HydrogenDays 2014

Praha, 2 to 4 April 2014

UNIVERSITY OF BIRMINGHAM

Fuel Cells and Hydrogen – What can they offer for our energy future?

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School of Chemical Engineering
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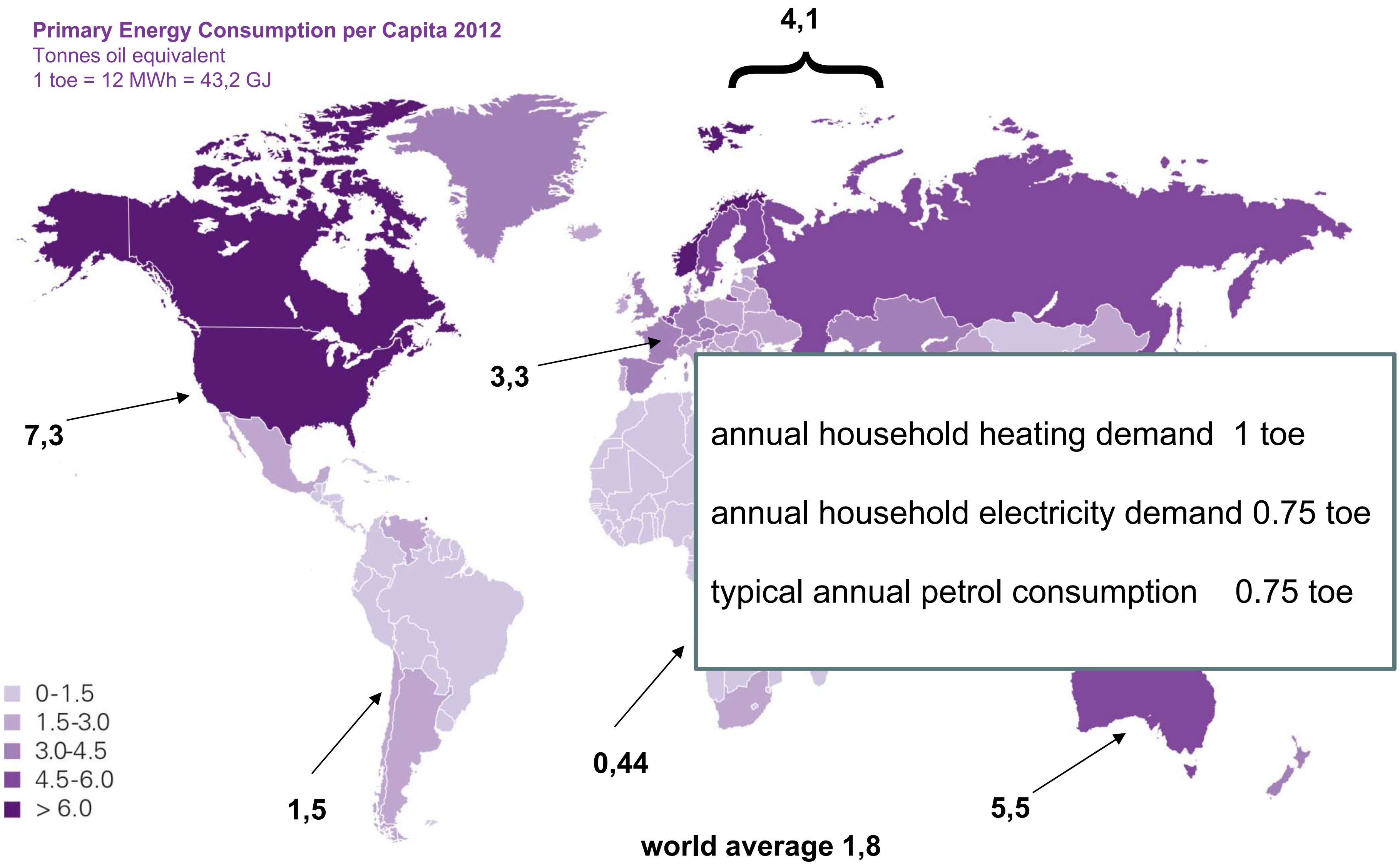
The World Needs Energy

Primary Energy Consumption per Capita 2012
Tonnes oil equivalent
1 toe = 12 MWh = 43,2 GJ



annual household heating demand 1 toe

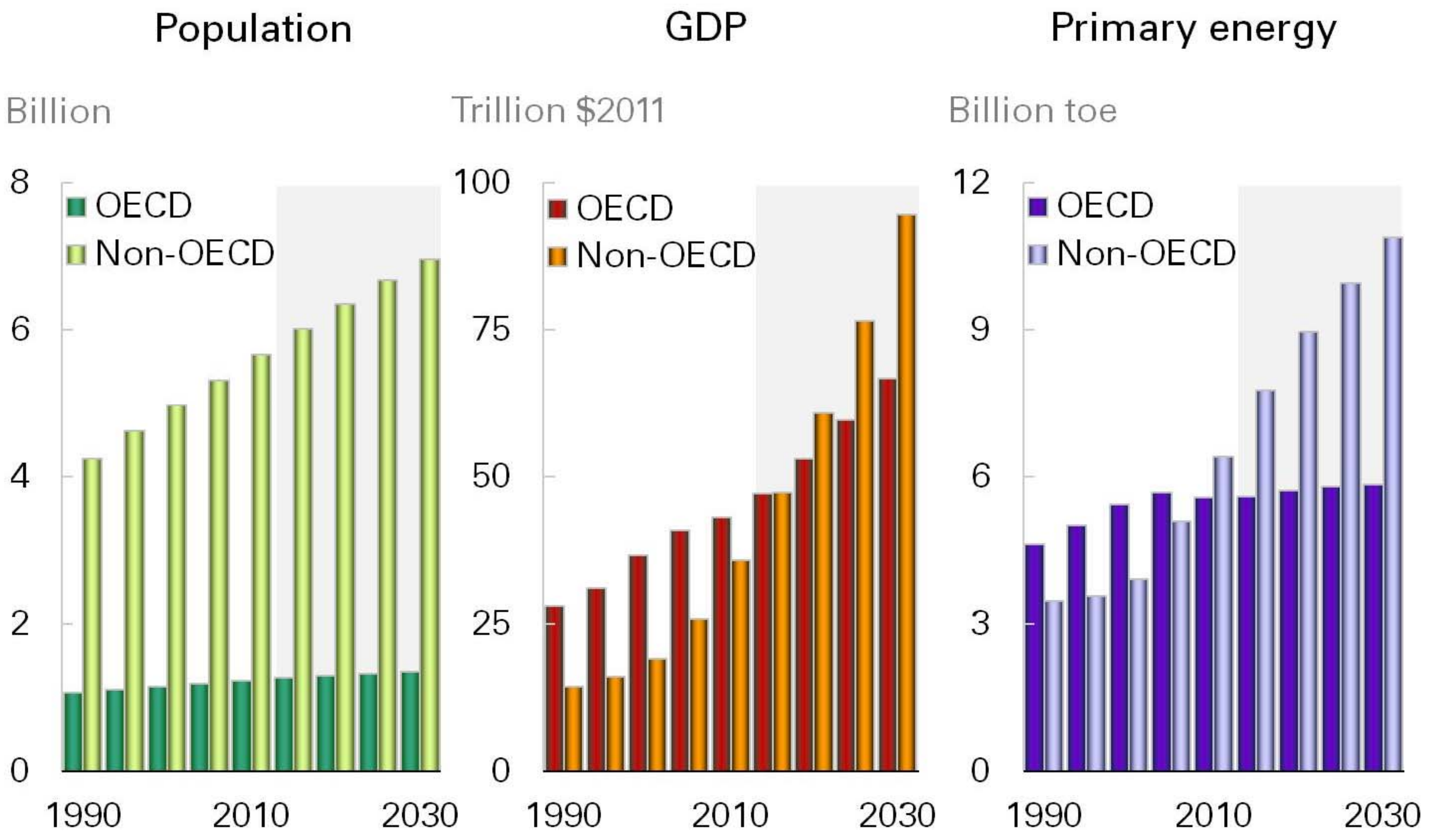
annual household electricity demand 0.75 toe

