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Hydrogen from Renewable Energy Sources

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Content

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- Global Future Energy Trends
- Hydrogen from Renewable Energy Sources Compared to Other Alternative Fuels
- Potentials of Renewable Energy Sources for the Production of Hydrogen as Transport Fuel
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Global Future Energy Trends

Global future energy trends
Peak of fossil energy supply

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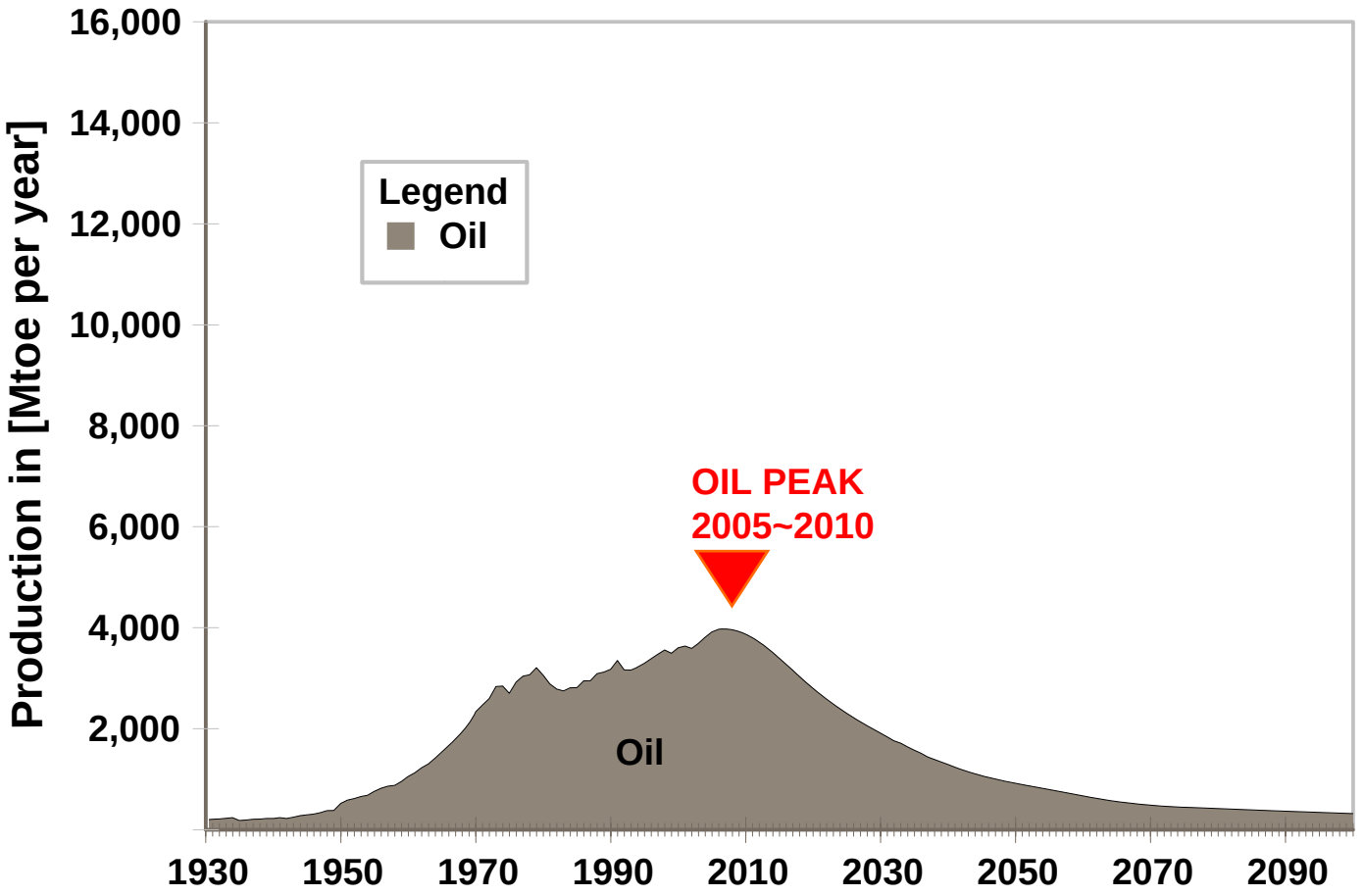

Oil Peak or 'Peak Oil': the point at which supply cannot match demand anymore

Source: LBST

Scenario assumption: decline rate after peak of 2.7%/yr
Actual experience: decline rates of 10%/yr and beyond (e.g. Alaska, Mexico, Norway, Oman, UK)

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Global future energy trends
Peak of fossil energy supply

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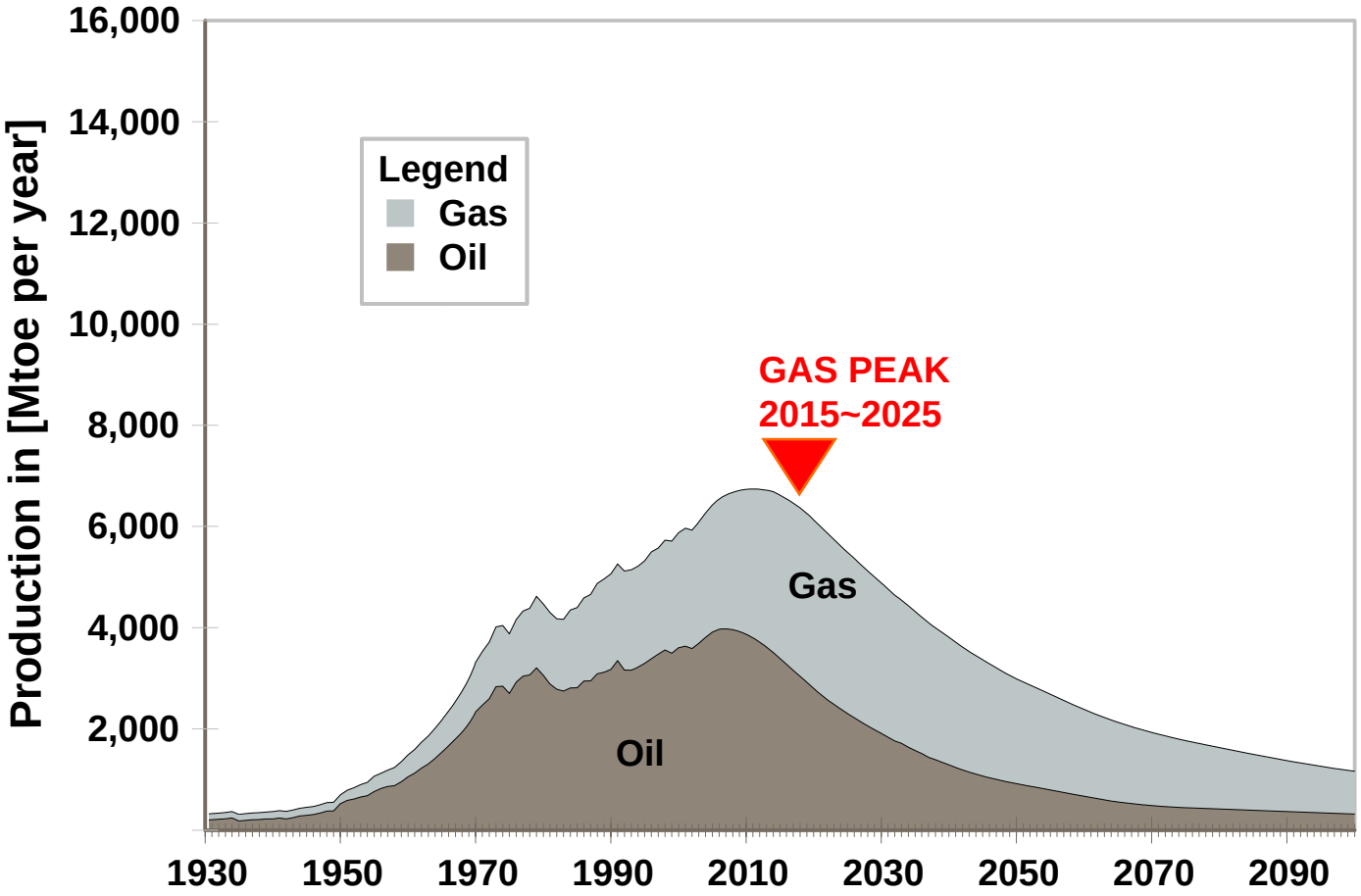

Source: LBST

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Global future energy trends
Peak of fossil energy supply

