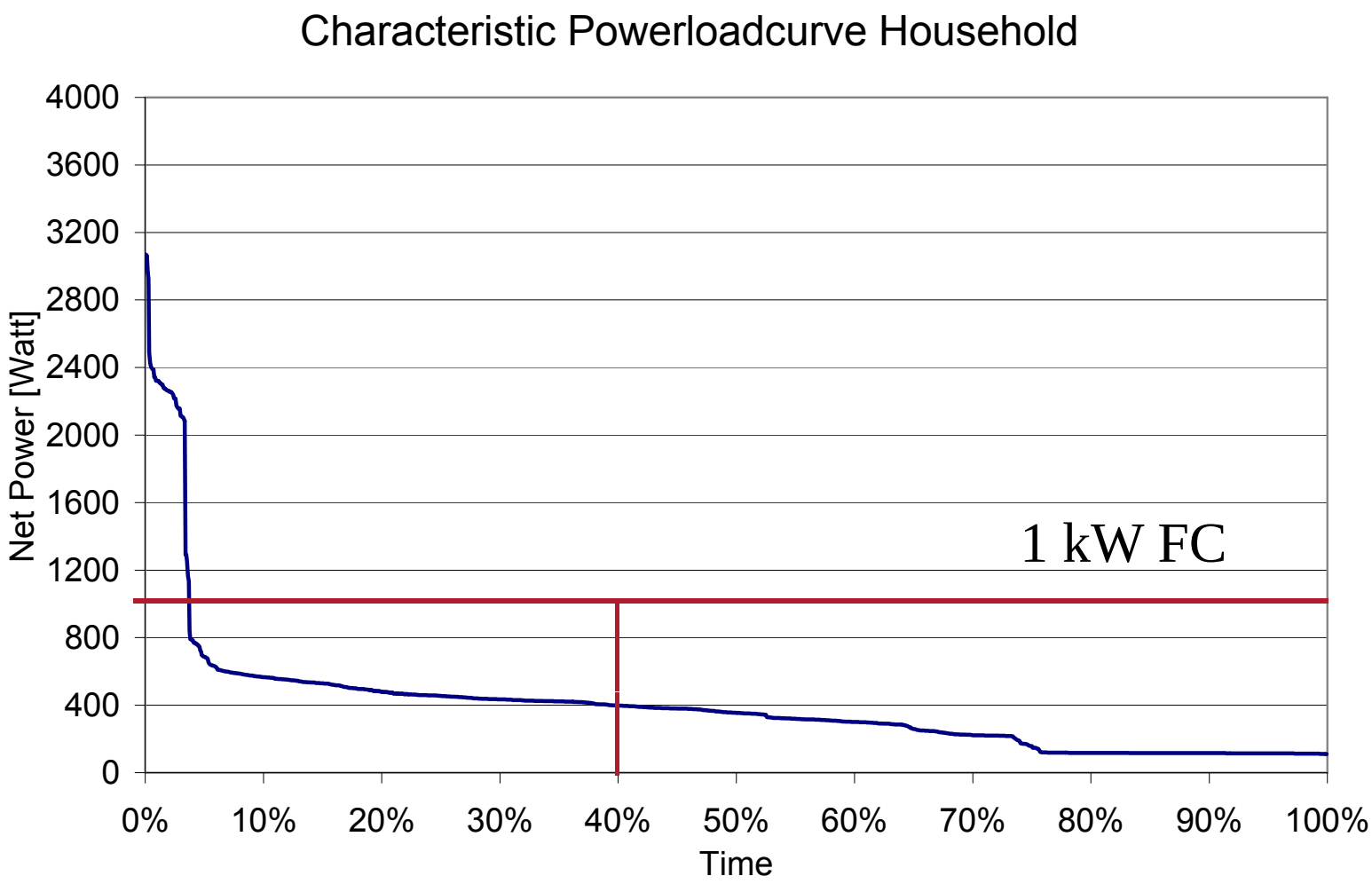
- High electricity prices
  - Household cost for heat and electricity
  - Feed-in tariffs
  - Household energy system demand
- Low hydrogen prices
  - Concepts for renewable hydrogen