typical annual petrol consumption 0.75 toe

world average 1,8

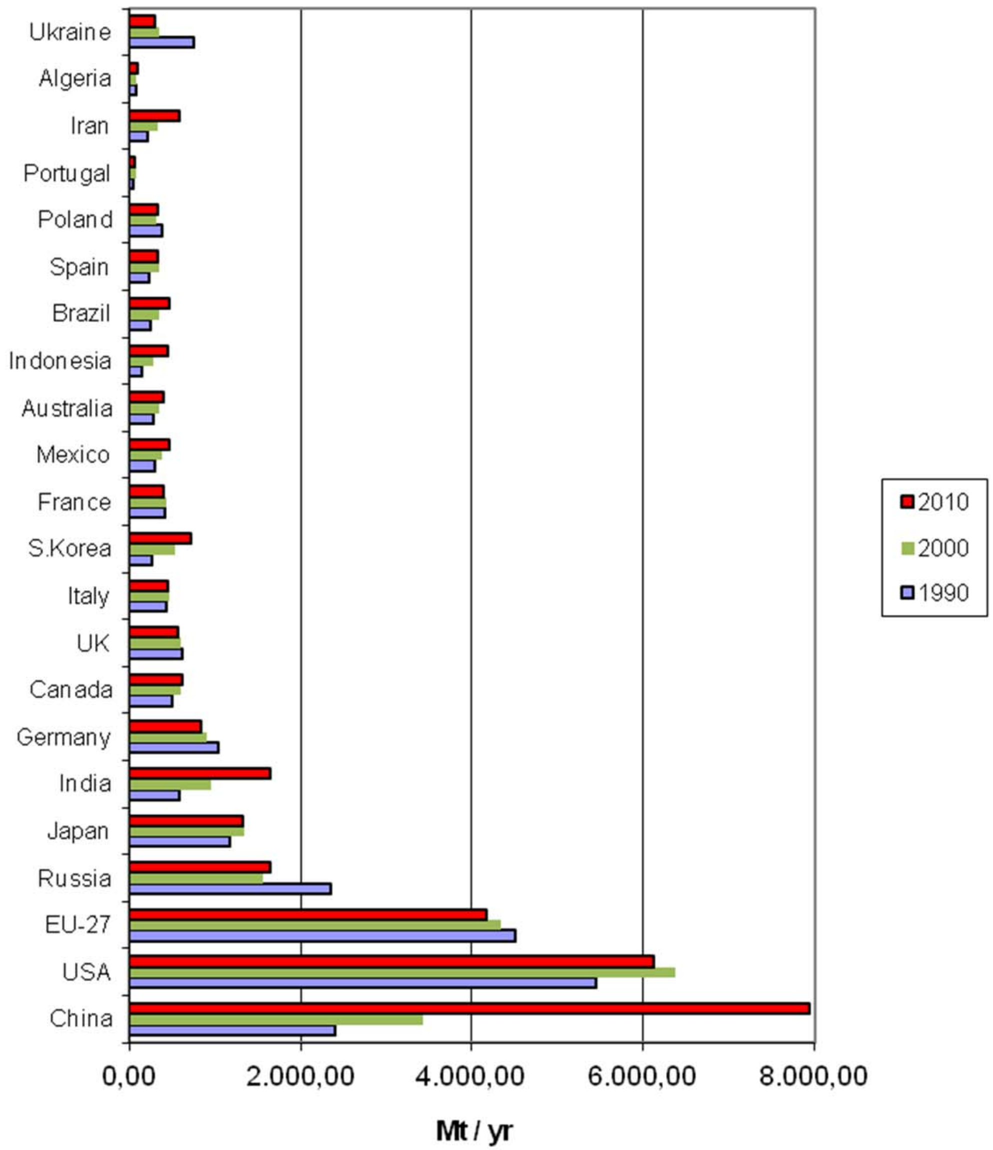
Source: BP 2013

OECD and non-OECD Developments



Source: BP 2013

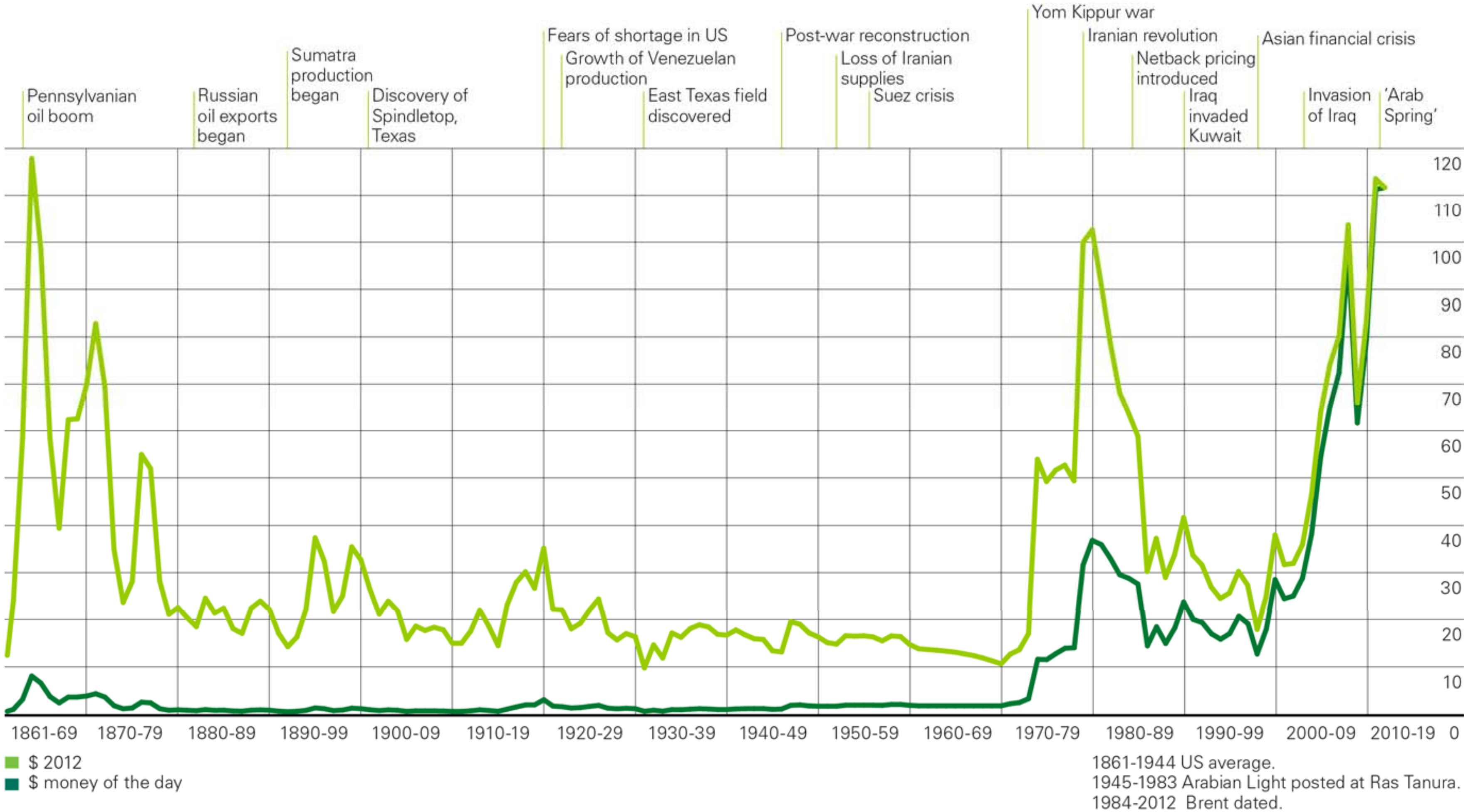
Changes in World CO_2 Release (1990 to 2010)



Data sources: BP 2013/wikipedia

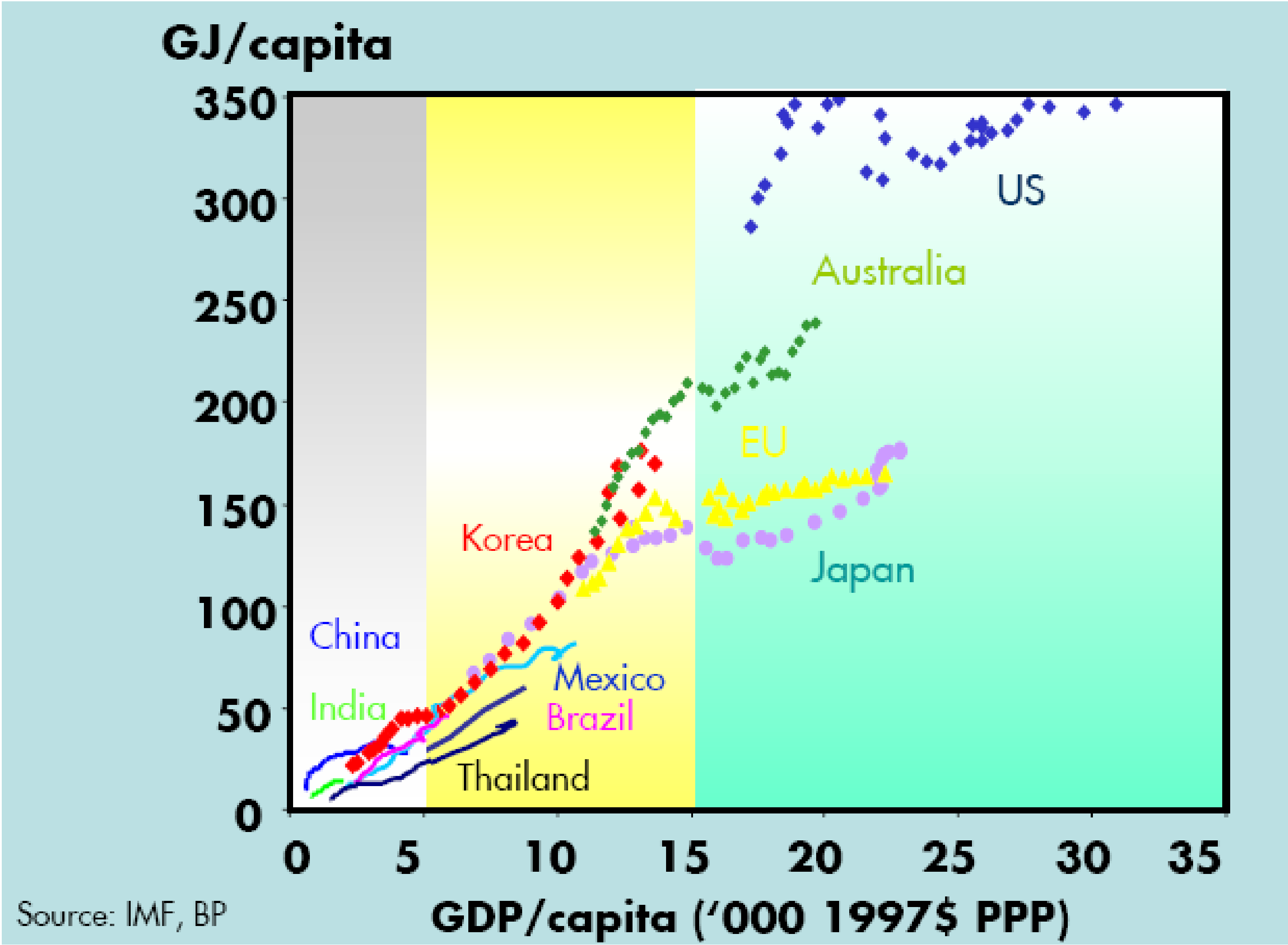
Crude Oil Prices

US$ / barrel



Source: BP 2013

GDP and Energy Consumption



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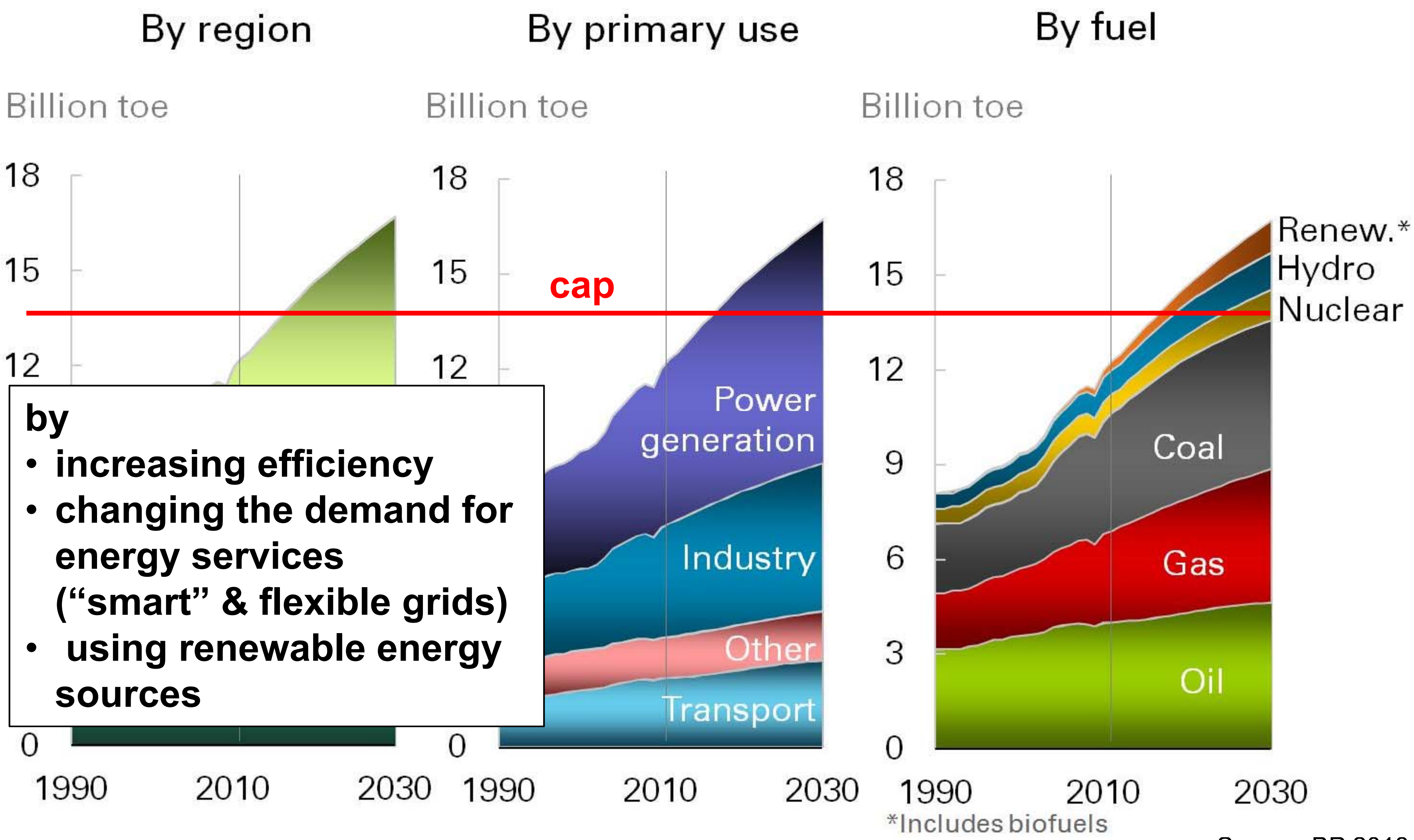
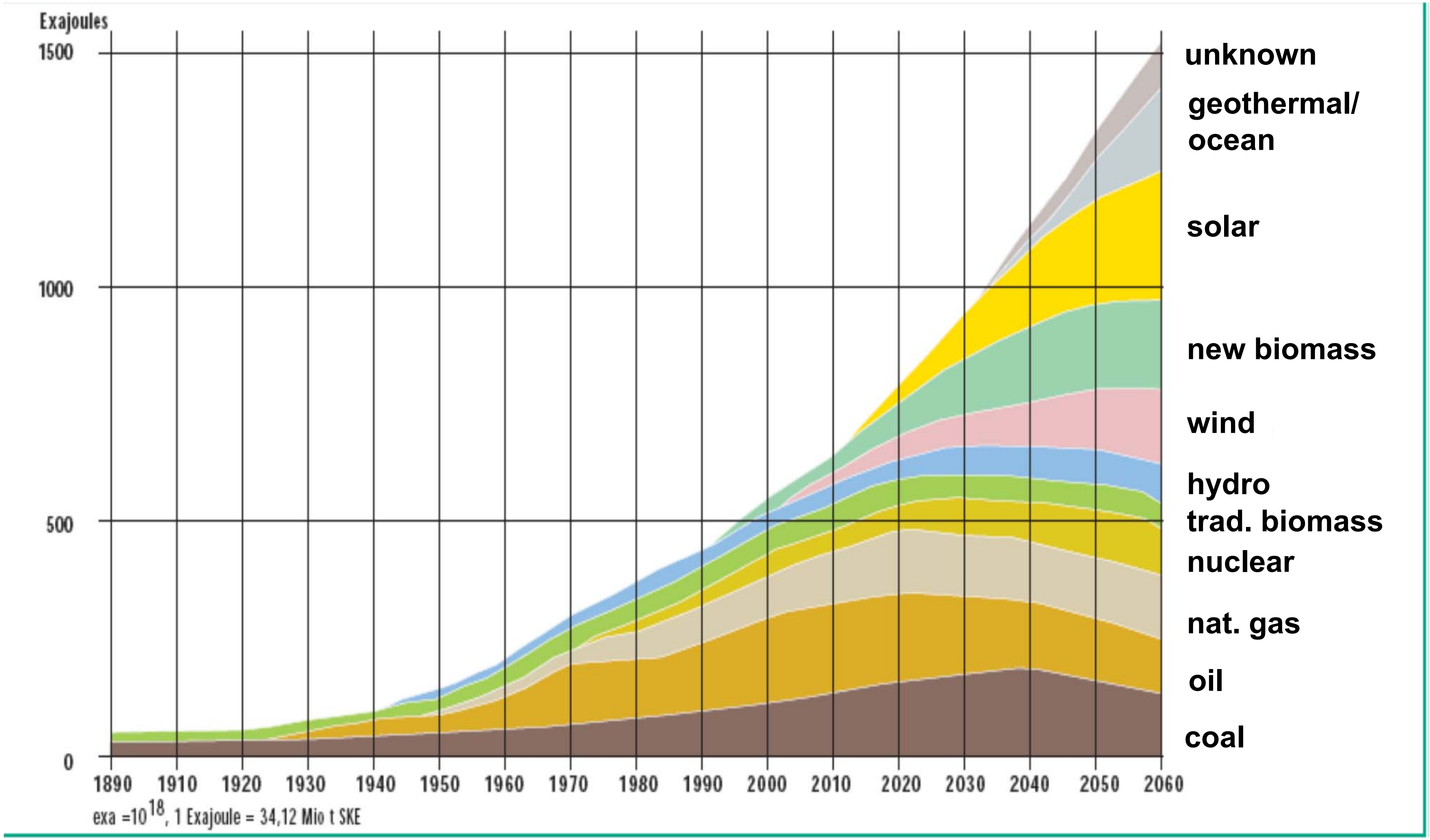
Future Scenarios of World Energy Demand



by
- **increasing efficiency**
- **changing the demand for energy services ("smart" & flexible grids)**
- **using renewable energy sources**