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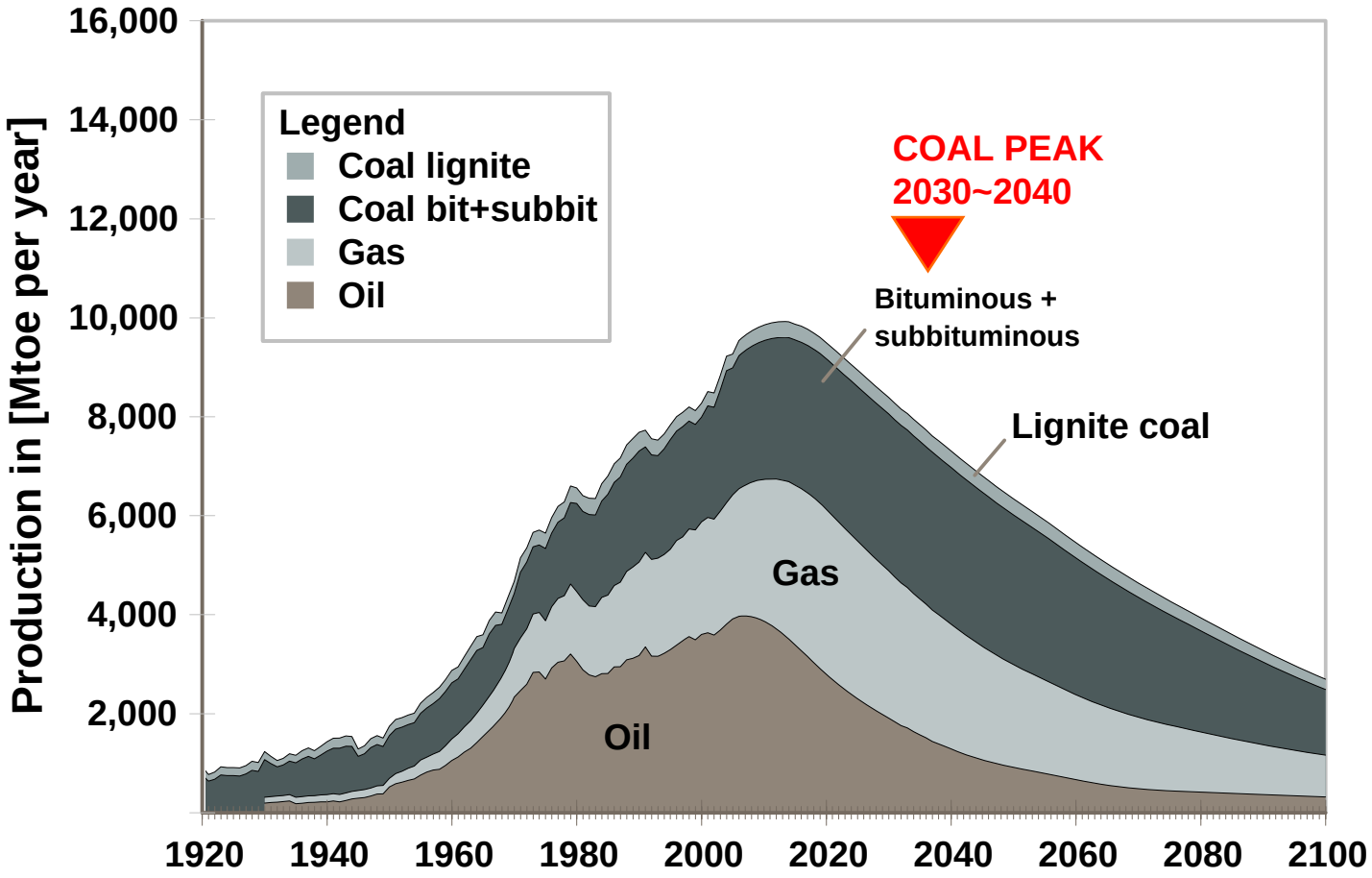

Source: LBST

For details on coal resource/reserve analysis, see EWG Report No. 1/ 2007 "Coal":
http://www.lbst.de/publications/studies__e/2007EWG-coal__e.html

Global future energy trends
Peak of fossil energy supply

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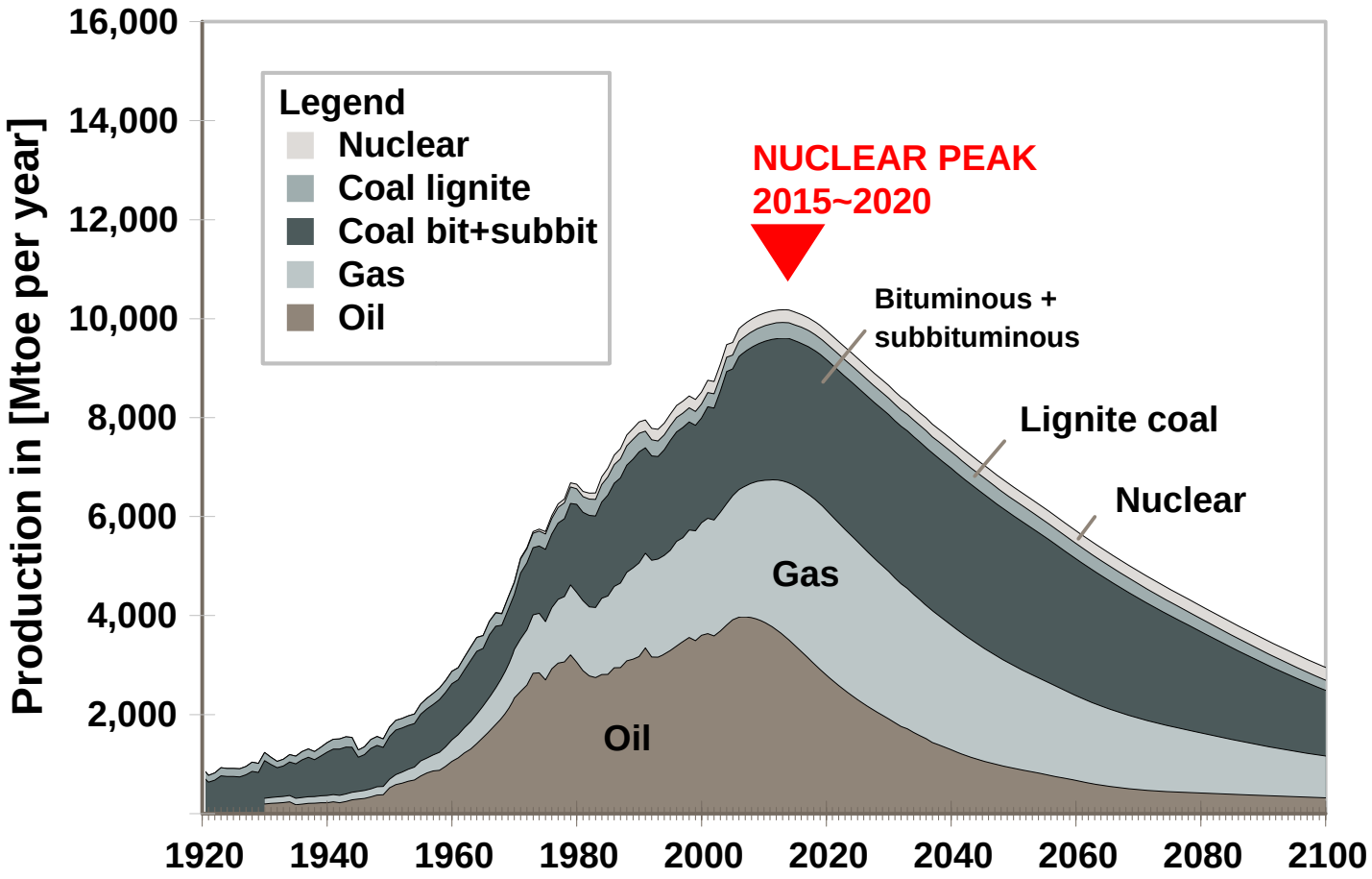

Source: LBST

For details on nuclear resource/reserve analysis, see EWG Report No. 1/2006 "Uranium":
http://www.lbst.de/publications/studies__e/2006EWG-uranium__e.html

Global future energy trends
Peak of fossil energy supply

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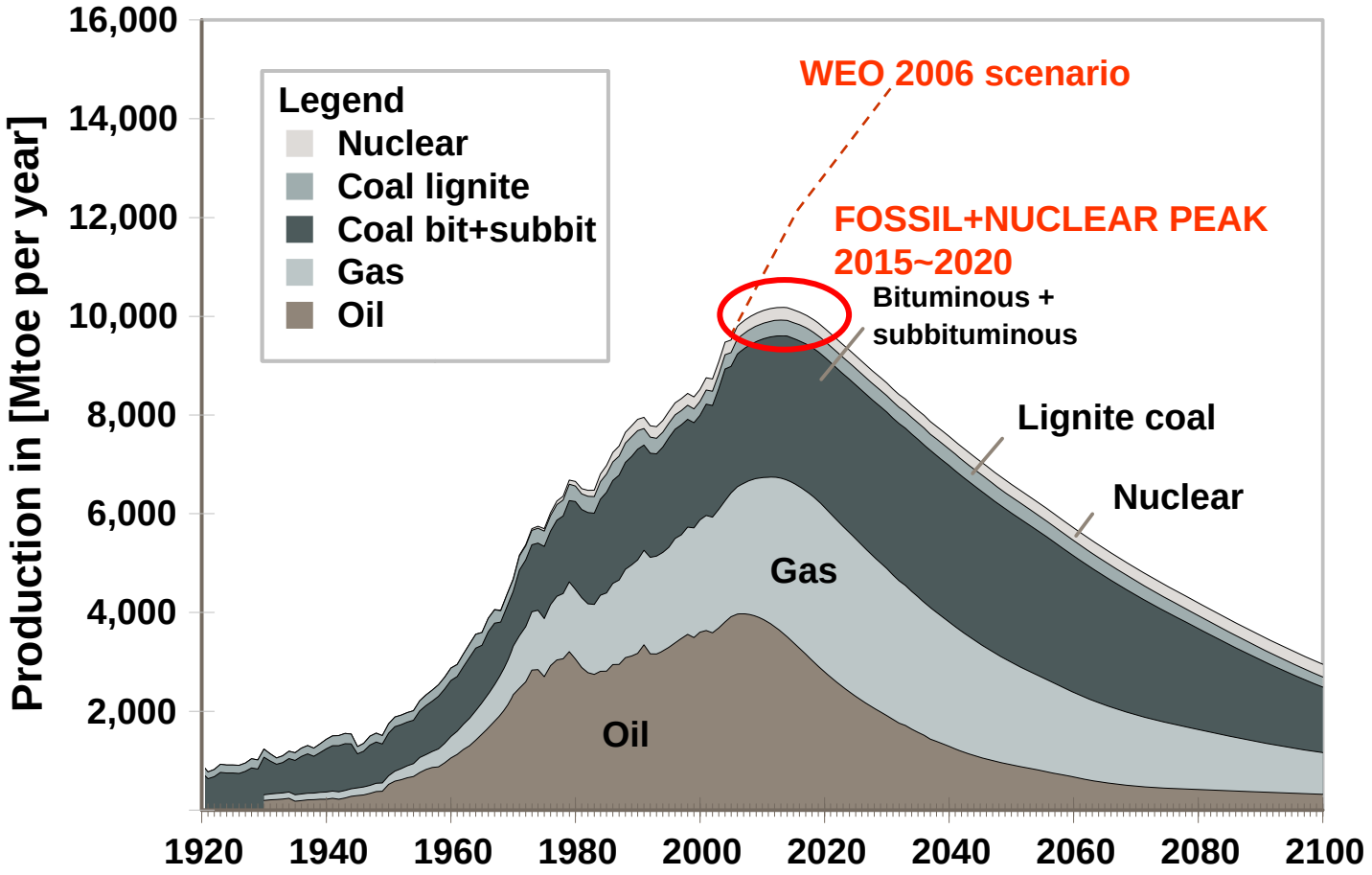