Presentation Claus Torbensen

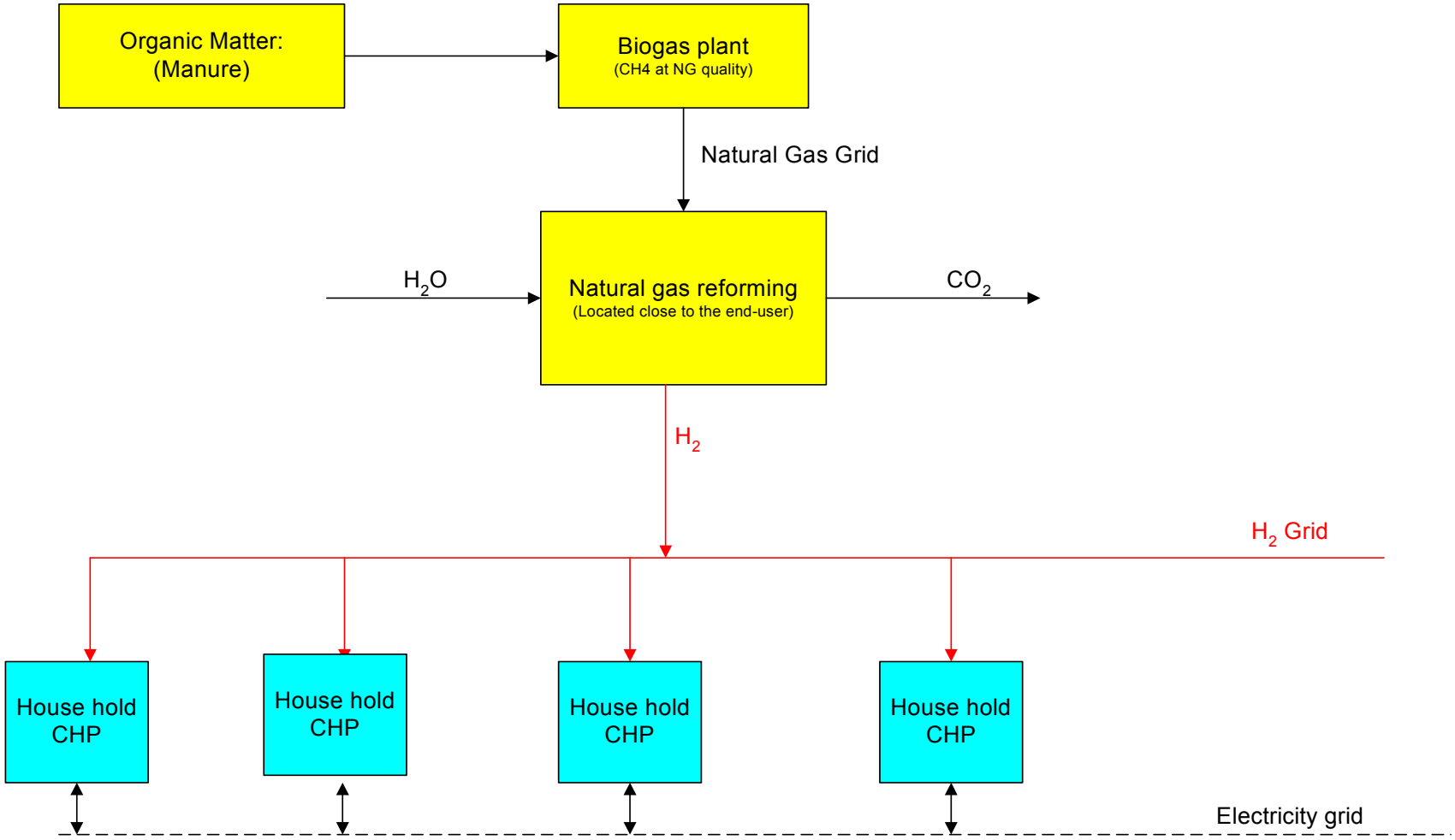
Electricity prices consumers EU-25 (2007/S1)



Residential load duration curve for 3500 kWh/yr



Biogas as renewable energy source



Biogas as renewable energy source

Biogas can be cleaned and upgraded to NG quality at 4-5 €ct/m^3
NG can be reformed and purified to H_2 (75% efficiency)
H_2 to be fed to a PEMFC

Alternatively: PEMFC stack on reformate gas

However
Biogas can be used directly with MCFC after cleaning
Simpler and more economical process
Size 250 kW => not for household application
Industrial use of heat or heating grid instead of hydrogen