Source: BP 2013

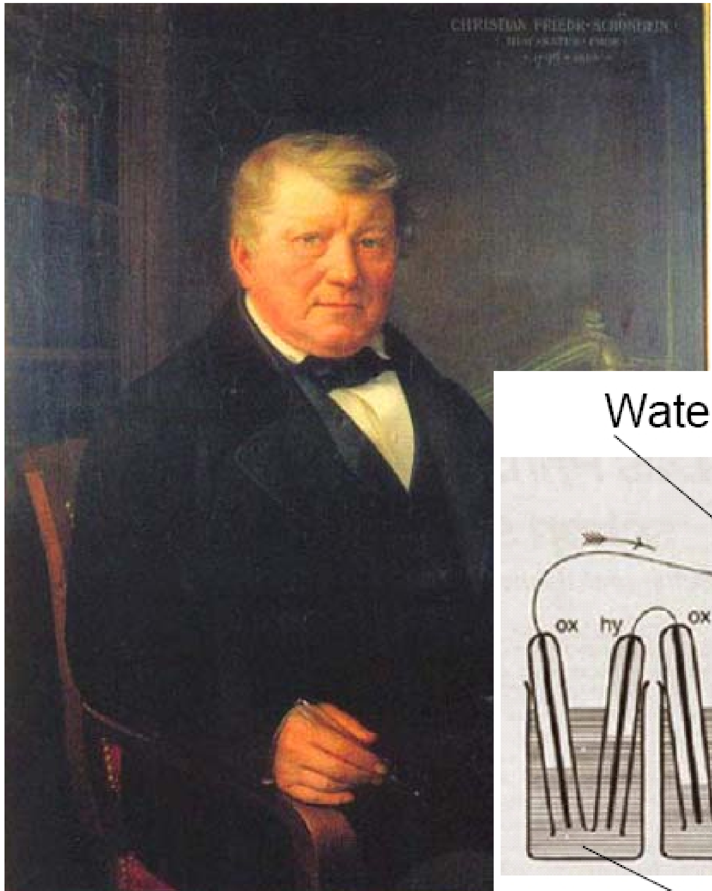
Shell World Energy Scenario (‚thinkable‘ development)



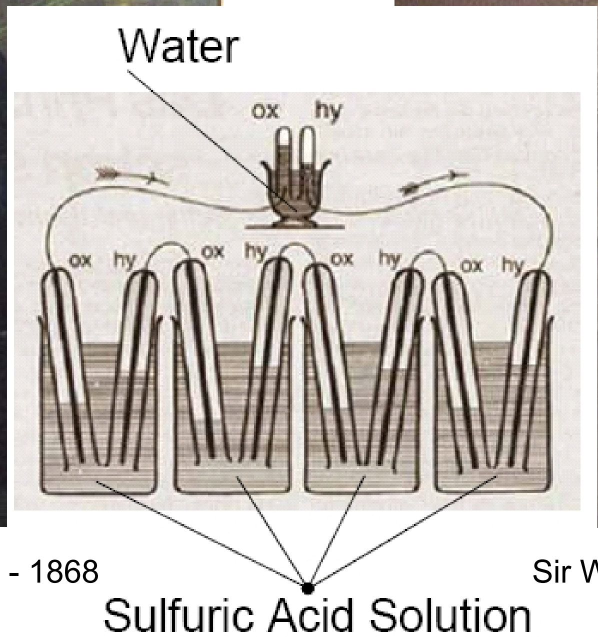
Source: Deutsche Shell , 1999

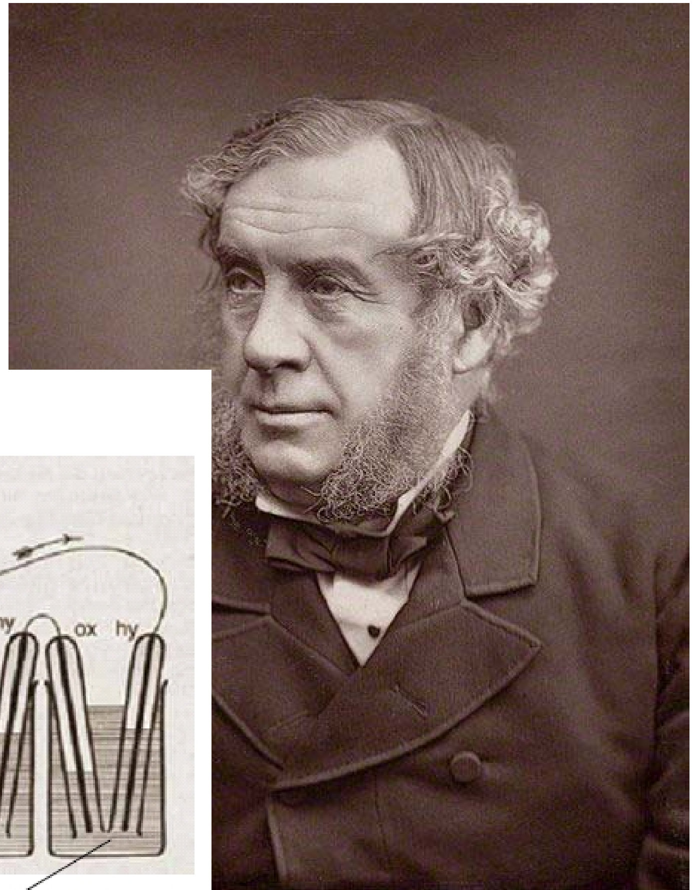
How Can Fuel Cells Contribute?

Discoverers of the Fuel Cell Principle



Christian Friedrich Schönbein (1799 - 1868





Sir William Robert Grove (1811 – 1896)

Proton Conducting Fuel Cell Principle

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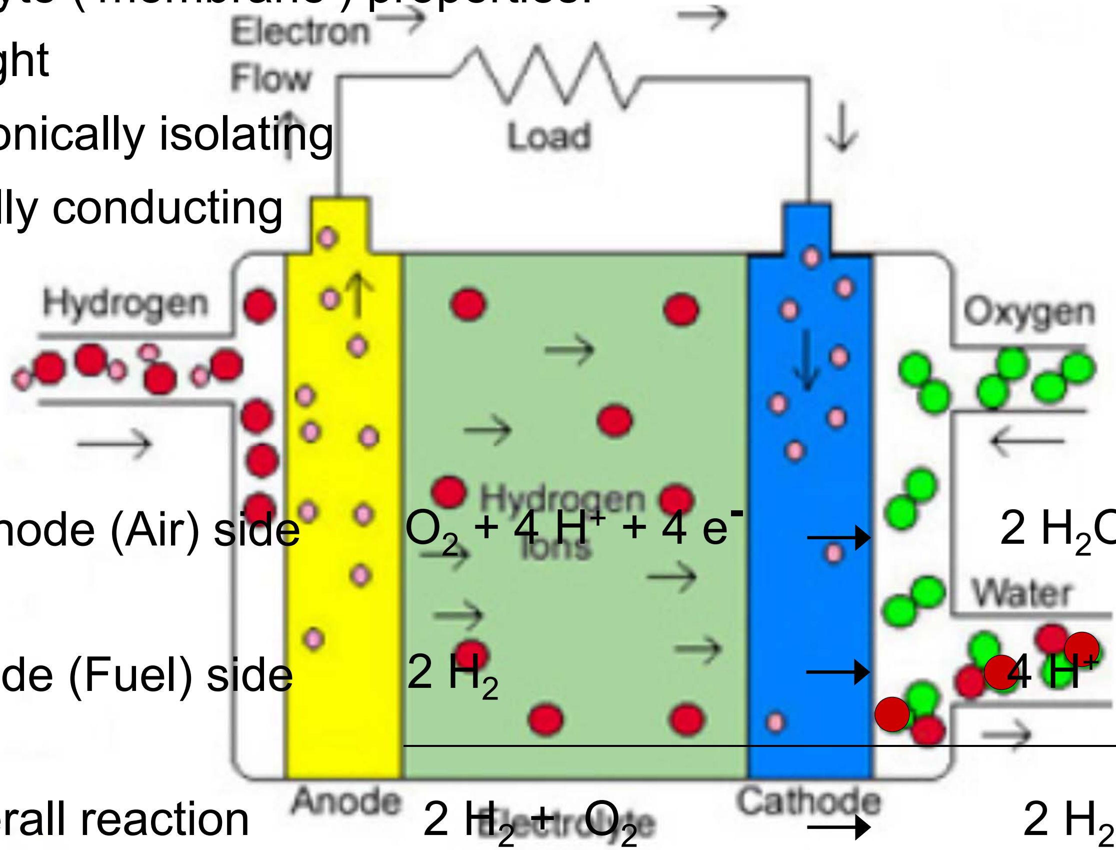
electrolyte ('membrane') properties:
- gas tight
- electronically isolating
- ionically conducting



Cathode (Air) side $O_2 + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O$

Anode (Fuel) side $2\,H_2 \rightarrow 4\,H^+ + 4\,e^-$

Overall reaction $2\,H_2 + O_2 \rightarrow 2\,H_2O$

in other electrolytes: O^{--} ions right to left

Other Types of Fuel Cells

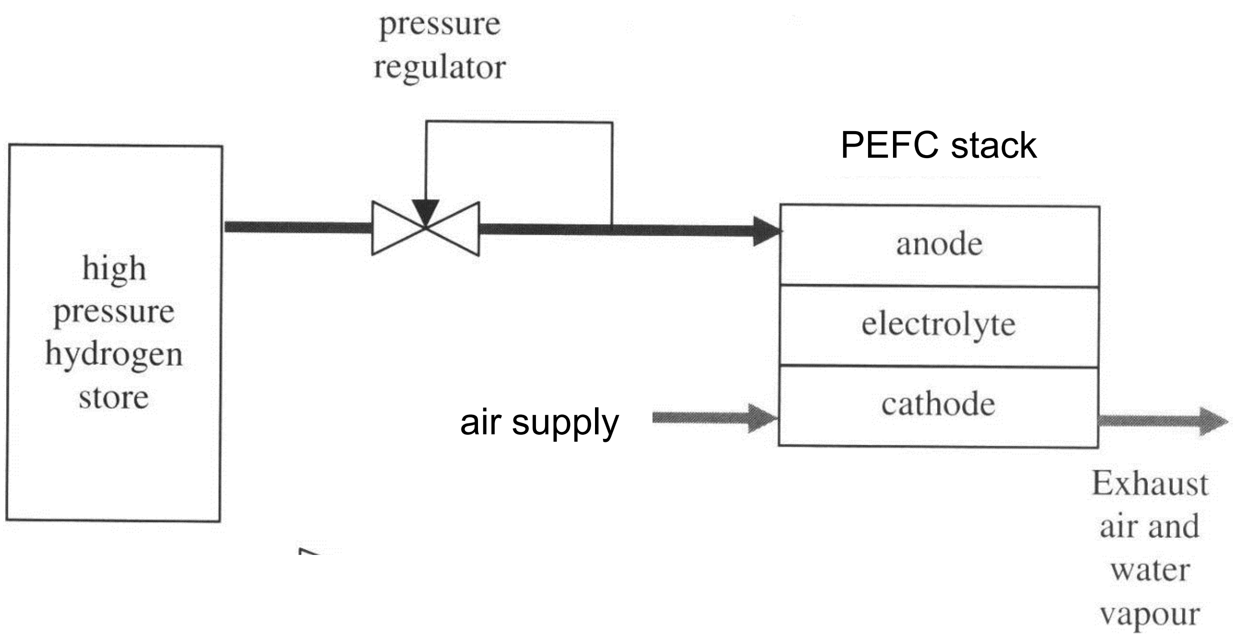
liquid electrolytes:	alkaline or phosphoric acid (AFC and PAFC)
molten salt electrolytes:	molten carbonates (MCFC)
ceramic electrolytes:	solid oxides (SOFC)

Typology:

Low temperature (PEFC, AFC, PAFC) – 80 to 200 °C – hydrogen

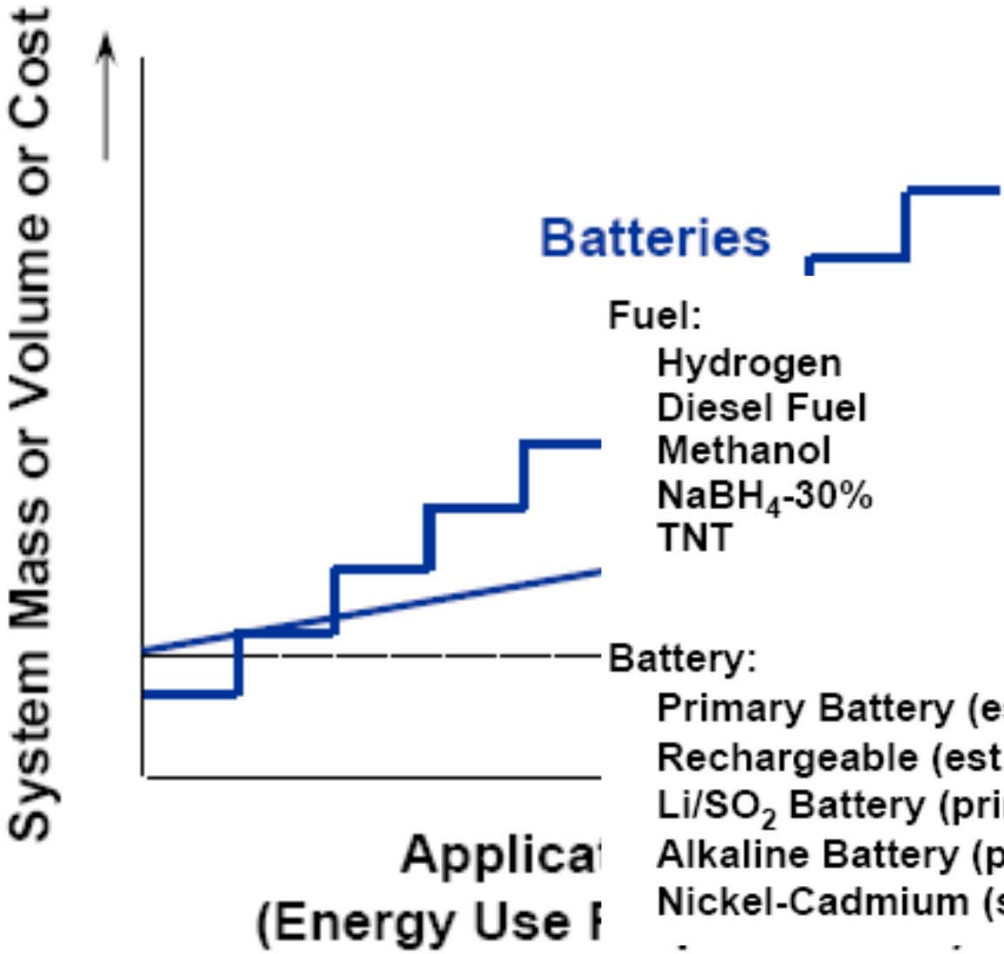
High temperature (MCFC, SOFC) – 500 to 900 °C – hydrogen and hydrocarbons

The Beauty of Simplicity



Source: adapted from Larminie/Dicks

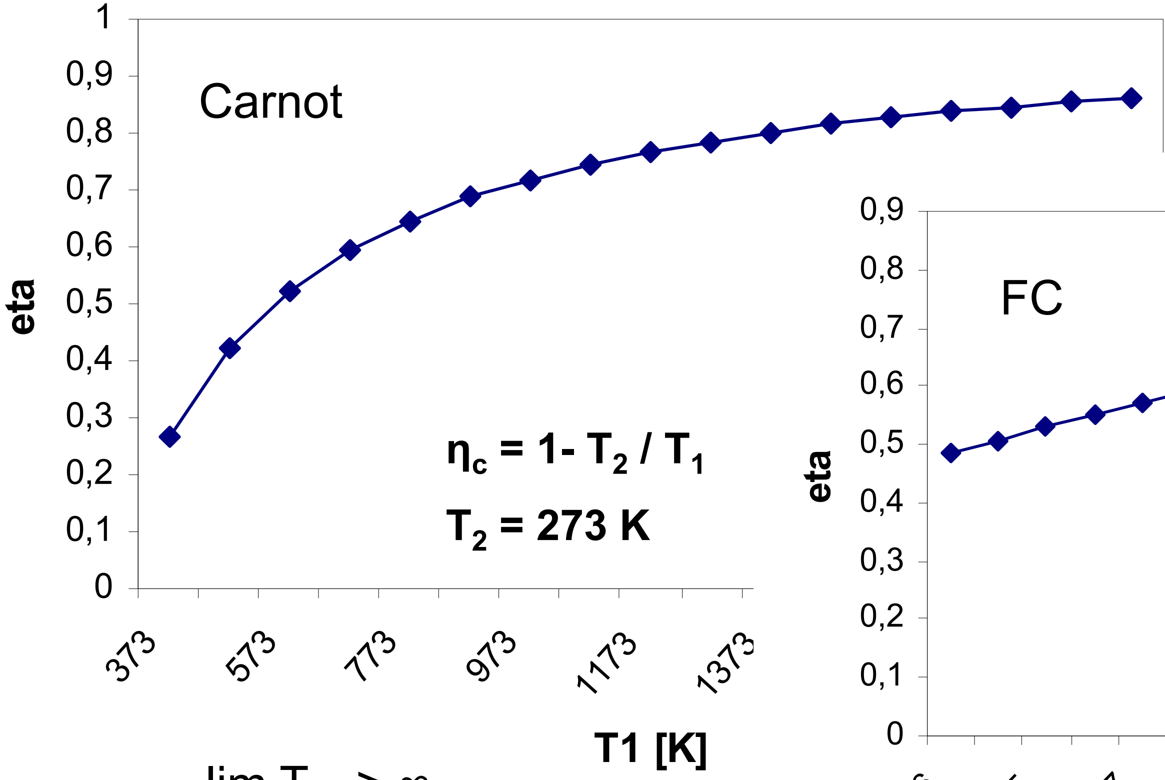
Competing with Batteries



Fuel:	Specific Energy (Wh/kg)
Hydrogen	33,000
Diesel Fuel	13,200
Methanol	6,200
$NaBH_4$-30%	2,500
TNT	1,400
Battery:	
Primary Battery (est. max.)	500
Rechargeable (est. max.)	200
Li/SO_2 Battery (primary)	176
Alkaline Battery (primary)	80
Nickel-Cadmium (secondary)	40

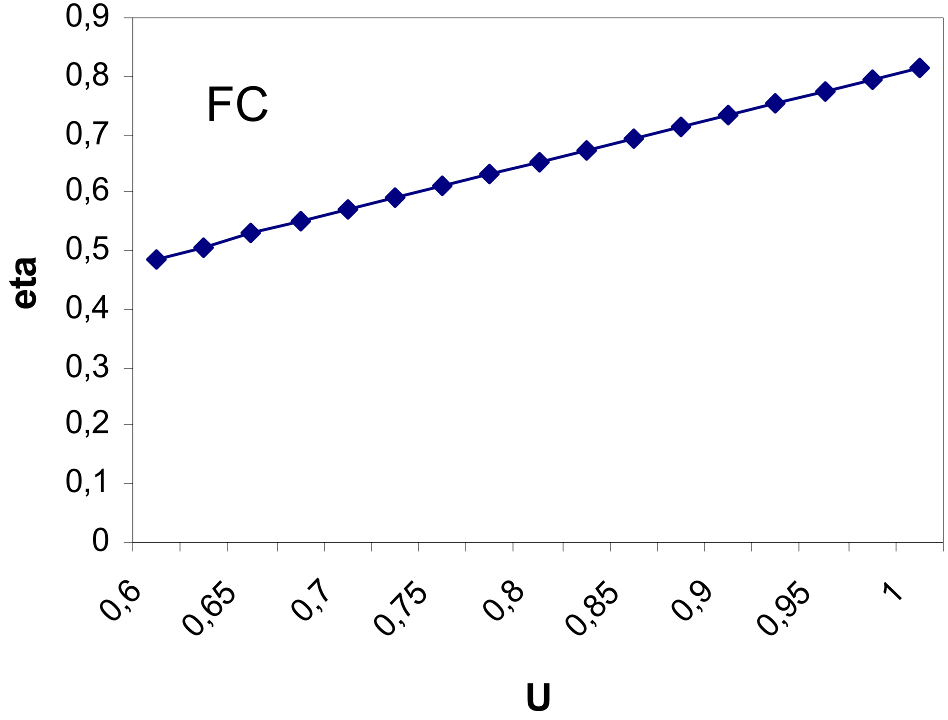
Source: AZ State Univ

Limiting Efficiencies



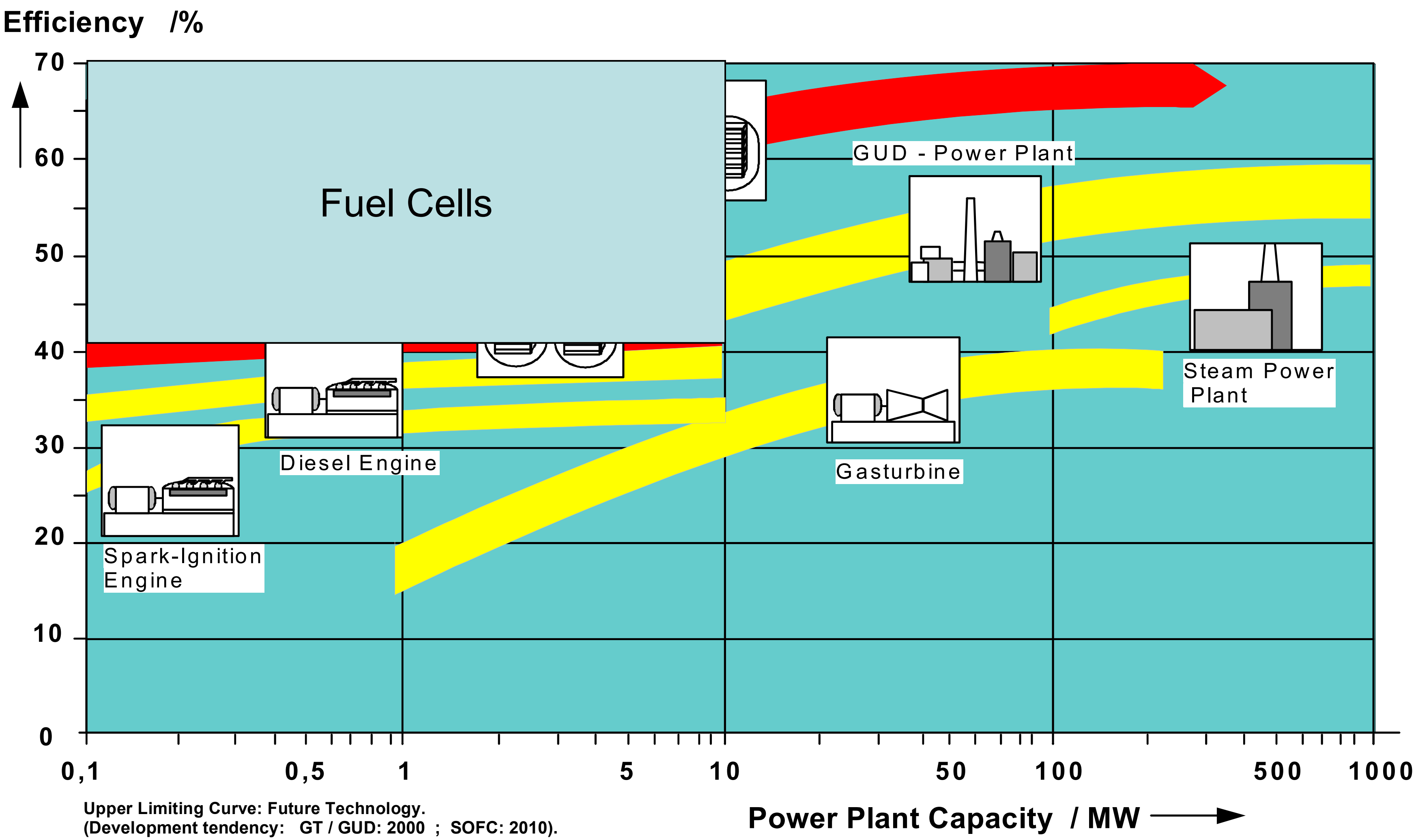
lim $T_1 \to \infty$

lim $T_2 \to 0$



lim $U \to U_o$

Fuel Cells: High Efficiency Electricity Production



Upper Limiting Curve: Future Technology.
(Development tendency: GT / GUD: 2000 ; SOFC: 2010).
Lower Limiting Curve: Actual Technology.

Source: adapted from Siemens graph

What Can Fuel Cells Do?