Source: LBST

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Global future energy trends

Alternative World Energy Outlook by LBST

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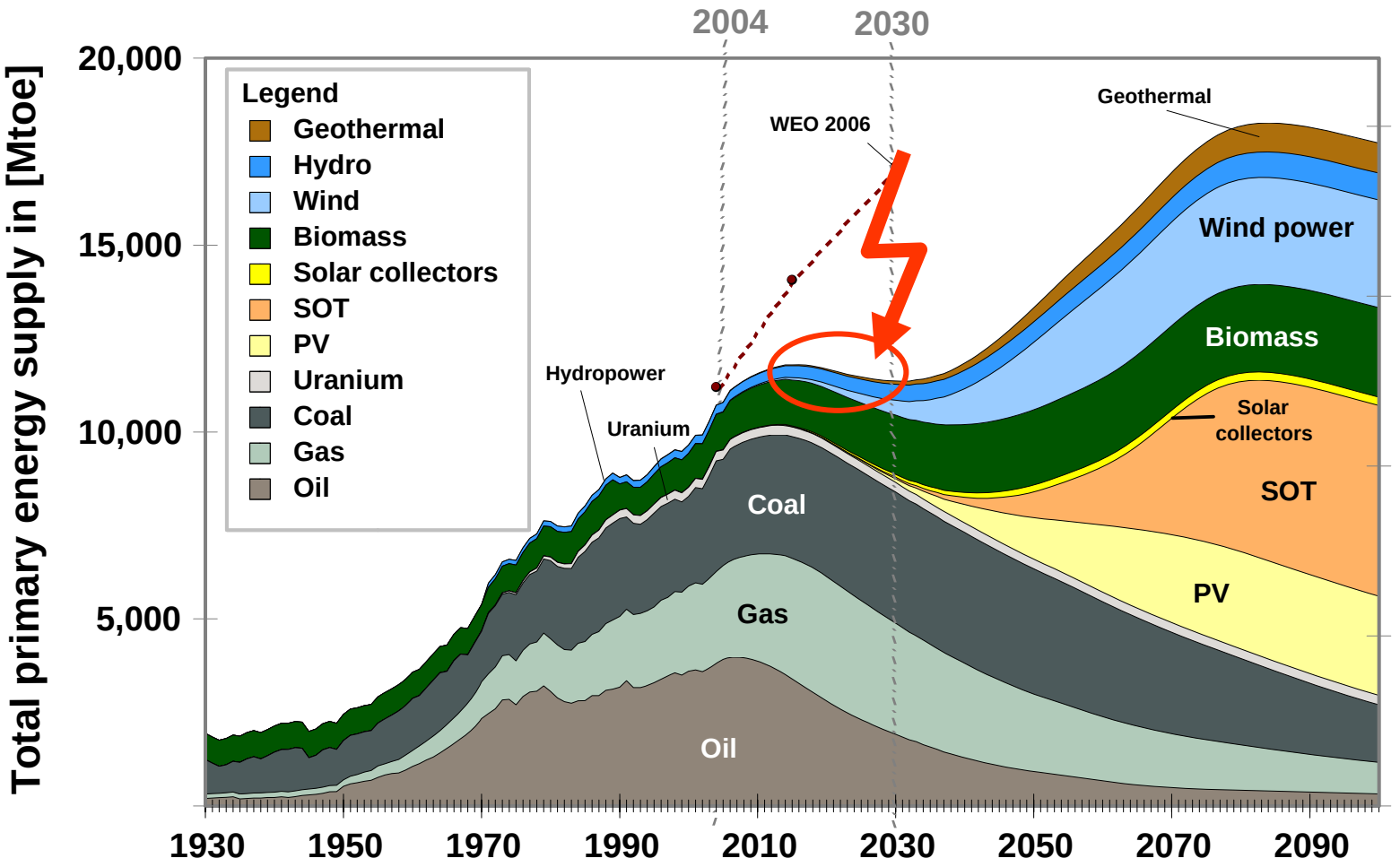

Source: LBST

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Hydrogen from Renewable Energy Sources Compared to Other Alternative Fuels

Alternative Transport Fuels (i.e. non petroleum-based)

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Today available alternatives:

- Fatty acid methyl ester (bio-diesel)
- Virgin plant oil
- Bio-ethanol
- Natural Gas (CNG)
- Electricity (battery electric vehicles)

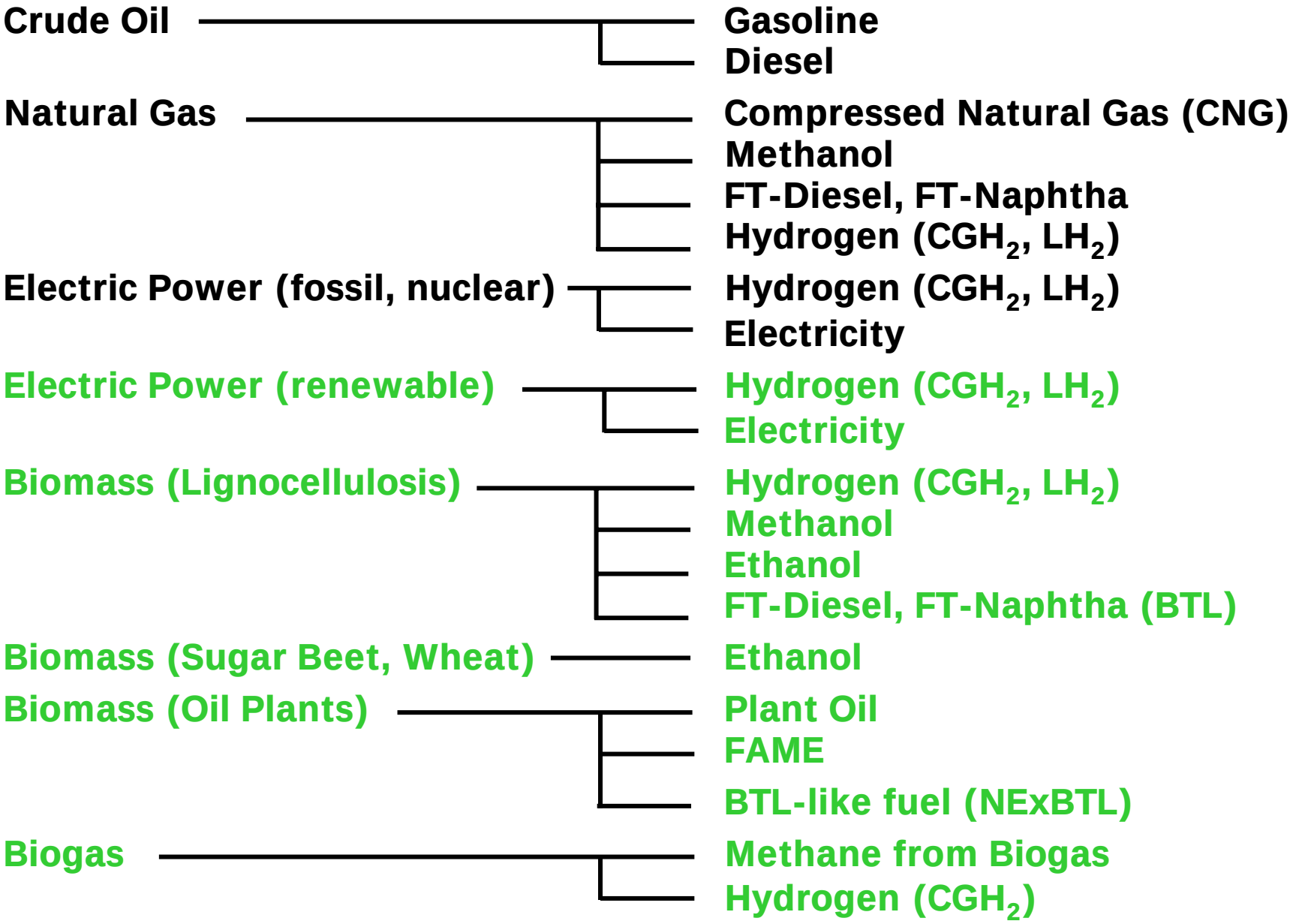
Further future alternatives:

- Synthetic liquid hydrocarbons from biomass (BtL)
- Synthetic liquid hydrocarbons from coal (CtL)
- Purified biogas ("Compressed Methane Gas" from biogas)
- Hydrogen (CGH_2, LH_2) from all hydrocarbons or water containing sources

Compilation: LBST

www.lbst.de

Conventional and Renewable Transportation Fuel Supply Paths



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Compilation: LBST

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Compressed Hydrogen (CGH_2) from Biomass Gasification

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Gasification of Wood Chips (WC)

WC

Water

Gasifier (allothermal)

CO, H_2

CO Shift

Pressure Swing Adsorption (PSA)

Spülgas

Gas Engine/ MCFC

Grid

Electricity

Compression

Compressed Hydrogen (for 70 MPa Vehicle Tanks)

$\eta \approx 50\ \%$

Compilation: LBST

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Compressed Hydrogen (CGH_2) from Renewable Electricity

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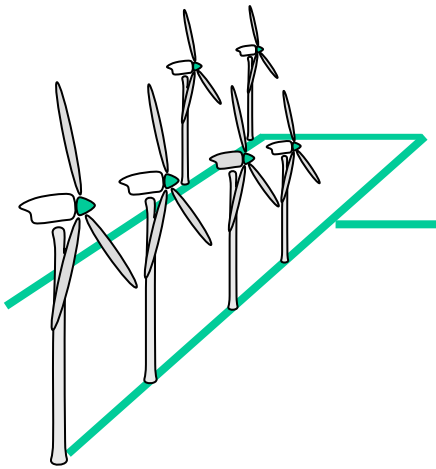
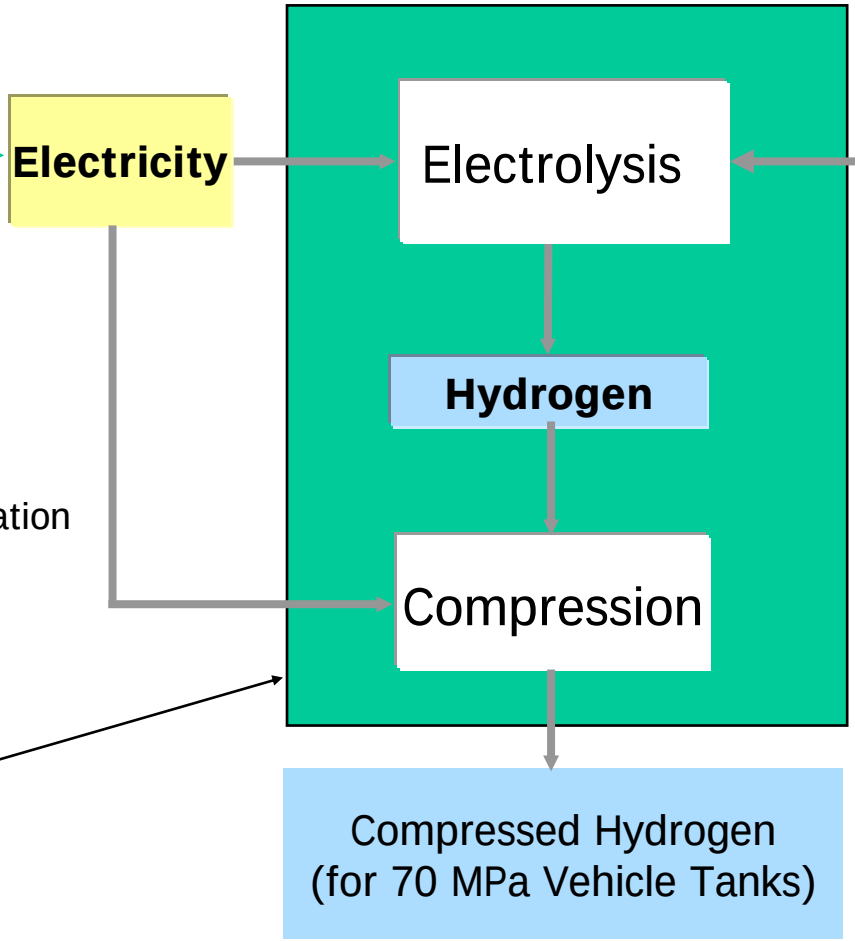
η_{WKA} = 100 %



Compressed Hydrogen from Renewable Electricity



Concept for CGH_2 Refuelling Station (Hydrogen Systems)

$\eta \approx 60$ %

Compilation: LBST

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Liquid Hydrogen (LH_2) from Renewable Electricity

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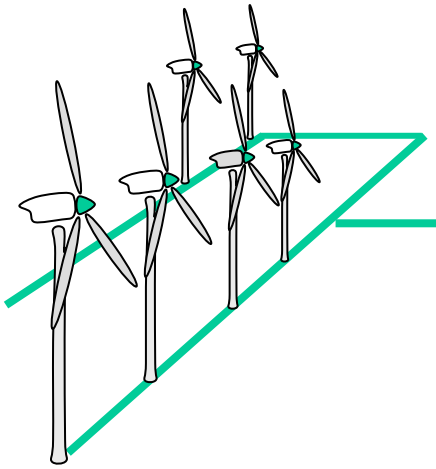
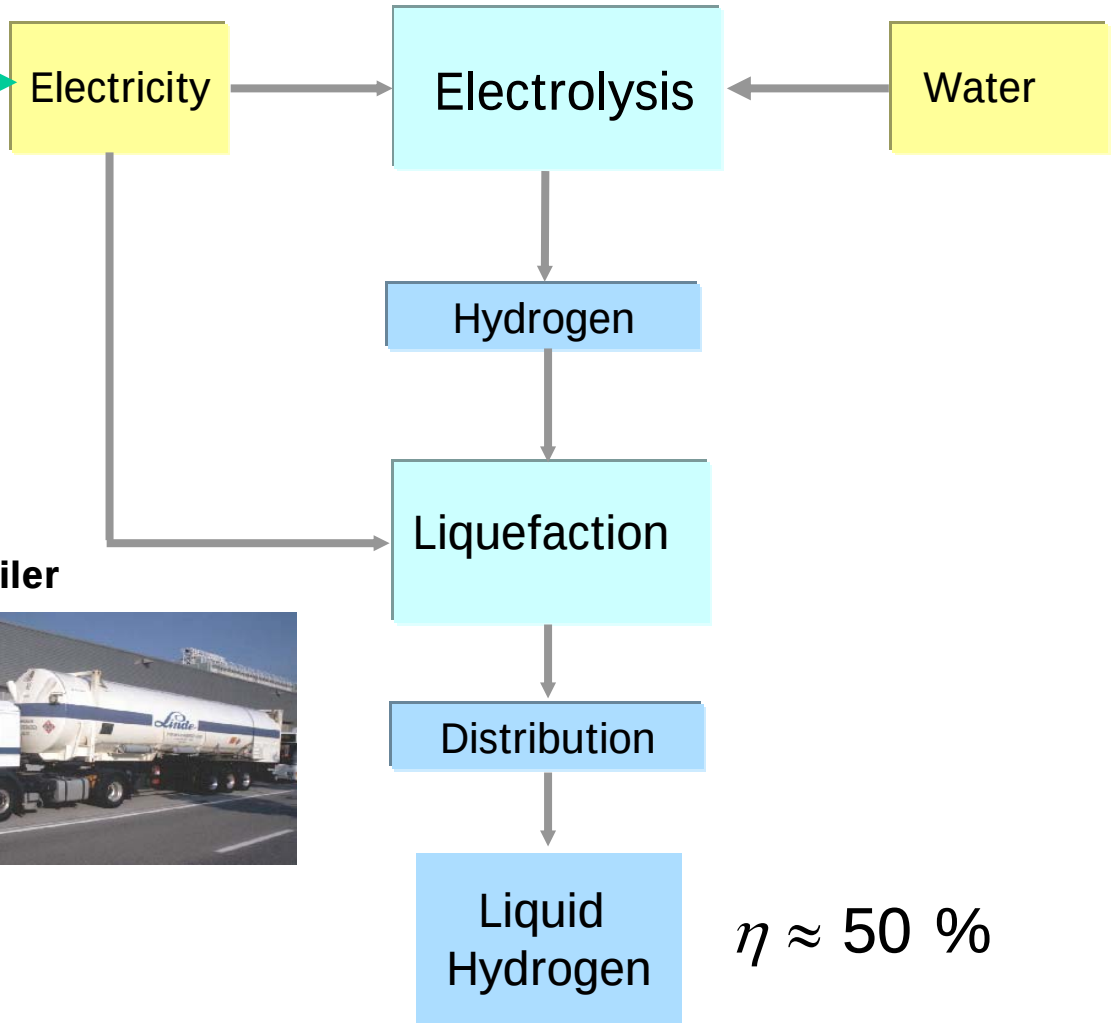