Biogas as renewable energy source

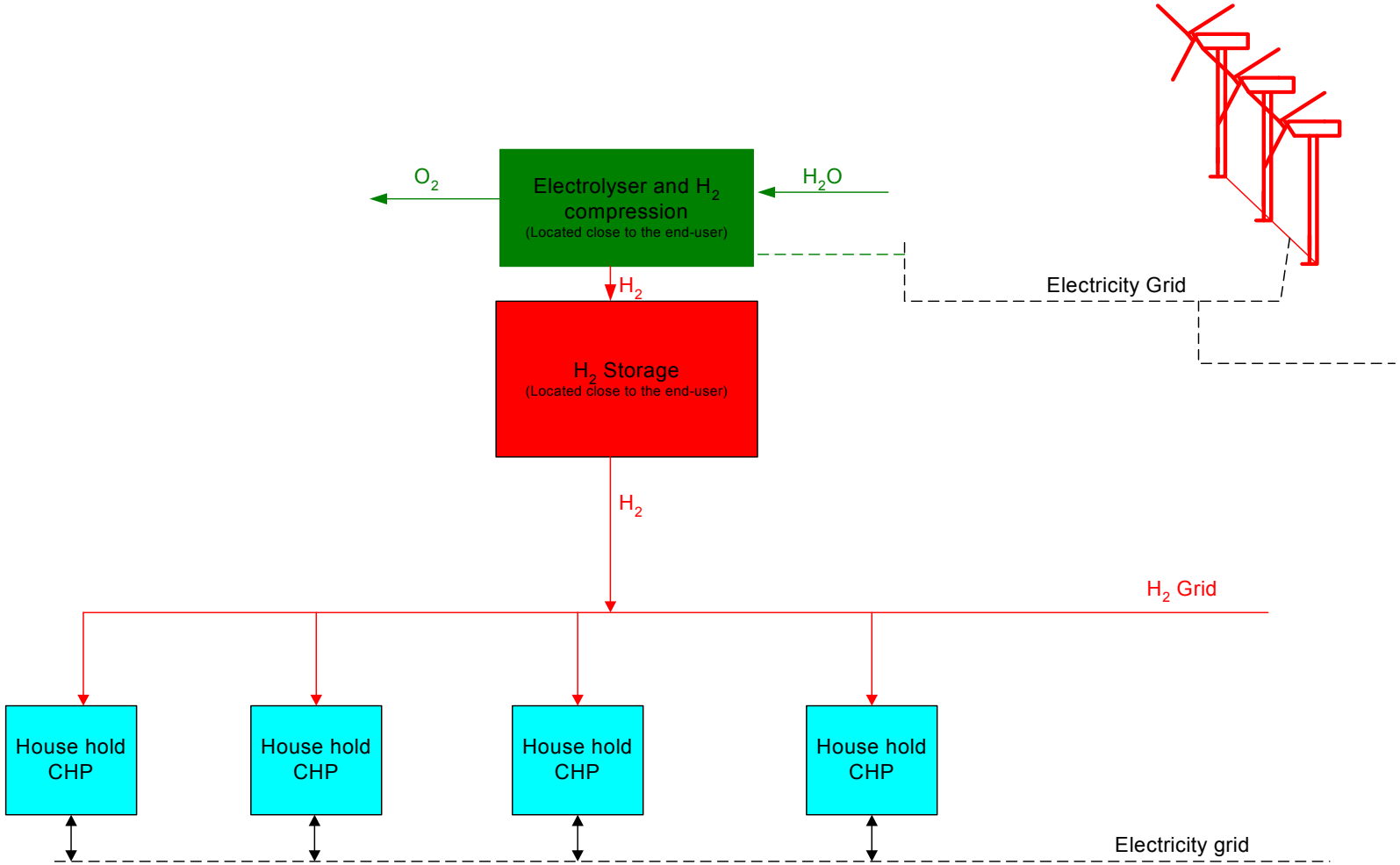
European electricity production from biogas.

Germany	5564 GWh
Denmark	274 GWh

	2004	2005
Germany	4 414,0	5 564,0
United Kingdom	4 383,0	4 690,0
Italy	1 170,3	1 313,1
Spain	824,7	879,4
France	444,0	460,0
Netherlands	282,0	286,0
Denmark	265,0	274,0
Belgium	231,9	236,9
Greece	179,0	179,0
Poland	155,0	175,1
Czech Republic	138,8	160,9
Ireland	101,0	122,0
Austria	57,7	57,7
Portugal	14,6	34,4
Slovenia	30,3	32,2
Sweden	61,6	53,4
Luxembourg	20,3	27,1
Hungary	23,0	25,0
Finland	21,7	21,7
Slovakia	2,0	2,0
Total EU	**12 819,9**	**14 593,8**