SFC ENERGY

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Fuel Cell Vehicles

DaimlerChrysler f-cell A & B class

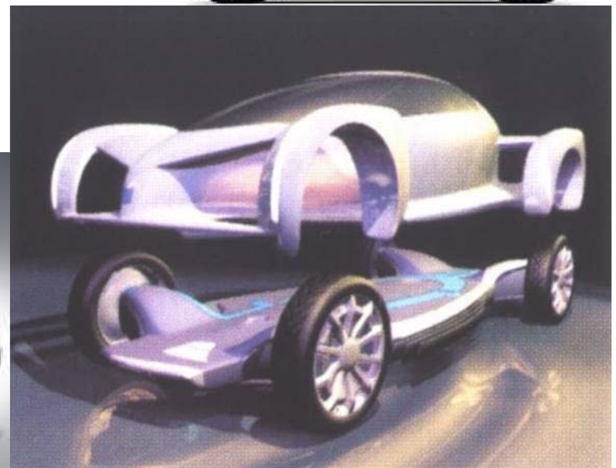
Hyundai

Proton Motor

MicroCab

Evobus

Toyota RAV4L V



Sources: various

Automobile: Appearance and handling

GM HiWire concept vehicle

GM Autonomy
concept vehicle

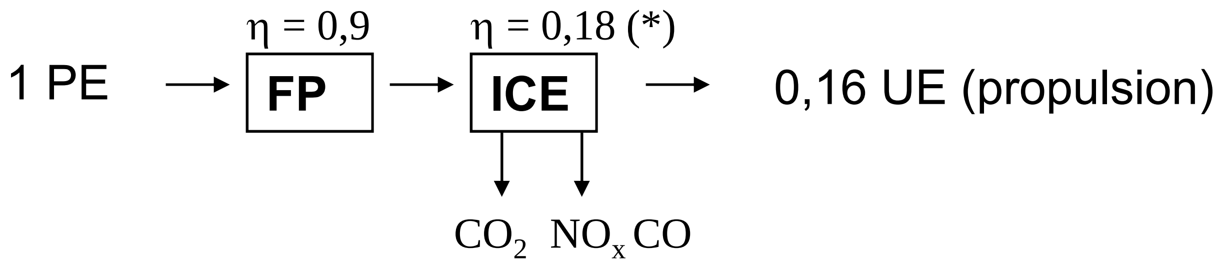
source: GM/Opel

Vehicle Efficiencies

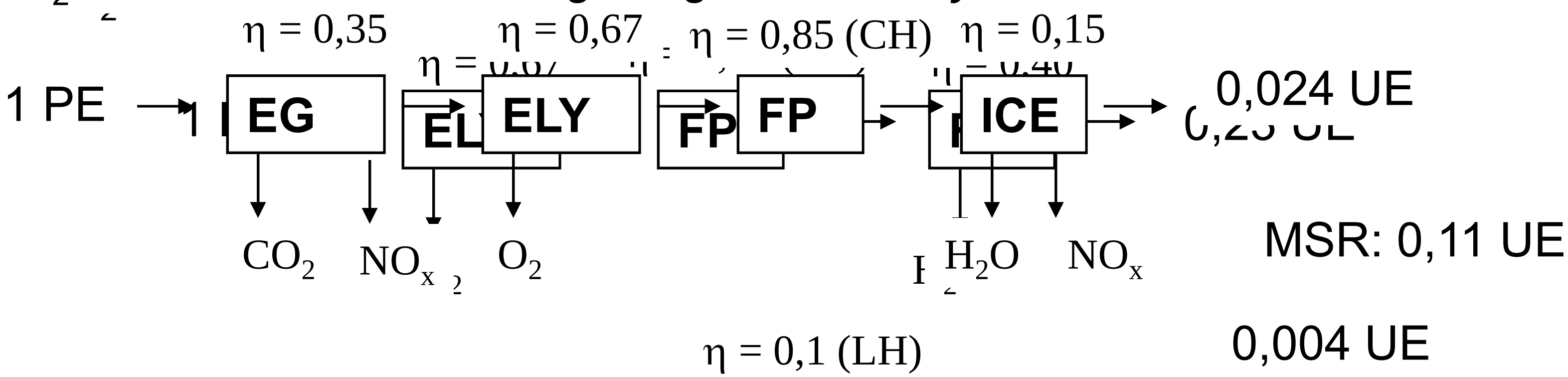
PE primary energy
UE useful energy
EG electricity generation
ICE internal combustion engine
FP fuel processing
CH compressed H_2

(*) in driving cycle

Internal combustion engine (diesel)

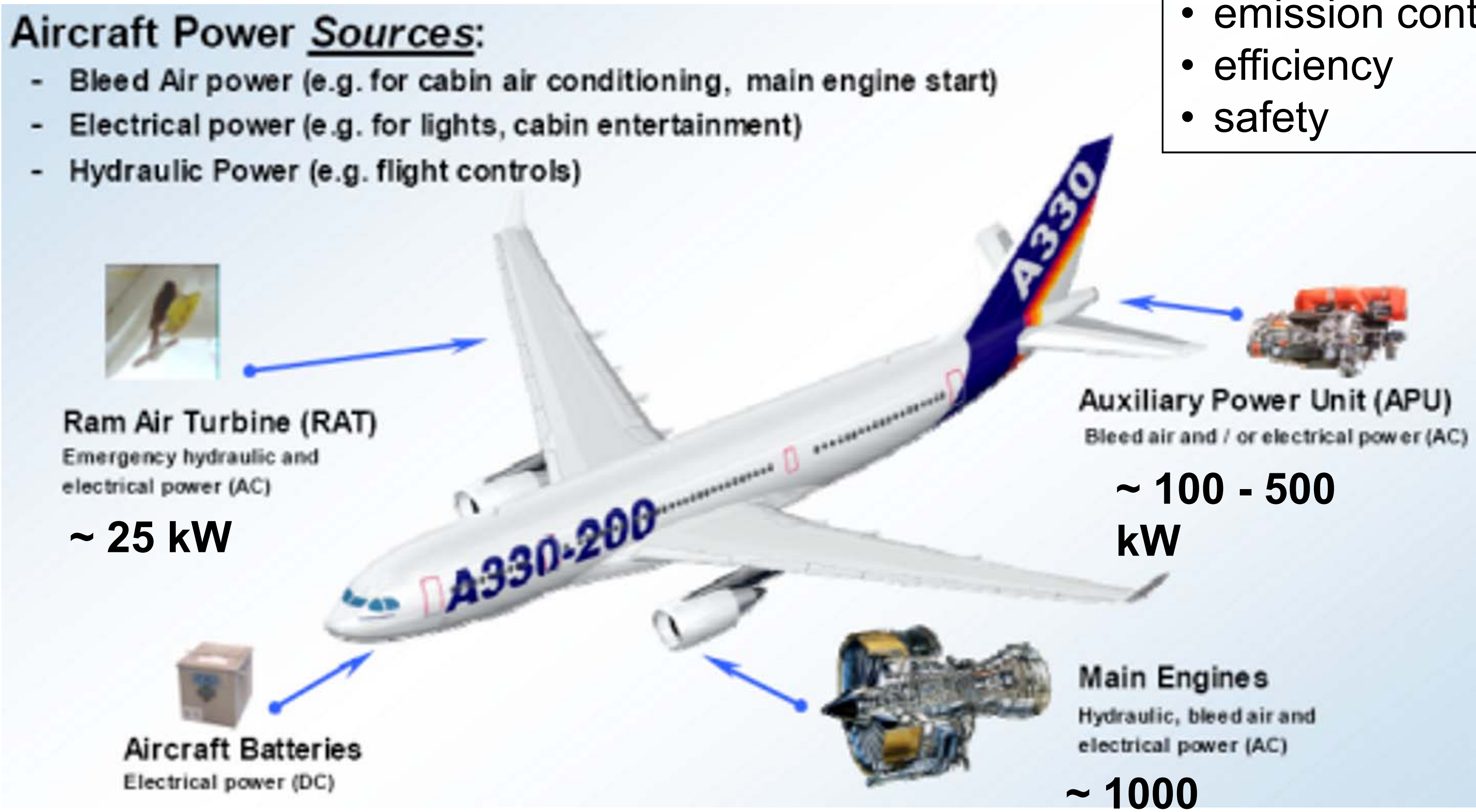


H_2 Internal combustion engine, grid electricity



Fuel Cells in Aircraft

- emission control
- efficiency
- safety



~ 25 kW

~ 100 - 500 kW

~ 3 kW

~ 1000 kW

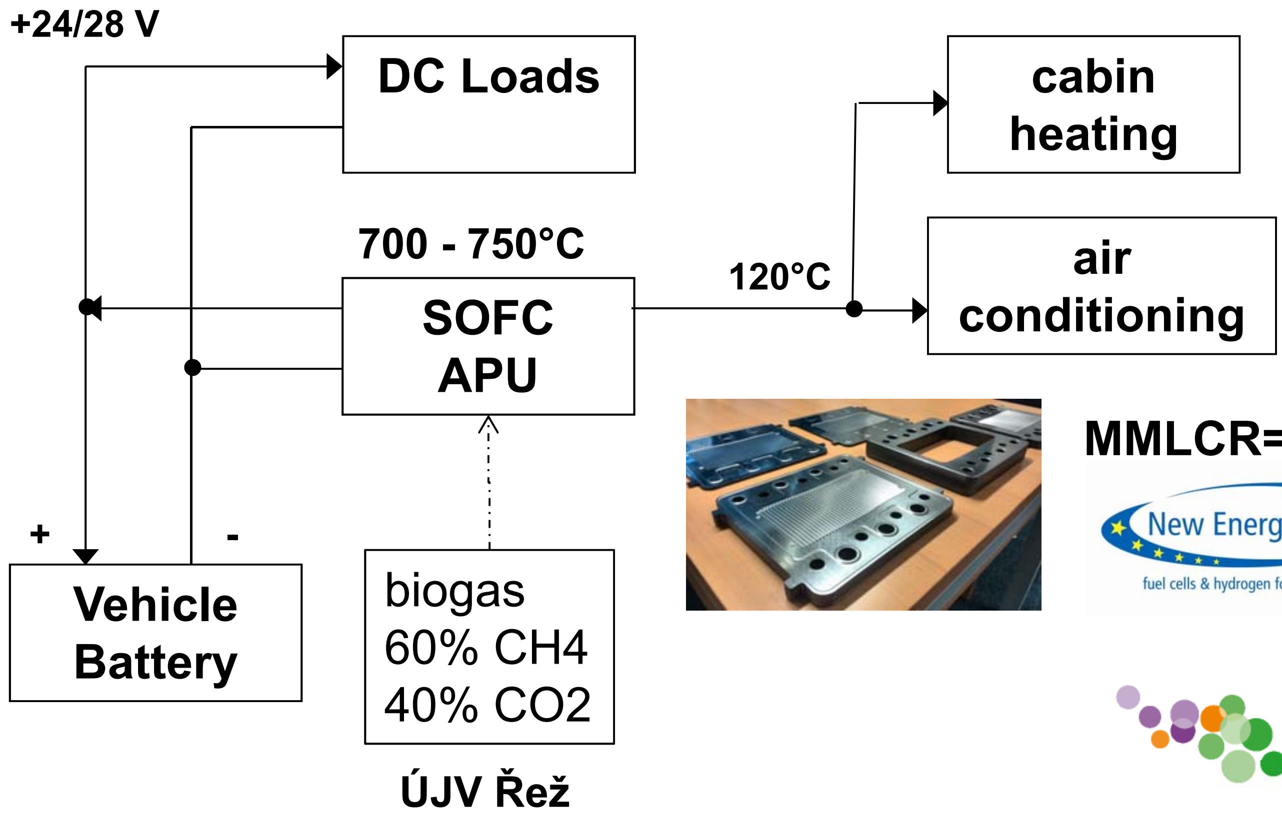
source: Airbus

Fuel Cells in Ships

- emission control
- efficiency
- safety

source: Wartsila, wikipedia & Lloyd‘s register

Electrical On-Board System Architecture with APU



MMLCR=SOFC

New Energy World JU
fuel cells & hydrogen for sustainability

Baltic Biogas Bus

ATI erc
ATI erc gGmbH
education - research - furtherance of cooperations

PLANET GbR

- no gas processing
- high electrical efficiency >50%

www.balticbiogasbus.eu

Added Value

fuel cells allow for new possibilities of use

- in electric vehicles
- in off-grid situations
- in replacing batteries

for

- more personal independence
- higher efficiencies and safety
- environmental benefits
- fuel flexibility

Residential Fuel Cell Units

BAXI PEFC
1 kW_e/1.7 kW_{th}
η_{el} = 32%
Integrated boiler

HEXIS SOFC
1 kW_e/2 kW_{th}
η_{el} = >30%
Integrated boiler

Viessmann / Panasonic (PEFC)
Vitovalor 300-P
700 W_{el}, 20 kW_{th}

Junkers / Aisin Seiki (Kyocera, SOFC)
Cerapower FC
700 W_{el}, 25 kW_{th}

Bloom Energy: Adobe, e-bay & Wal-Mart

- 100 and 200 kW units
- >150 installed (partly in ‚clusters‘)
- decentralised electricity generation, grid stabilisation & backup
- partly running on bio-fuels
- high subsidies (>50%)

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Efficiency and Efficiency Chains