η_{WKA} = 100 %

Liquid Hydrogen from Renewable Electricity



LH_2 trailer

$\eta \approx 50$ %

Compilation: LBST

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Acreage Yields for Several Renewably Produced Transportation Fuels

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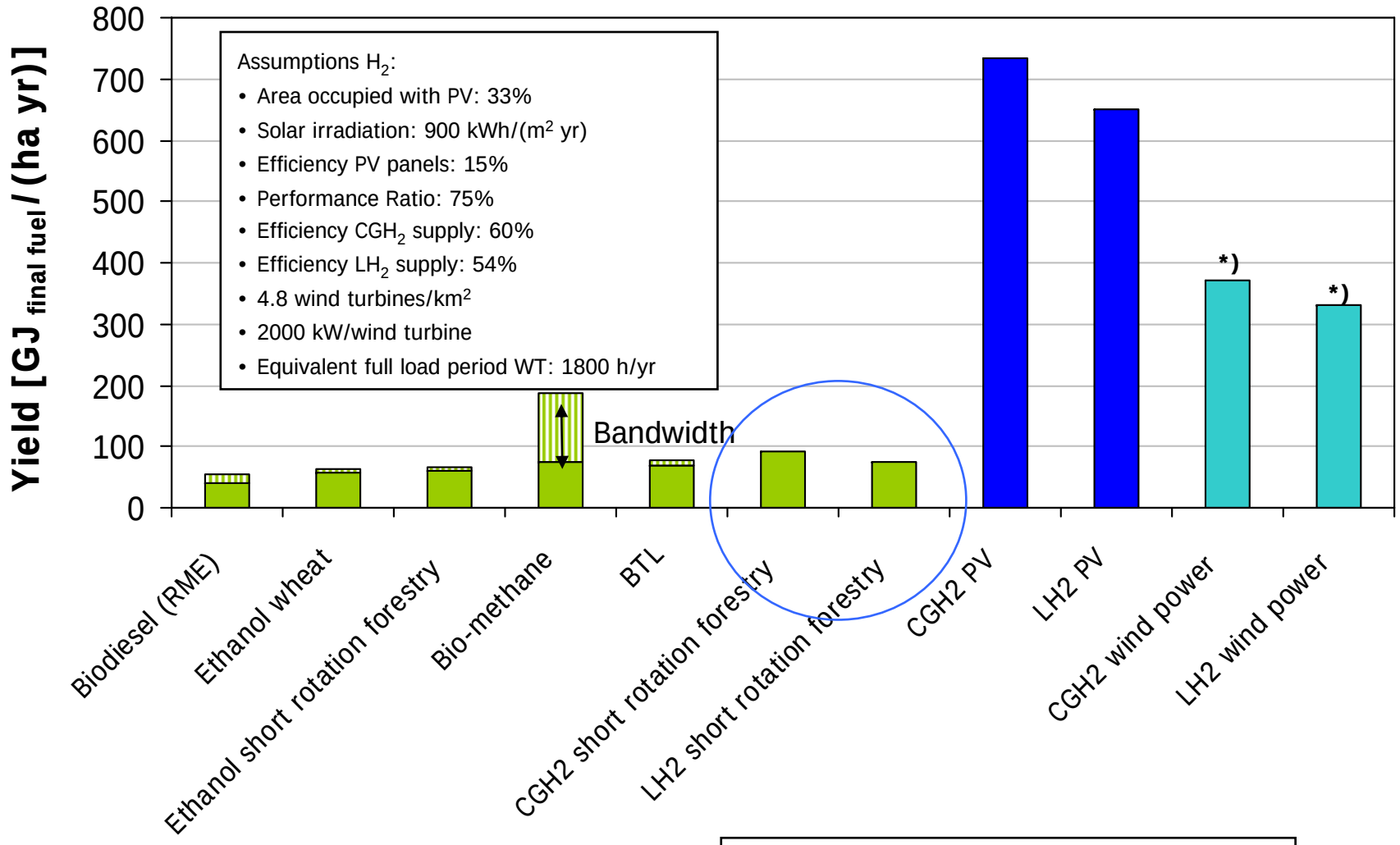

*) more than 99% of the land area can still be used for other purposes e.g. agriculture

Source: LBST

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Flächenerträge für verschiedene erneuerbare Kraftstoffe

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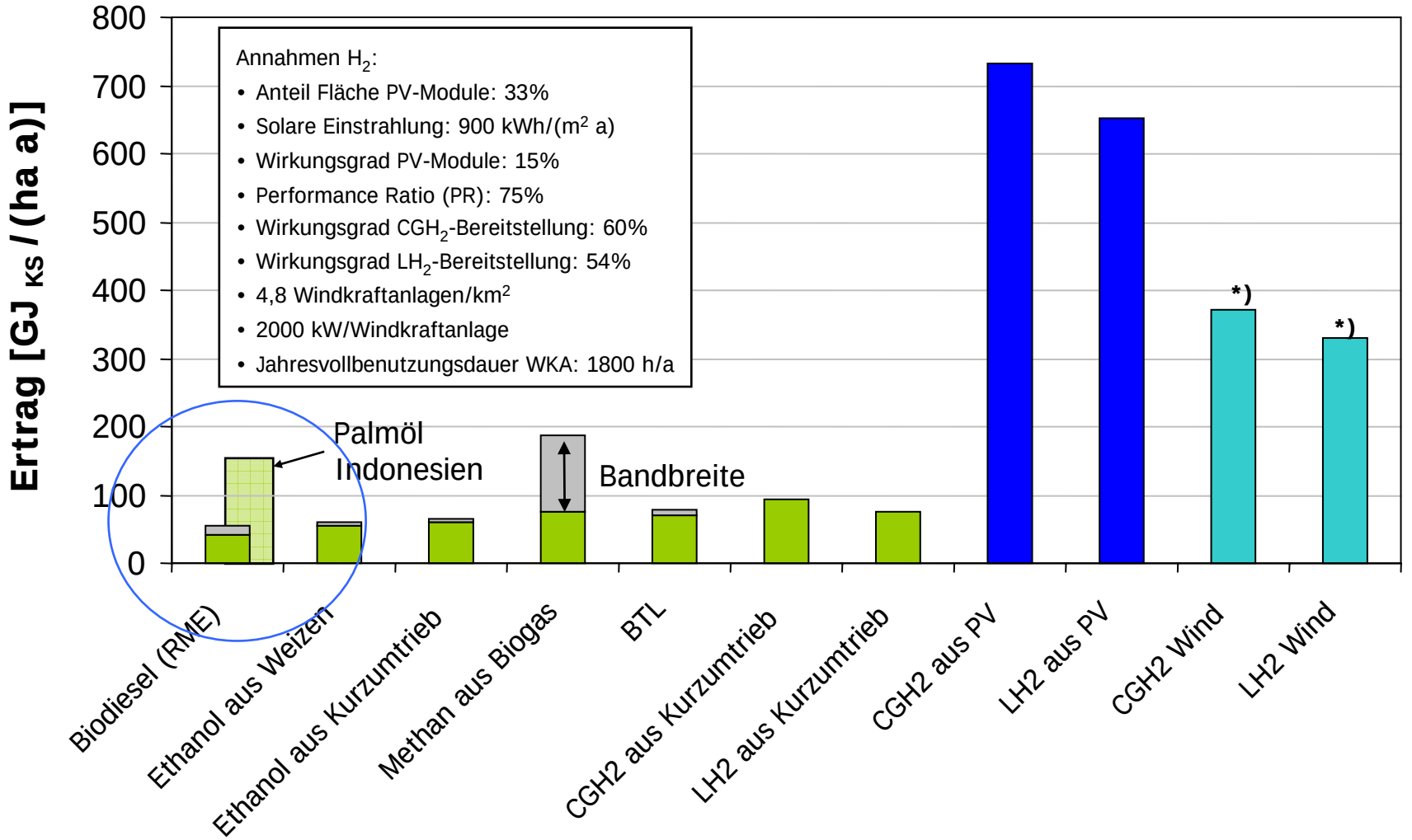

*) more than 99% of the land area can still be used for other purposes e.g. agriculture

Source: LBST

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Number of Passenger Cars (hybrid) which can be supplied per ha