Source: EurObserv'ER 2006

Wind as renewable energy source



Wind as renewable energy source

Regions with network integration questions (DK;DE;ES)
Stochastic wind production

Seasonal/daily hydrogen storage

Low load factor; either electrolysis **or** fuel cell operation

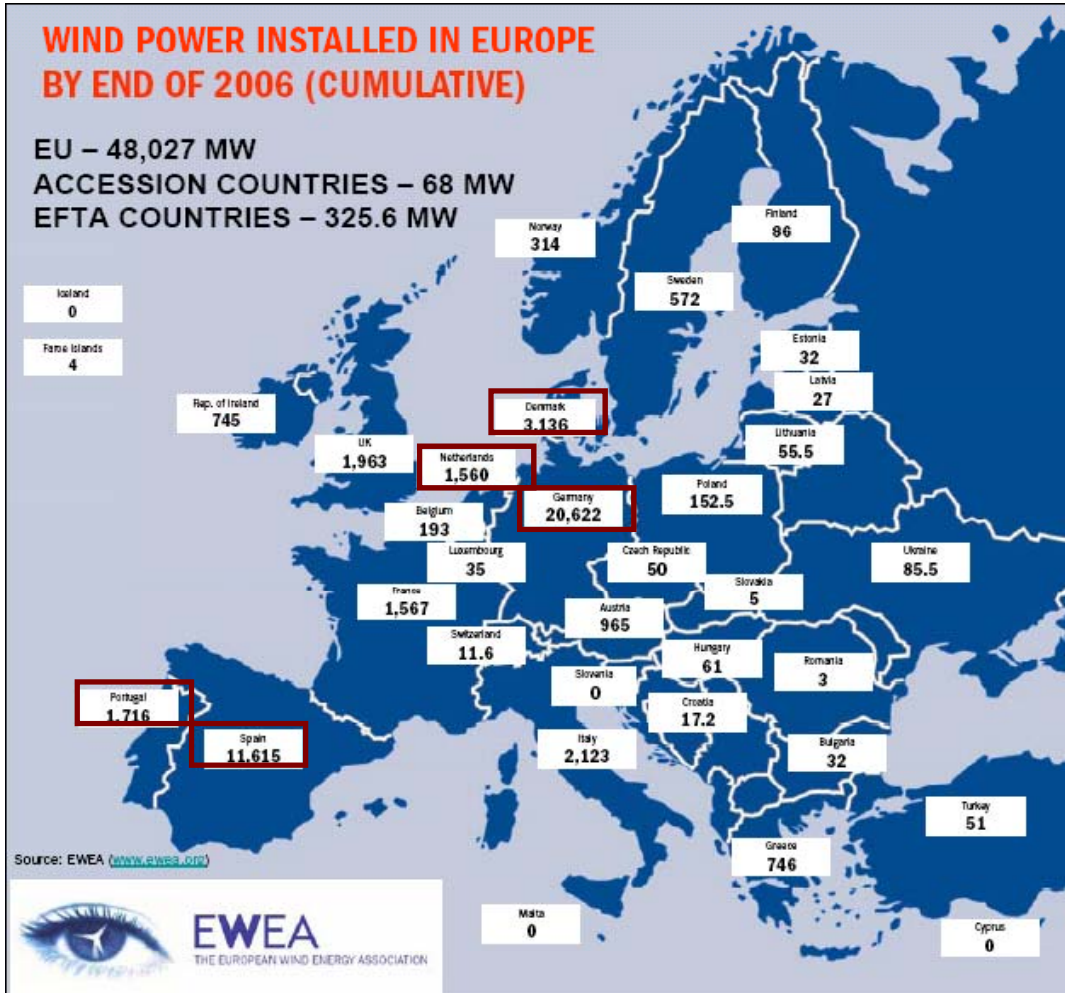
Round trip electrical efficiency 31%

- Electrolyser 67% (LHV) (= 80% HHV)
- Compression/transport/storage 90%
- Fuel cell system 50% (LHV) (=42% HHV)