PE primary energy
UE useful energy
EG electricity generation

Average Electricity Grid

1 PE → **EG** → 0,35 UE

CO_2 NO_x

reference case

Gas Engine CHP

1 PE → **CHP** → 0,6 UE heat ← 0,65 PE **condensing boiler**

→ 0,3 UE electricity ← 0,86 PE **electricity grid**

CO_2 NO_x

$\eta_{total} = 90\%$

$\sum = 1{,}51$ PE

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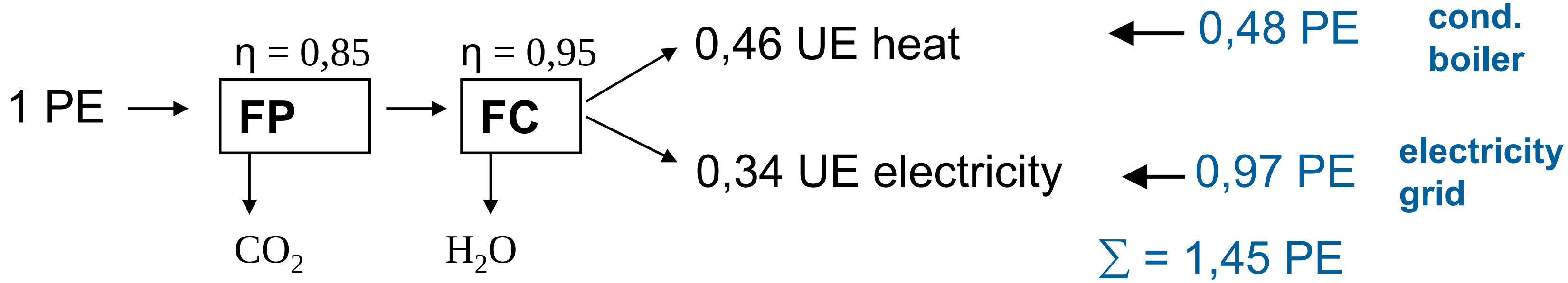
Fuel Cell Efficiency Chains

PE primary energy
UE useful energy
FC fuel cell
FP fuel processing

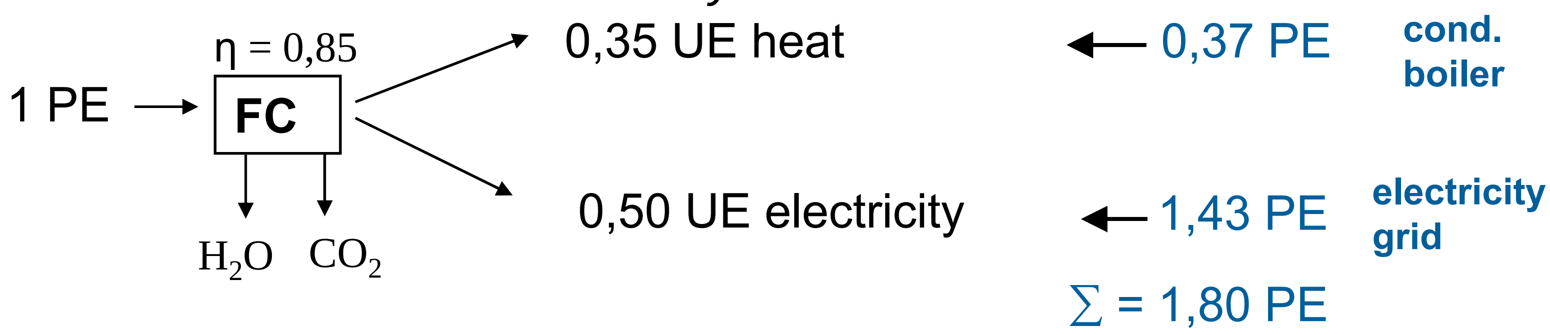
Natural Gas PEFC Residential System

reference case

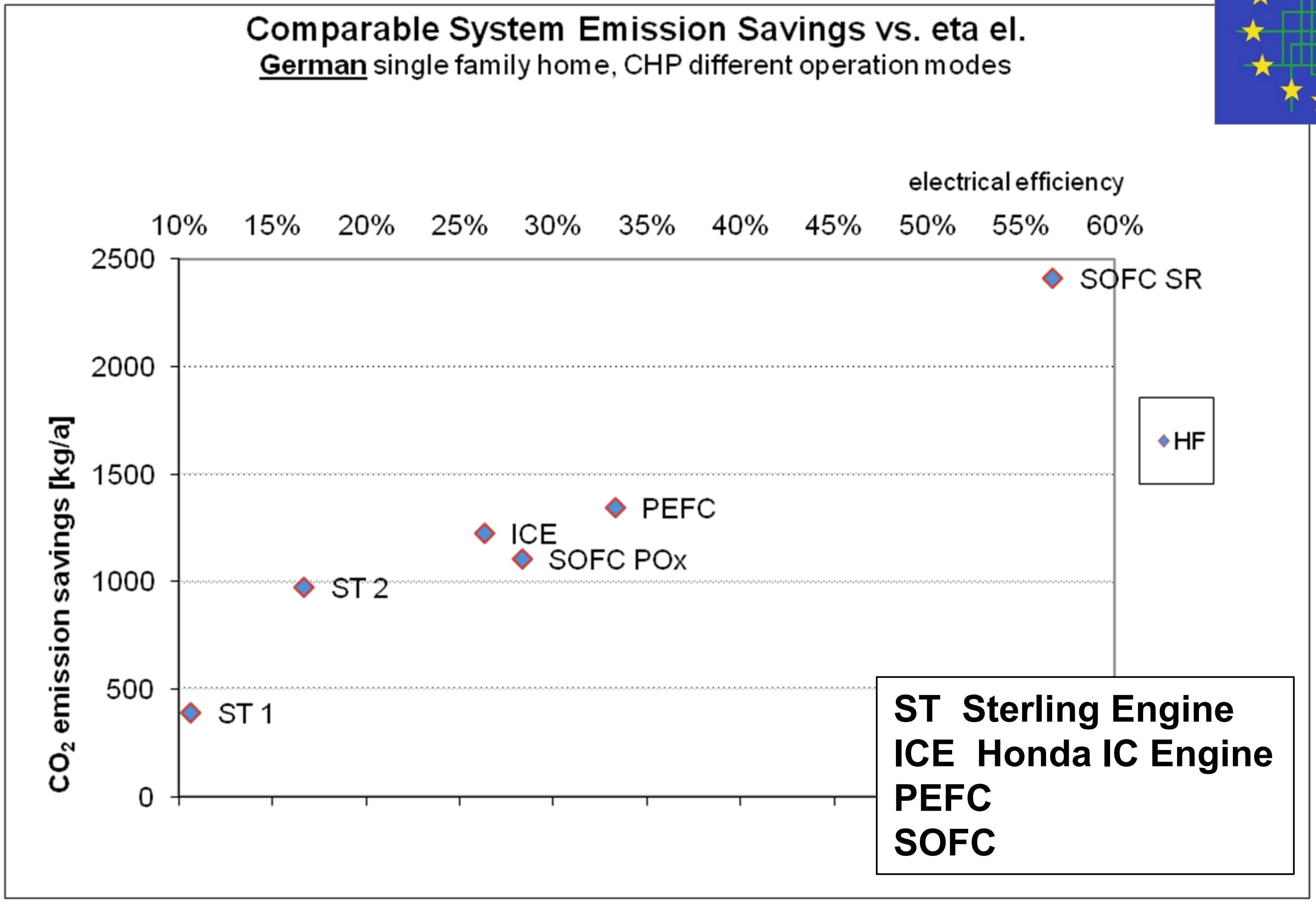


Natural Gas SOFC Residential System

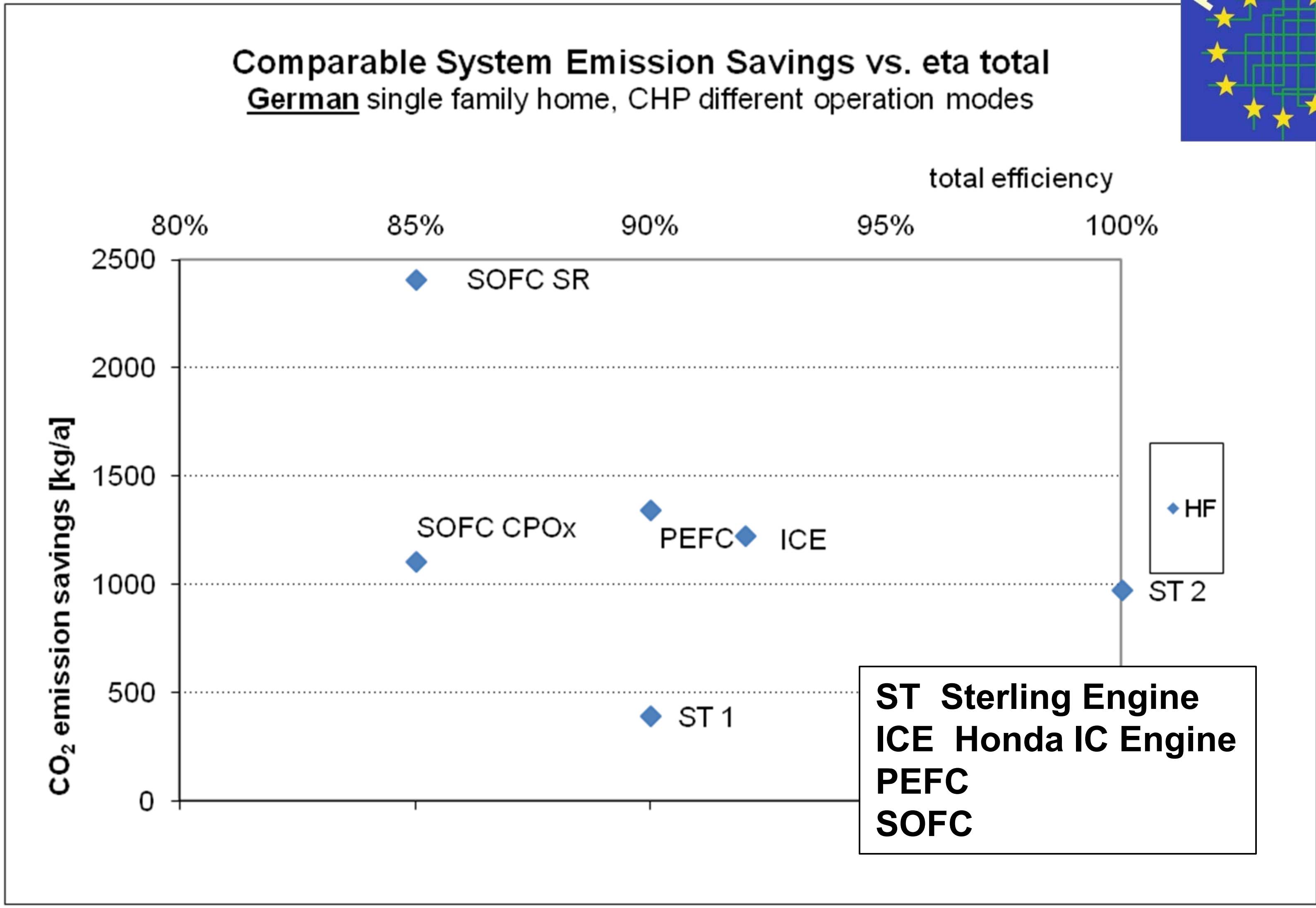
reference case



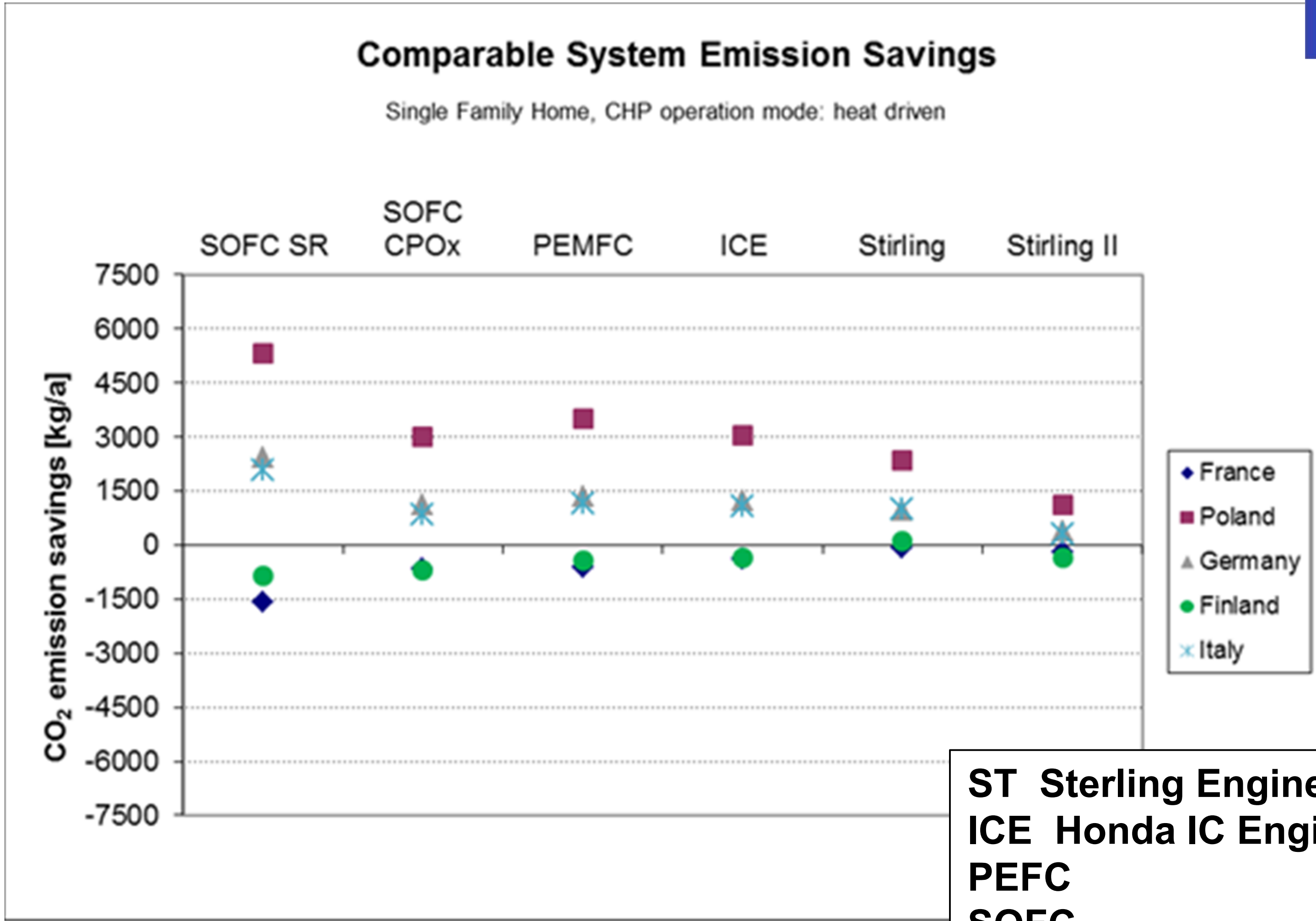
CO_2 Reduction and Electrical Efficiency