Annual operating range passenger cars: 12,000 km

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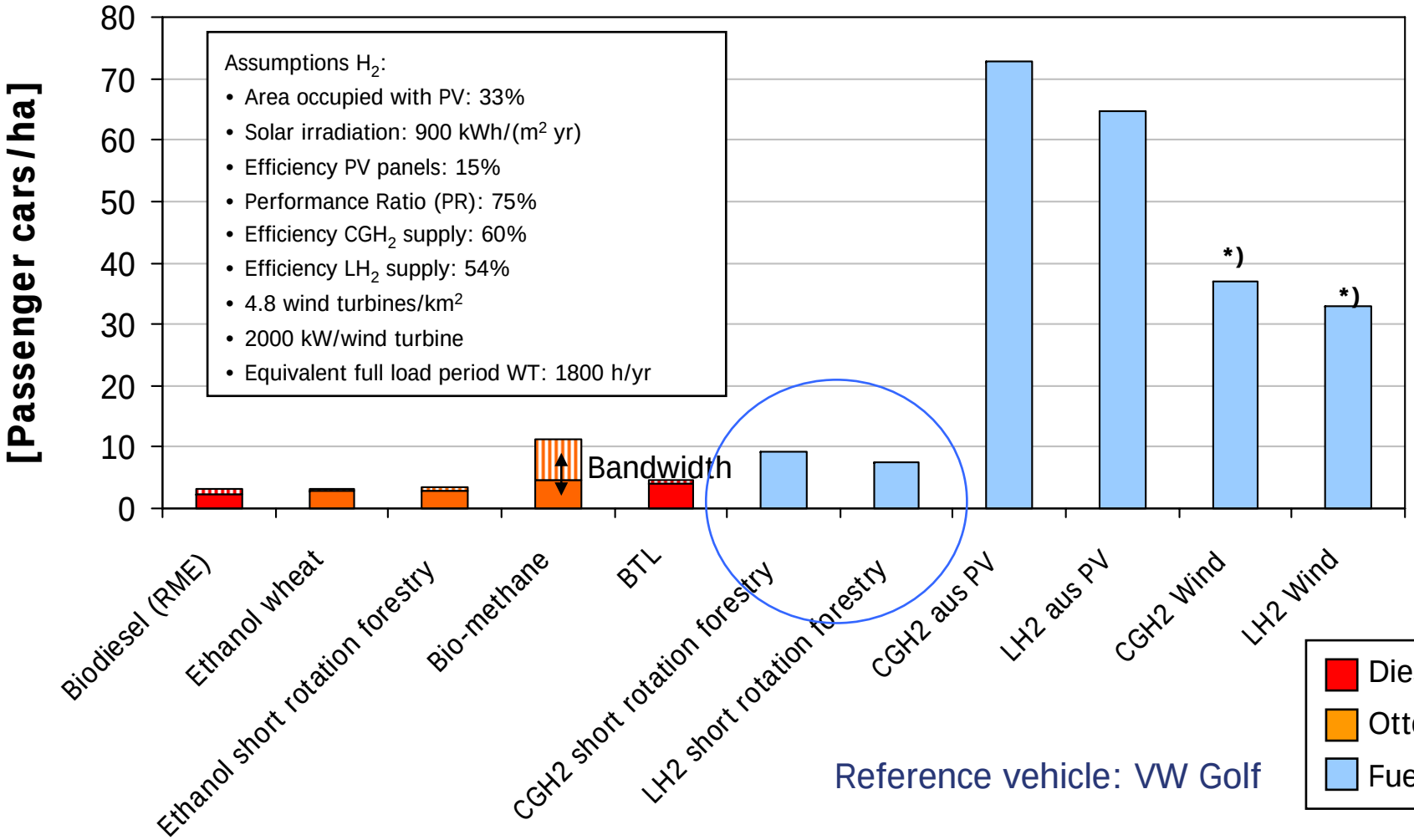

Compilation: LBST

Reference vehicle: VW Golf

*) more than 99% of the land area can still be used for other purposes e.g. agriculture

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Number of Passenger Cars (hybrid) which can be supplied per ha

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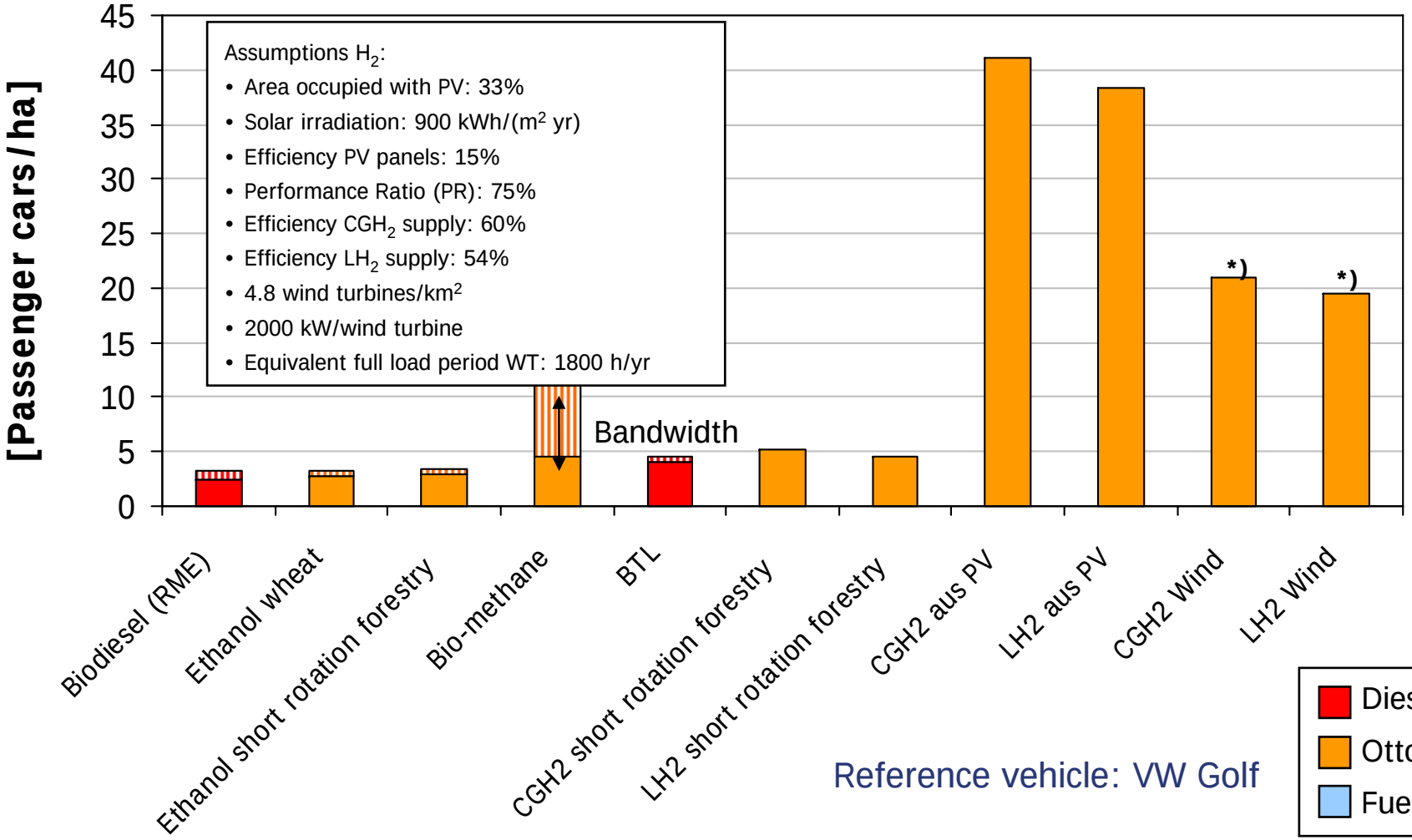

Compilation: LBST

Reference vehicle: VW Golf

Diesel engine
Otto engine
Fuel cell

*) more than 99% of the land area can still be used for other purposes e.g. agriculture

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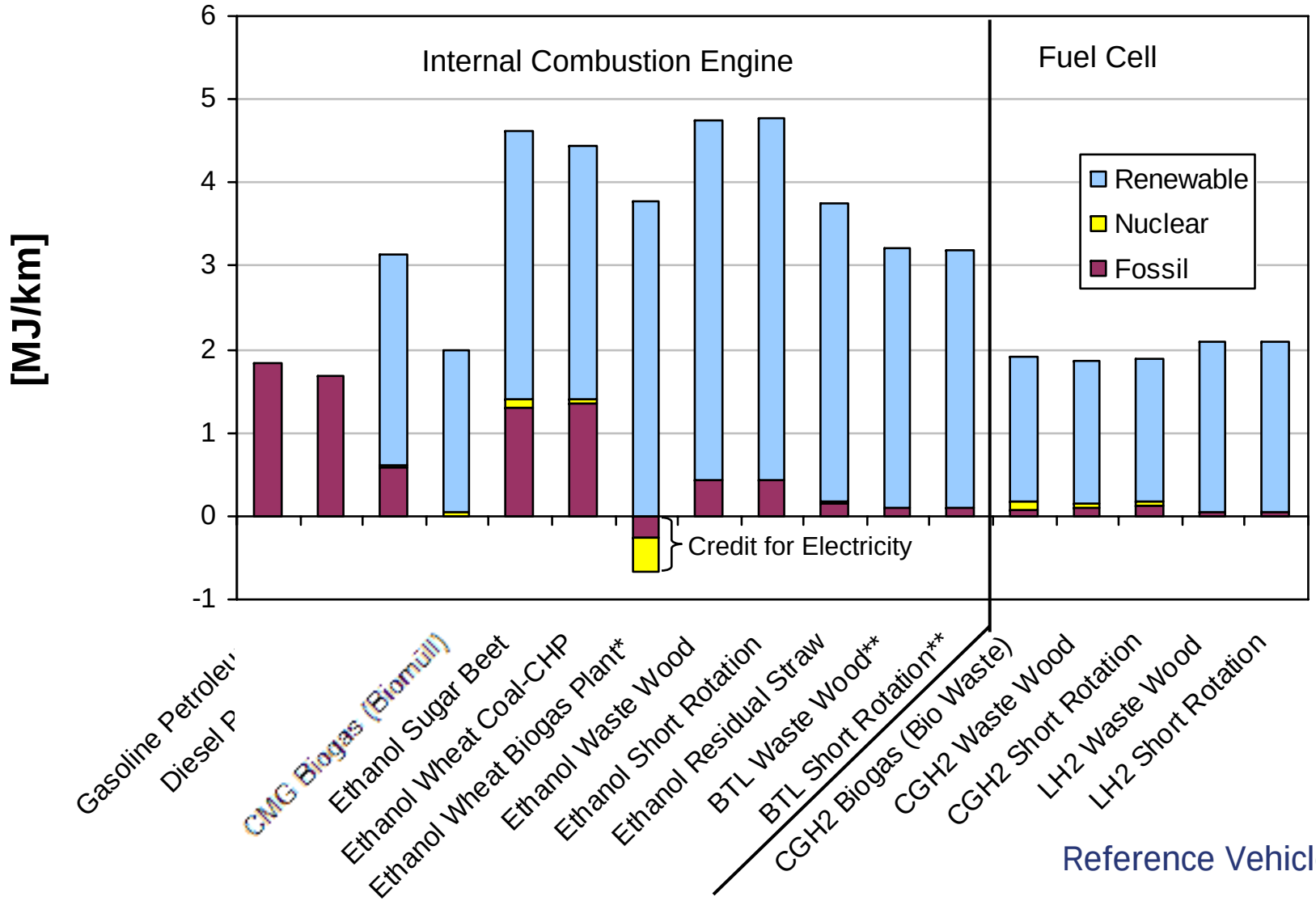
Energy Use "Well-to-Wheel“ hybrid