Electrolysers

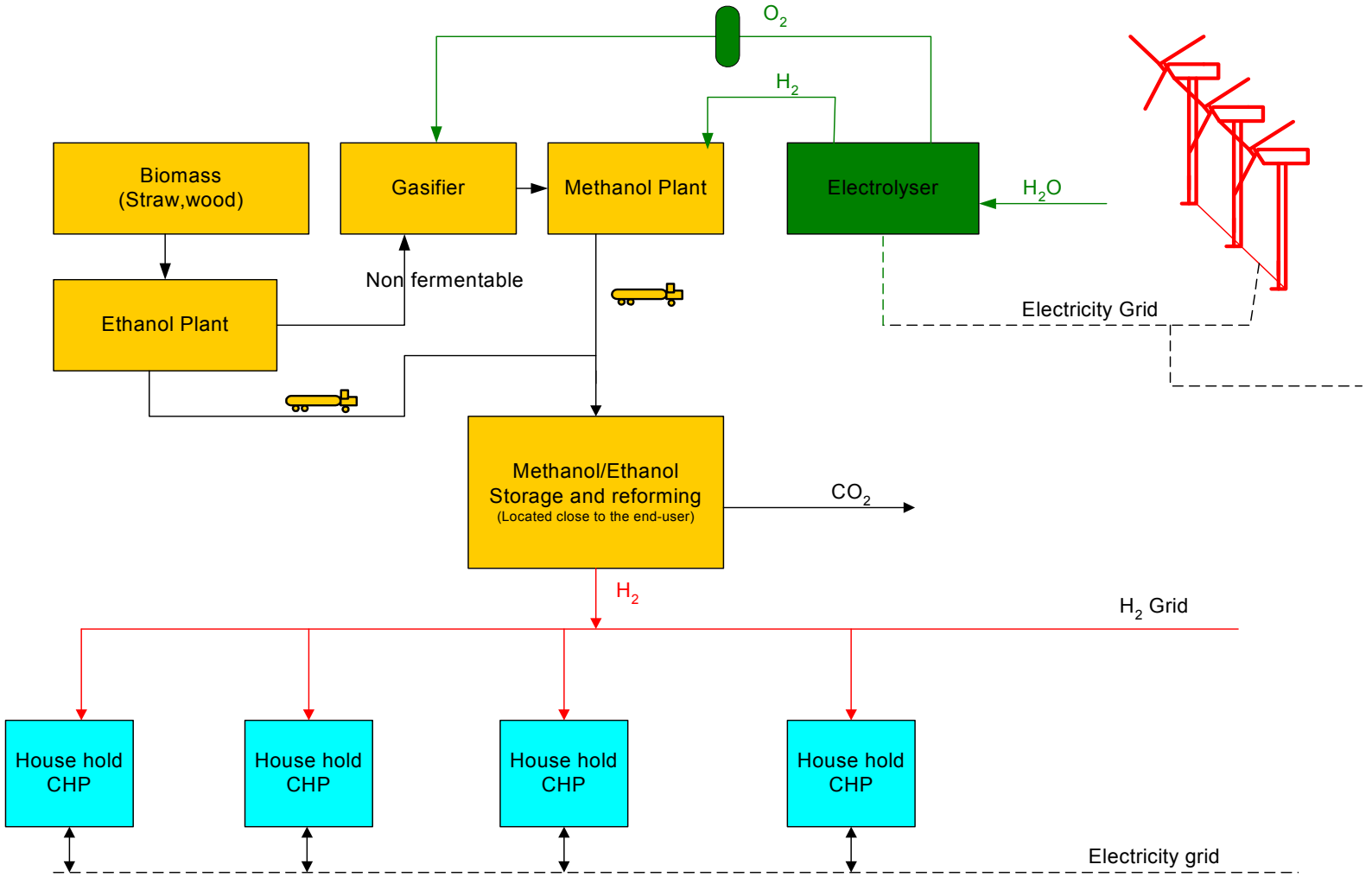
Presentation Lars Yde

Wind as renewable energy source



Germany	20.6 GW
Spain	11.6 GW
Denmark	3.1 GW
Portugal	1.7 GW
Netherlands	1.6 GW

Biomass and Wind as renewable energy source



Biomass and Wind as renewable energy source

Transportation of (m)ethanol to households in more remote areas.

Biomass to (m)ethanol still in development scale;
Estimated future fuel price 17 €/GJ
Methanol from NG is standard process
Market fuel price 12.5 €/GJ
Methanol reforming and H_2 purification is possible (75% efficiency)

FCHS initiatives

Denmark
- Herning (200 units).
- Nolsoy, Sonderborg and Nakskov (200 units).

Germany
- 450 units in 2010.
- 2250 units in 2012.

Netherlands
- 10.000 SOFC units/yr from 2009 (if specs are met).

Spain; Portugal; Iceland
- Small scale demonstrations.

Favourable policy framework

Existing:

- EU target of 30 % GHG reduction in 2020
- Public awareness of climate change
- RES- subsidies and support

Required:

- Subsidy for fuel cell or μ-CHP electricity
- Legislation for H_2: Preliminary NEN-EN 50465

Other issues

Barriers:

- Cost of fuel cell residential system
- Low heat demand in Spain/Portugal

Other developments:

- H_2 use for transport
- Competing technologies
  - Solar heating in Spain and Portugal
  - Geothermal energy in Iceland
  - MCFC (Biogas)
  - Stirling (on NG)
  - SOFC (on NG)

Acknowledgement

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Thank you for your attention!