CO_2 Reduction and Total Efficiency



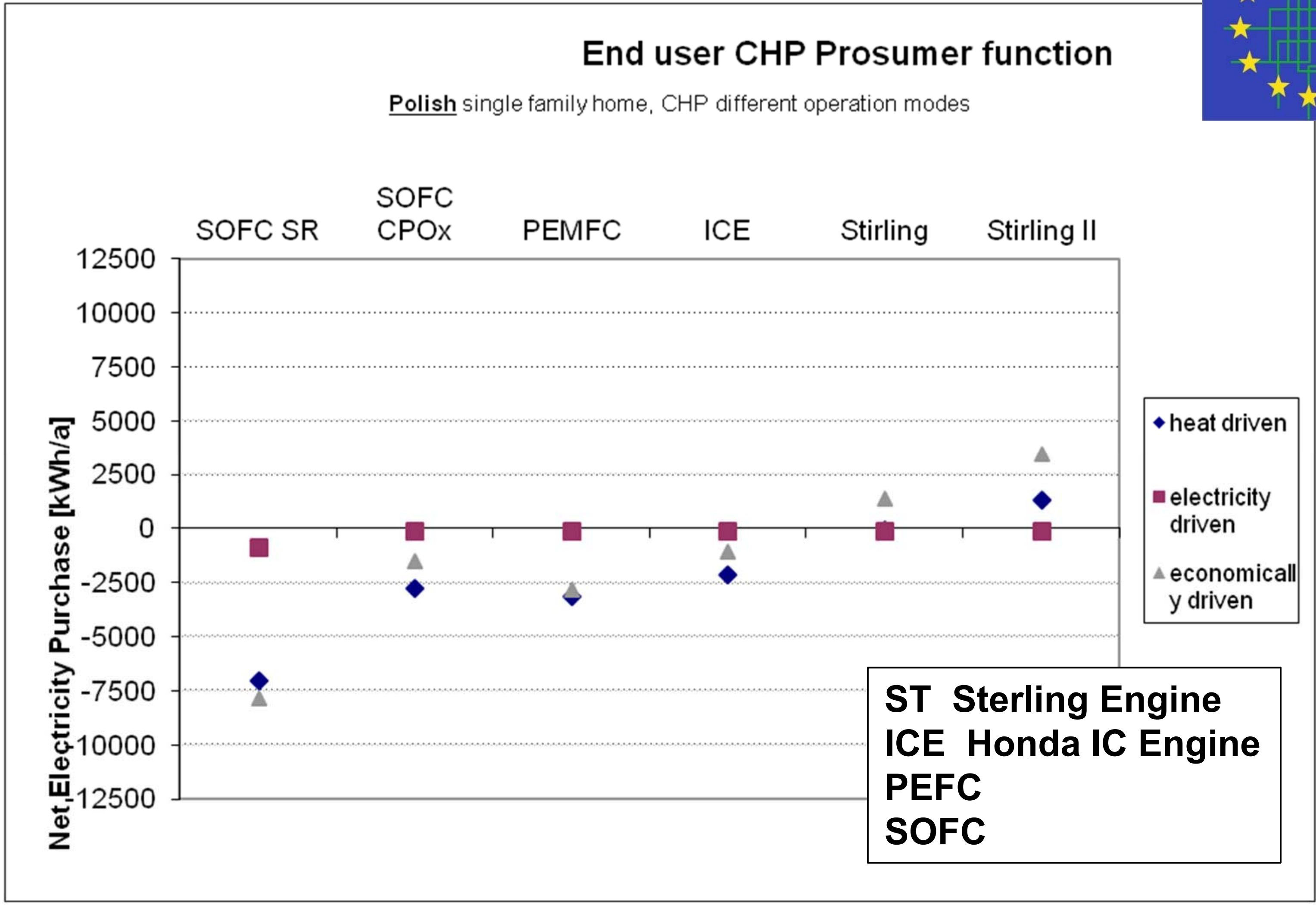
CO_2 Reduction and CO_2 Footprint



g/kWh
90
730
563
176
448

ST Sterling Engine
ICE Honda IC Engine
PEFC
SOFC

Consumer to ProSumer



Cautious Interpretation …

- results depend on the comparison reference:
  * single user choice
  * next replaced unit of electricity
- carbon footprints of grids will generally reduce in years to come
  * GHG saving benefits will dwindle
  * other functions of fuel cells will increase in importance (grid stability, fuel flexibility etc.)

Environmental Benefits

fuel cells can reduce

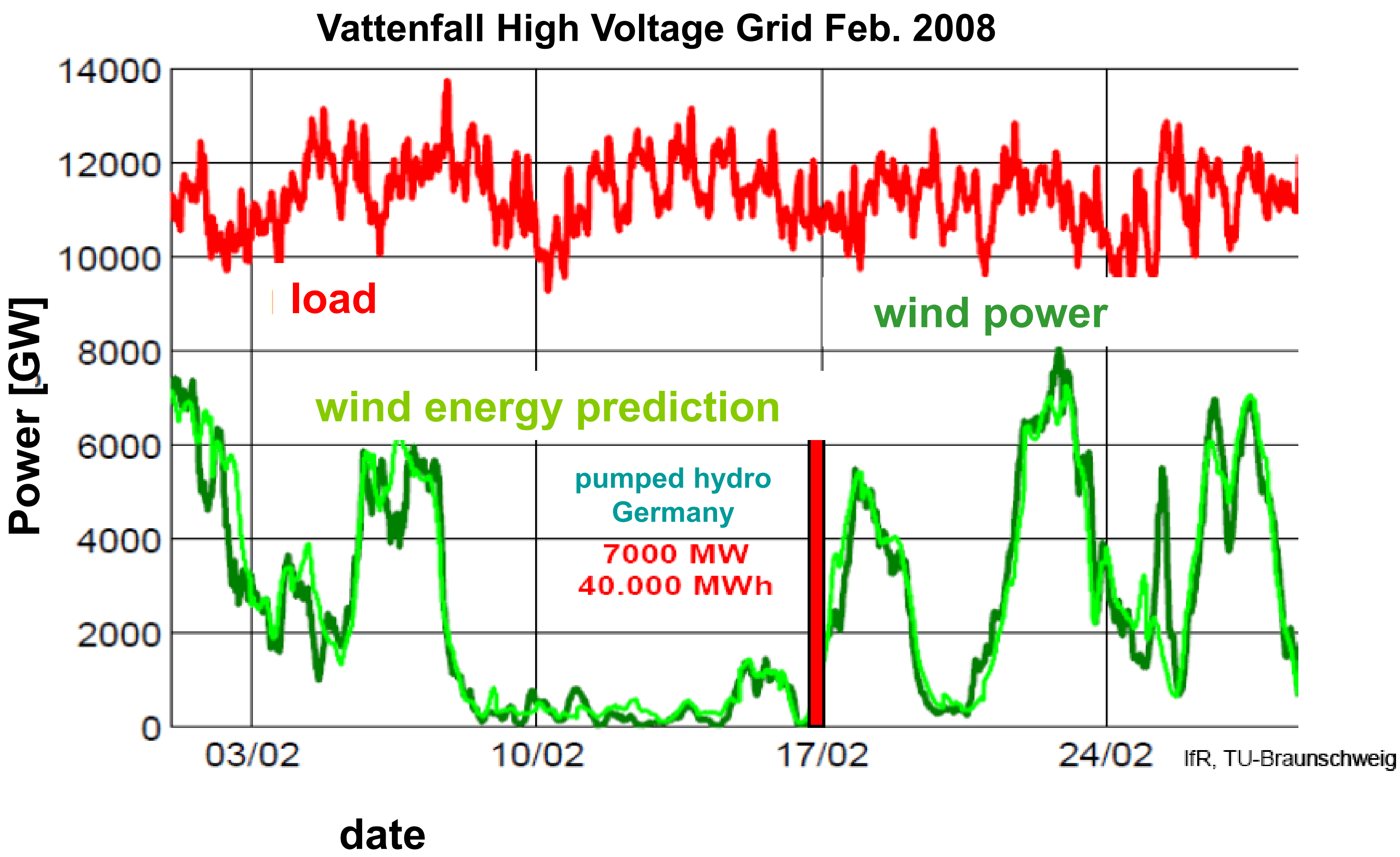
- CO_2 emissions from energy conversion
- other emissions from electricity generation
- fossil primary energy consumption

adding

- increased energy efficiency
- more flexible energy markets
- use of various different fuels
- safer grids and homes

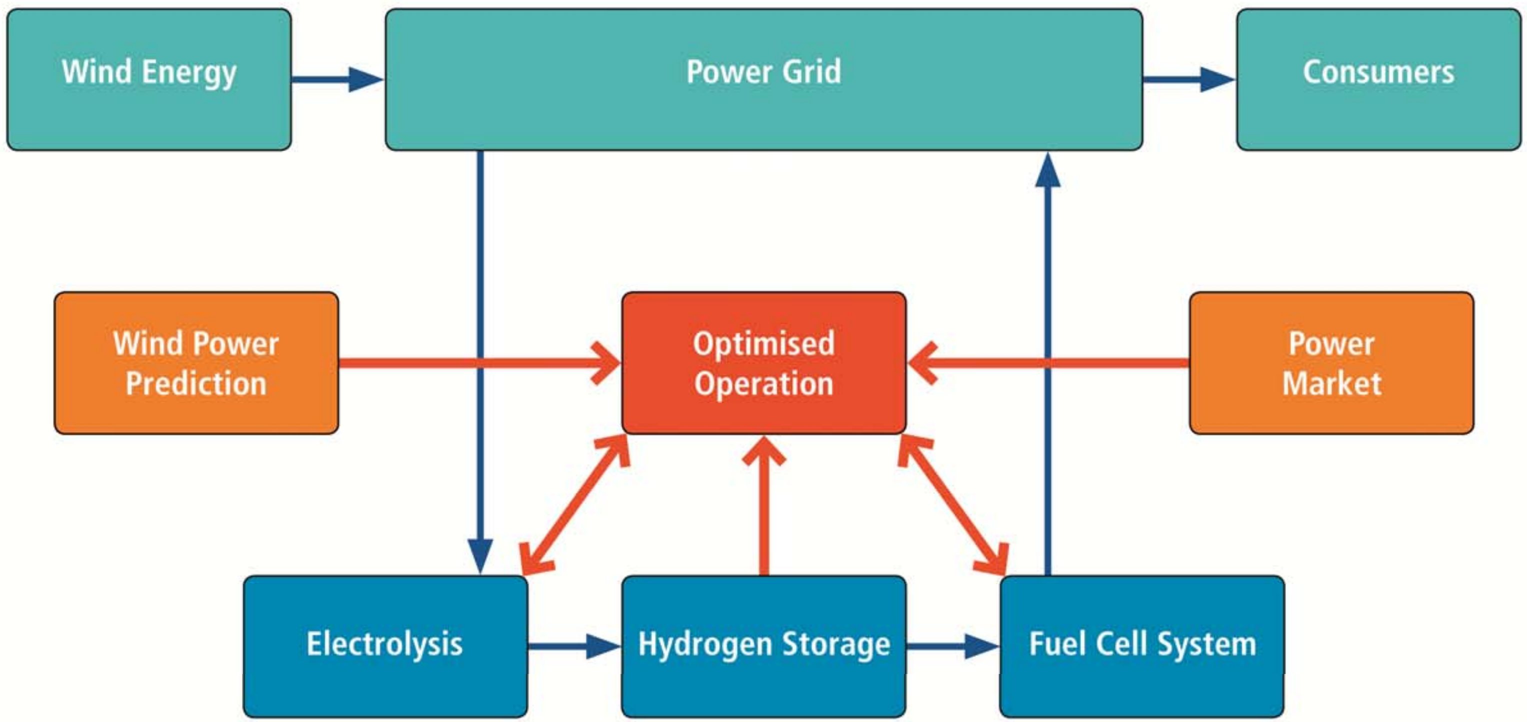
What Can Hydrogen Do?