Reference Vehicle: VW Golf

* Integrated ecological concept with recycling of residual products to the agricultural crop land

** Synthetic Diesel fuel from Fischer-Tropsch-Synthesis

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Compilation: LBST

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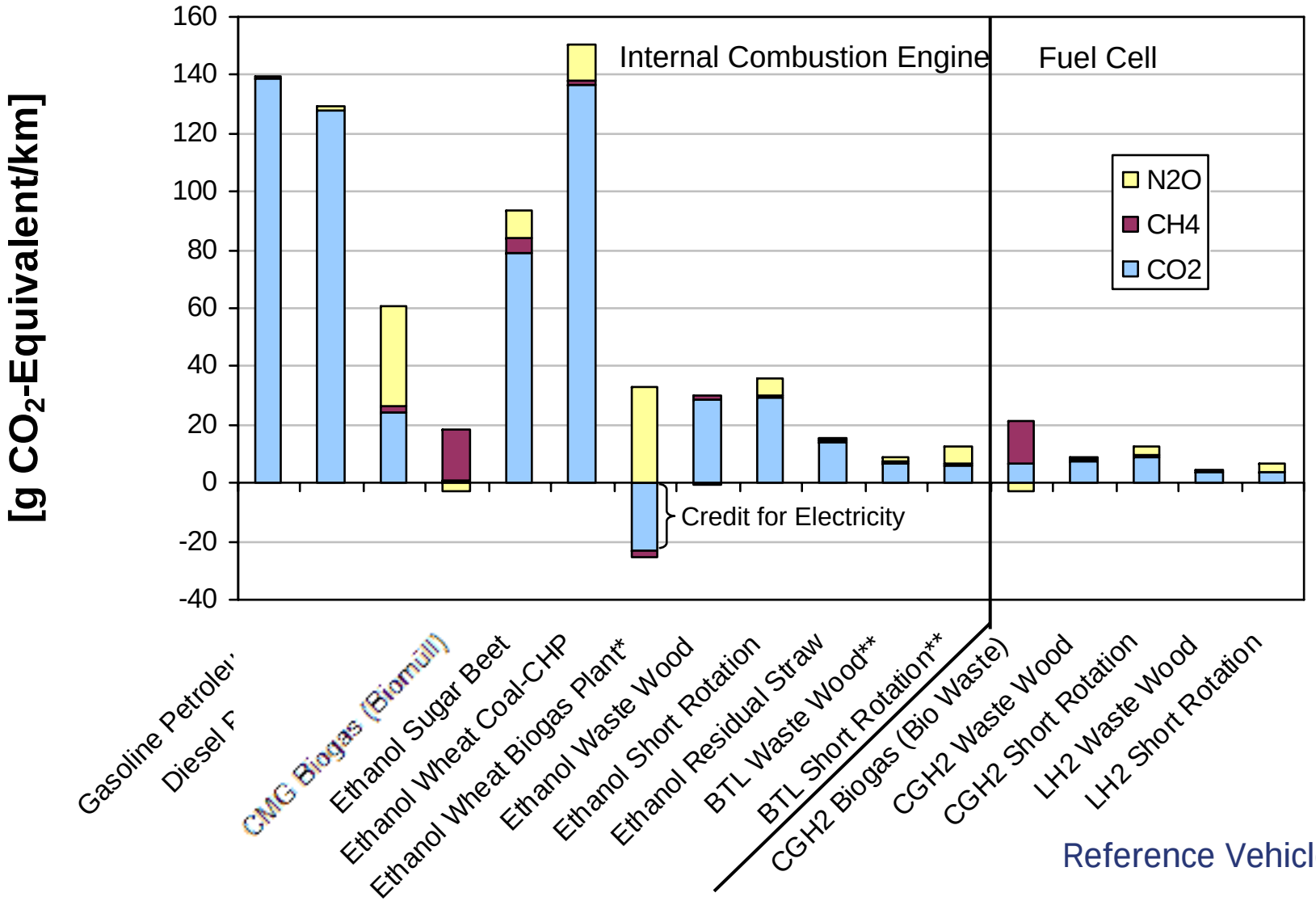
Greenhouse Gas Emissions "Well-to-Wheel“ hybrid



Reference Vehicle: VW Golf

* Integrated ecological concept with recycling of residual products to the agricultural crop land

** Synthetic Diesel fuel from Fischer-Tropsch-Synthesis

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Compilation: LBST

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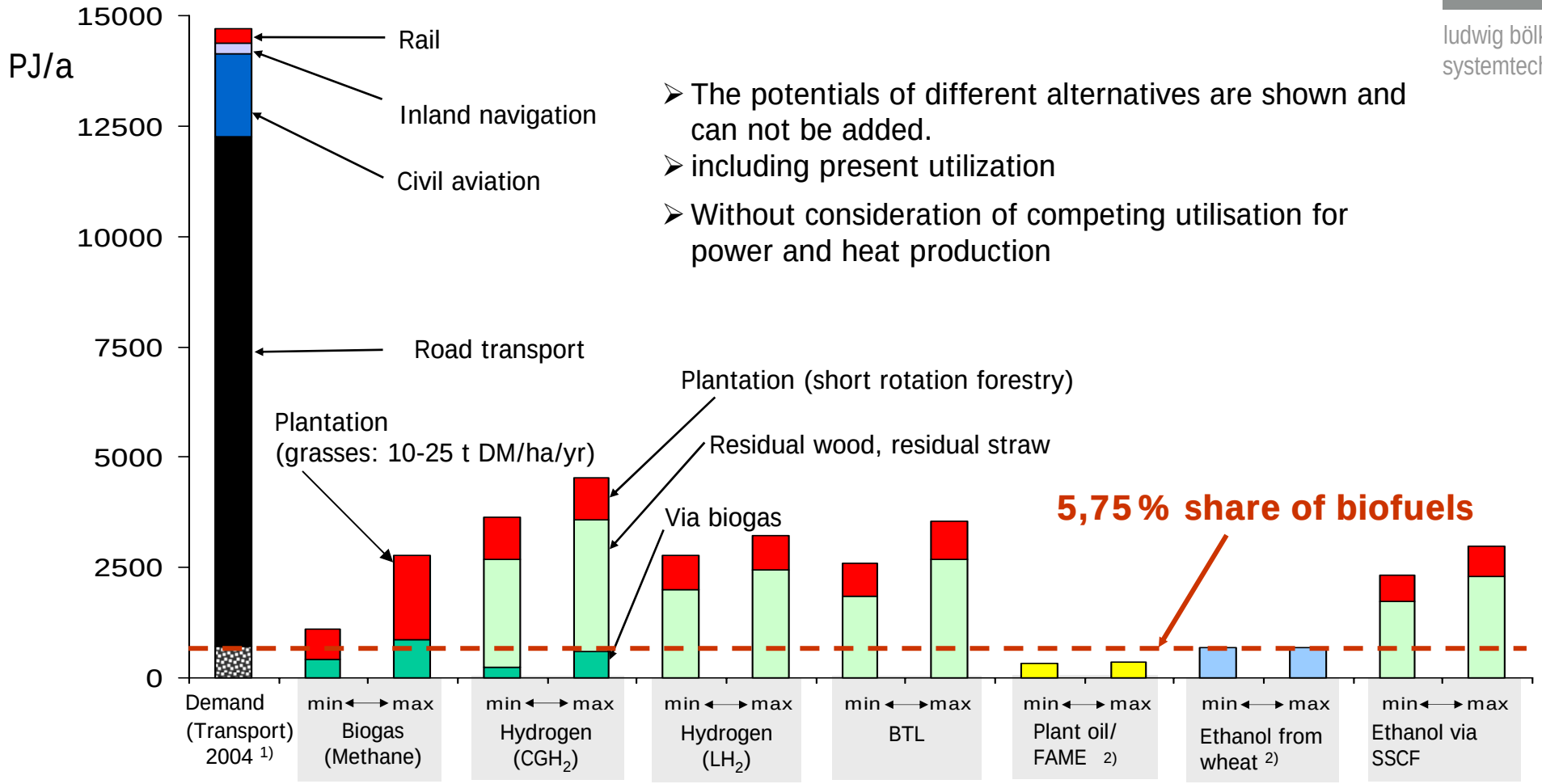
Potentials of Renewable Energy Sources for the Production of Hydrogen as Transport Fuel