Storage Needs for Wind Energy



-> requirement ~1 000 GWh

HyWindBalance
Wind-Hydrogen Balancing Power and Storage



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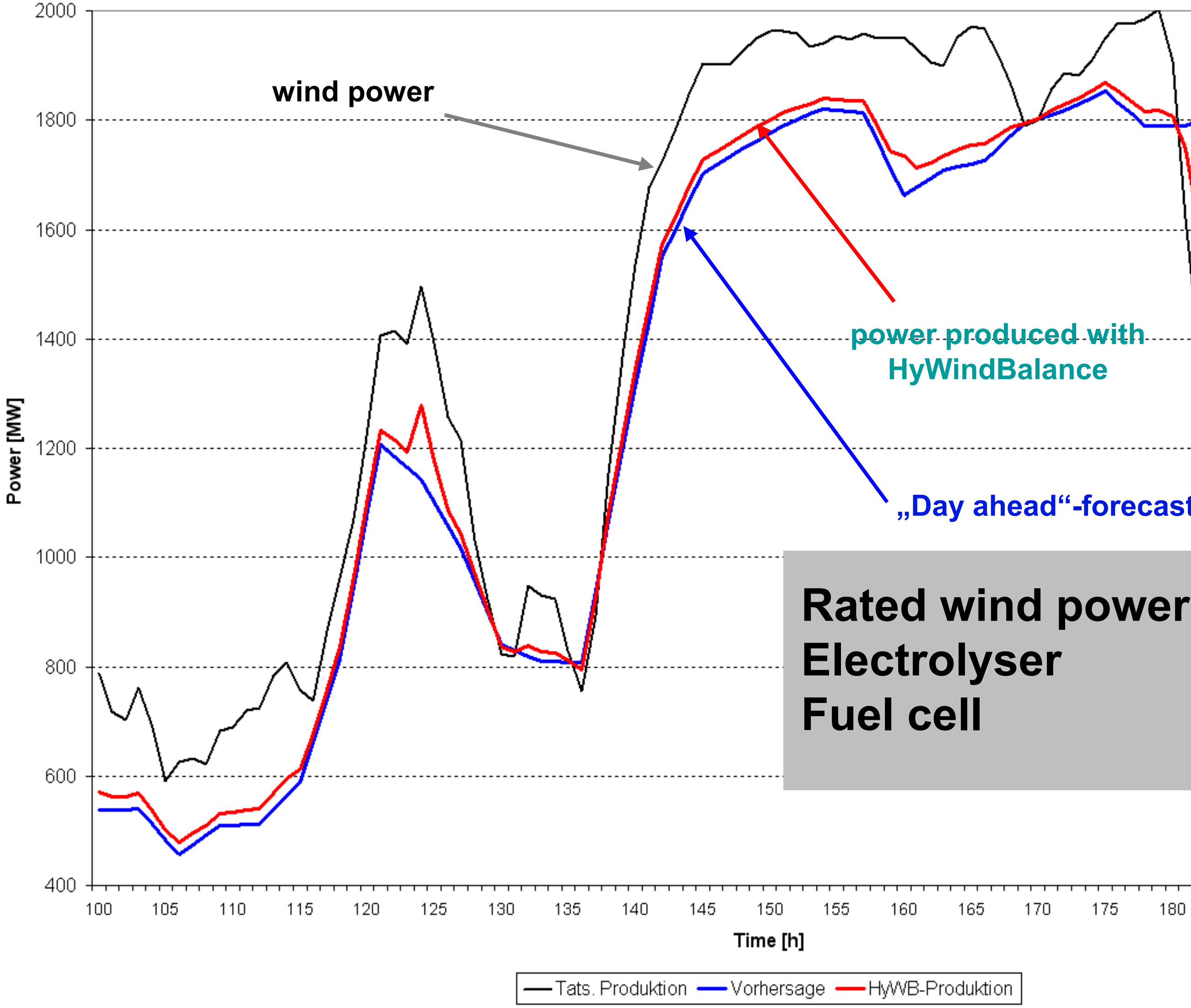
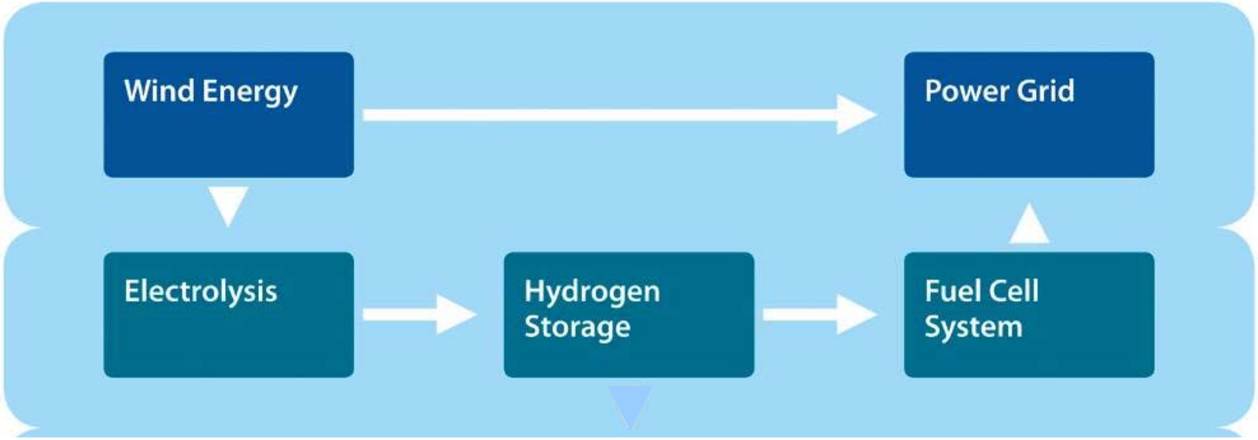
Effective Power Balancing



PLANET

Rated wind power	**2.300 MW**
Electrolyser	**230 MW**
Fuel cell	**230 MW**

Wind - Hydrogen – Infrastructure



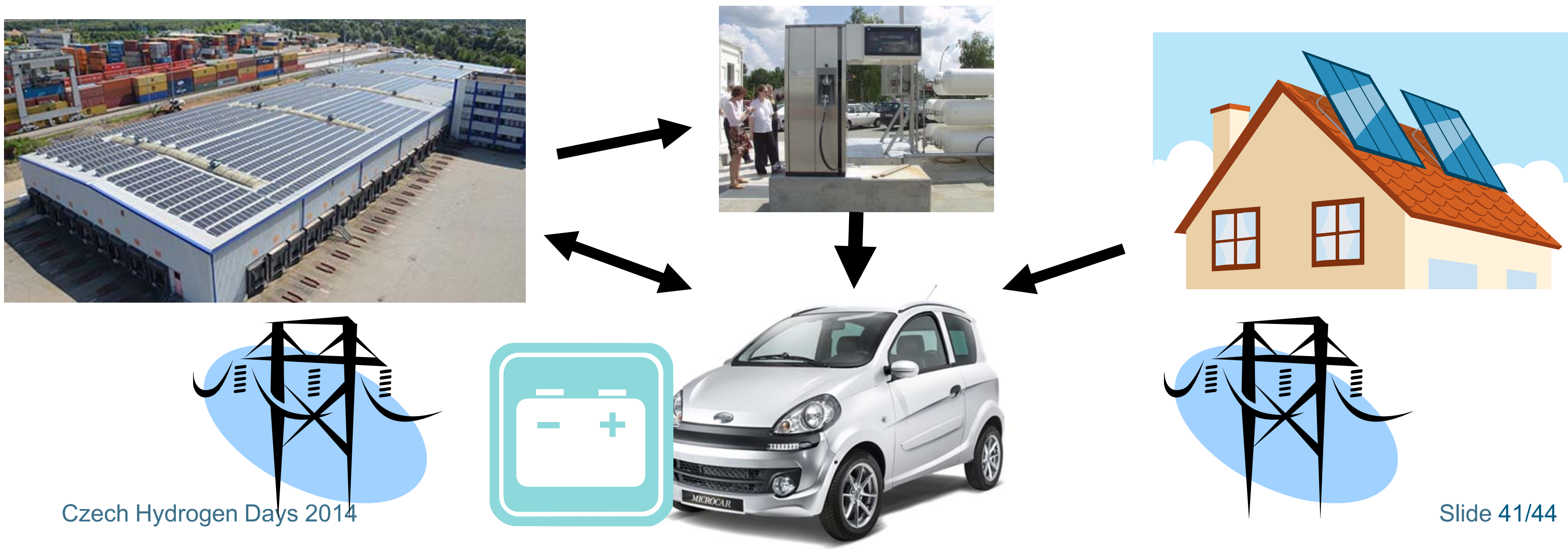
Hydrogen - Plug-in - Hybrids

- hydrogen tanks ~4 kg / vehicle

- corresponds to several TWh of storage capacity

- vehicle has sufficient range and is extremely flexible due to ‘dual fuel’

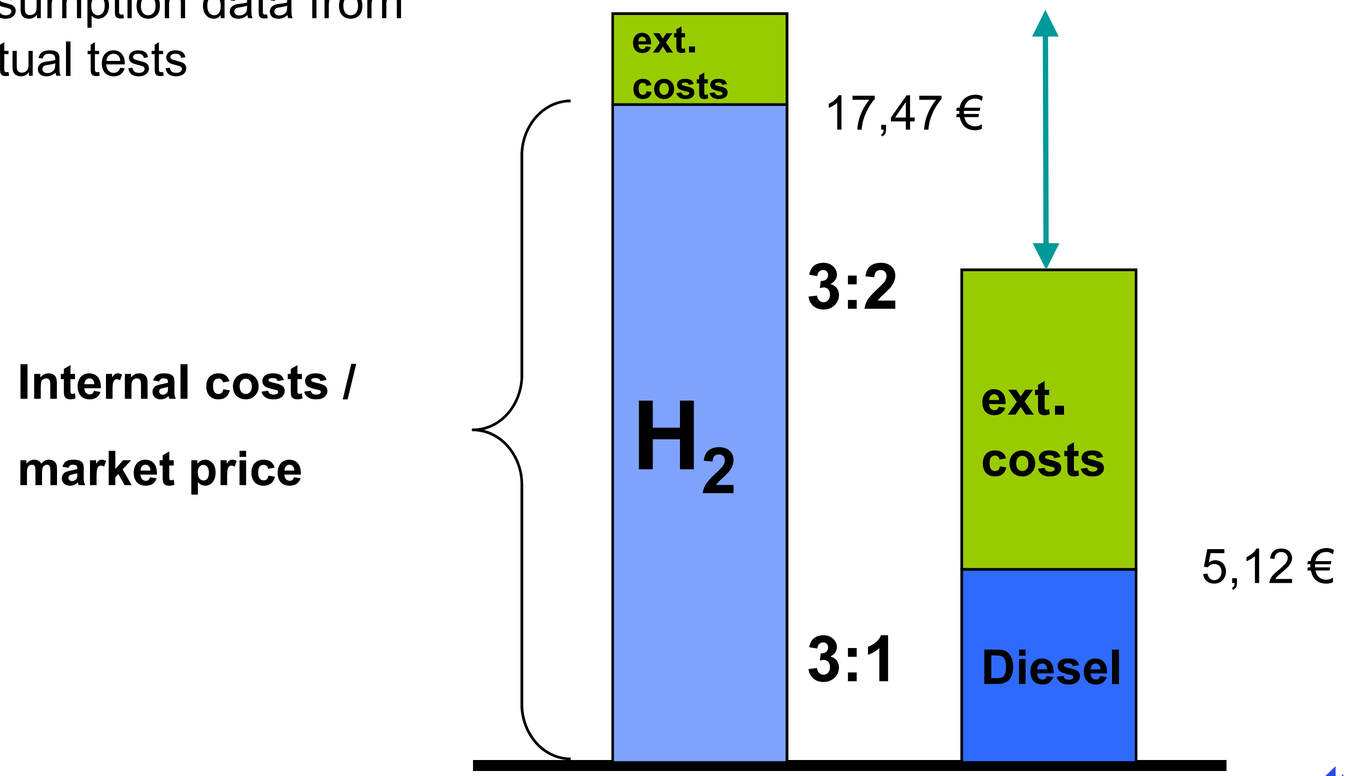
- potential for long-term storage



Including External Costs

all cost as of 2007 from
- state of the art technology quotes

consumption data from
- actual tests



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Summary

- fuel cells can contribute significantly to the goals of increasing the efficiency of energy use
- they increase economic stability by de-coupling from volatile energy markets and reducing energy imports to the EU
- they need to be carefully crafted and suited to application, though
- hydrogen and fuel cells will together serve to increase the use of renewable energies and indigenous energy sources
- together they reduce carbon dioxide emissions by de-carbonising transport

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Thank you for your attention!

and thanks to everyone in ChemEng, the College and especially my group for the superb support I am experiencing here!