Technical potential of different biofuels in the EU-27



- The potentials of different alternatives are shown and can not be added.
- including present utilization
- Without consideration of competing utilisation for power and heat production

1) Source: IEA-Statistics 2003-2004, 2006 edition
2) Gross (without the energy efforts for the supply of the fuels e.g. the use of external energy for the ethanol plant)

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Compilation: LBST

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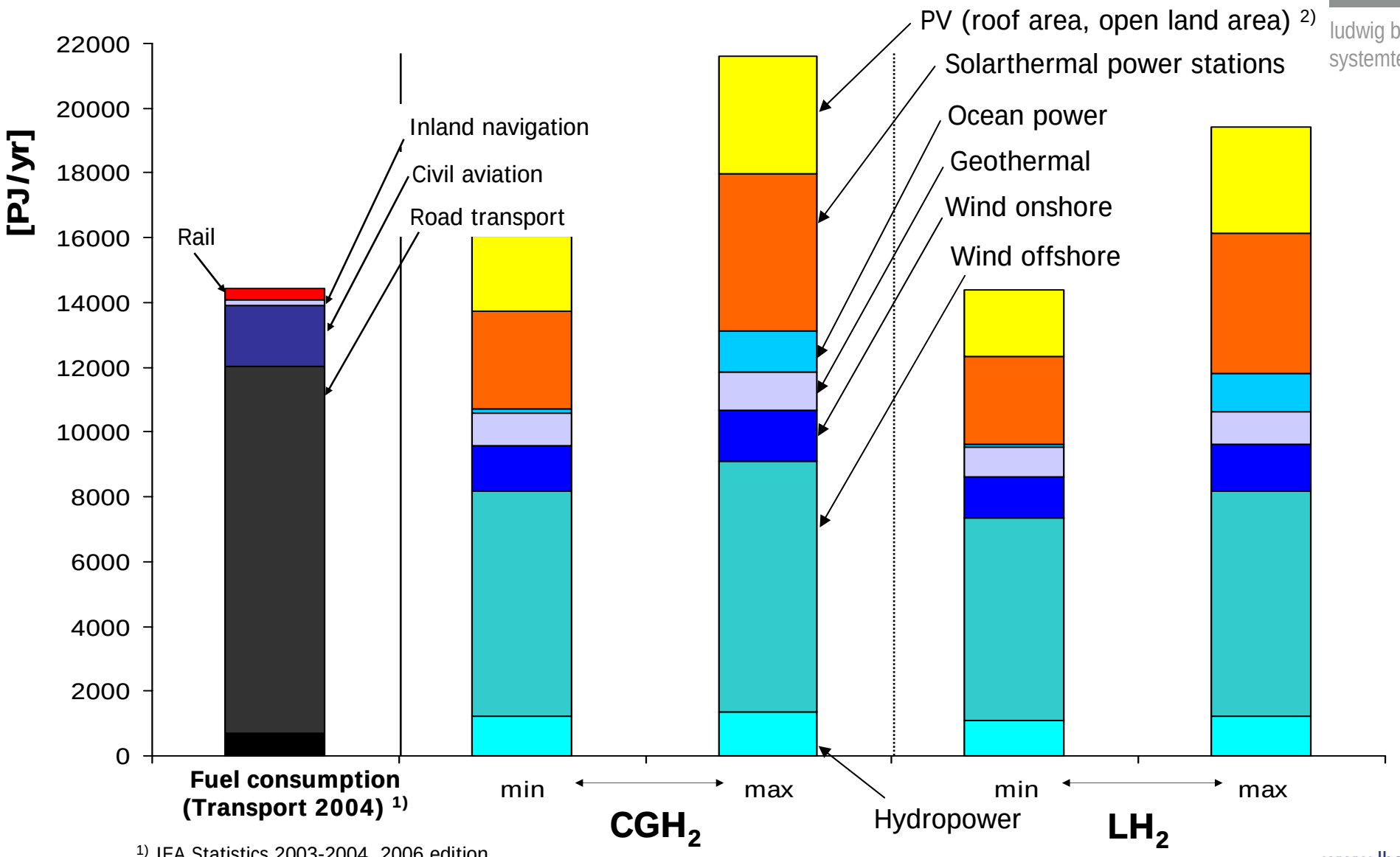
Technical potentials for hydrogen from renewable electricity in EU 27



1) IEA Statistics 2003-2004, 2006 edition

2) Photovoltaic plants on open land area: 0.1% of total land area

Compilation: LBST

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Substitution of global fossil based transportation fuel by hydrogen

Comparison hydrogen from photovoltaic electricity (PV) versus plant oil from jatropha

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	Unit	CGH_2	LH_2	Plant Oil (Jatropha)	
Fuel consumption transport 2004	Mtoe	1,975	1,975	1,975	1,975
~320 l gasoline/cap. @ 8 billion cap.	TWh/yr	22,964	22,964	-	-
Efficiency fuel supply		0.60	0.54	-	-
Electricity demand fuel production	TWh/yr	38,086	42,851	-	-
Solar insulation	kWh/(m^2 yr)	1,300	1,300	-	-
Efficiency PV panel		0.15	0.15	-	-
Performance ratio		0.75	0.75	-	-
Electricity yield PV panel area	kWh/(m^2 yr)	146	146	-	-
Fraction of area covered by PV panels		0.33	0.33	-	-
Yield plant oil	t/(ha yr)	-	-	0.7 [1)]	2.7 [2)]
Required area	Mill. km^2	0.8	0.9	29.0	7.3
Land area earth	Mill. km^2	149	149	149	149
Share of land area for fuel production	%	0.5	0.6	19.5	4.9

[1)] 2 t seed per ha and year, oil yield 0.34 kg/kg; without irrigation; [2)] 8 t seed per ha and year, oil yield 0.34 kg/kg; with irrigation;
Source: Abhiskek Maharishi, Centre of Excellence for Jatropha Biodiesel Promotion, India; www.jatrophabiodiesel.org

For comparison: land area of the USA is about ~9.2 million km^2

Compilation: LBST

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Energy Flux Densities Analysis

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Energy flux densities (a comparison)

Global Energy Supply Systems:	~ 0,03 Wm-2
Global Biomass Energy Flux Density:	~ 0,10 Wm-2
Global Geothermal Heat Flux Density:	~ 0,10 Wm-2
Global Kinetic Energy Dissipation:	~ 3 Wm-2
Global Surface Solar Energy Flux Density:	~ 165 Wm-2

Conclusions:

- In the long run, only the sun and the wind can be pillars of the energy supply system.
- Biomass energy ‚clashes' with food production.

Source: Prof. H. Graßl, MPI

Primary Energy Supply: Contributions from Renewable Energies

Growth rates and methodology

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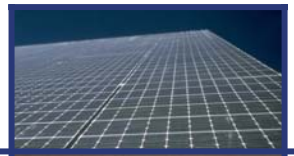
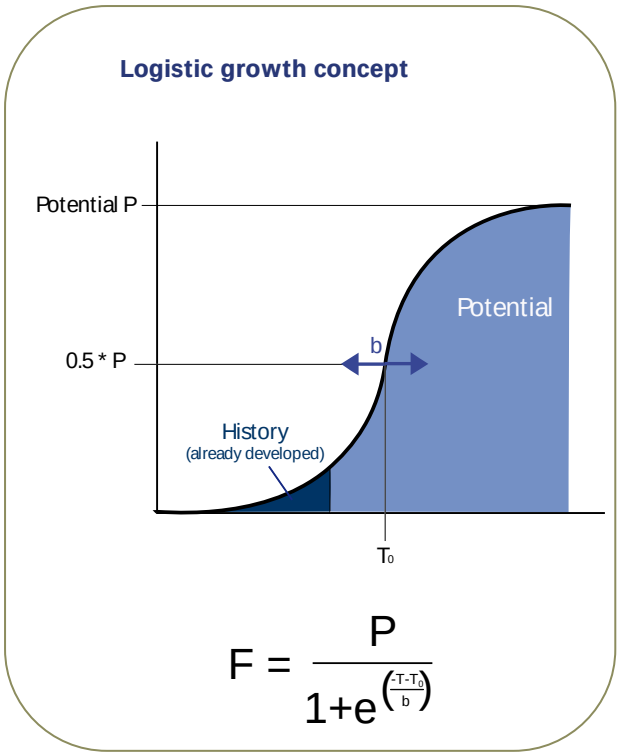
Photovoltaic (PV)		**+ 24 % per year**
Solar thermal power plants (SOT)		**+ 30 % per year**
Solar collectors (heat)		**+ 11 % per year**
Biomass		**+ 2.3 % per year**
Wind power		**+ 16 % per year**
Hydropower		**+ 2.3 % per year**
Geothermal		**+ 11 % per year**

Potential P:
available technical potential
[ecological limitations considered]



Compilation: LBST

Source: LBST

Average global growth rates

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Role of hydrogen

Where does the hydrogen come from? – Electricity by world region

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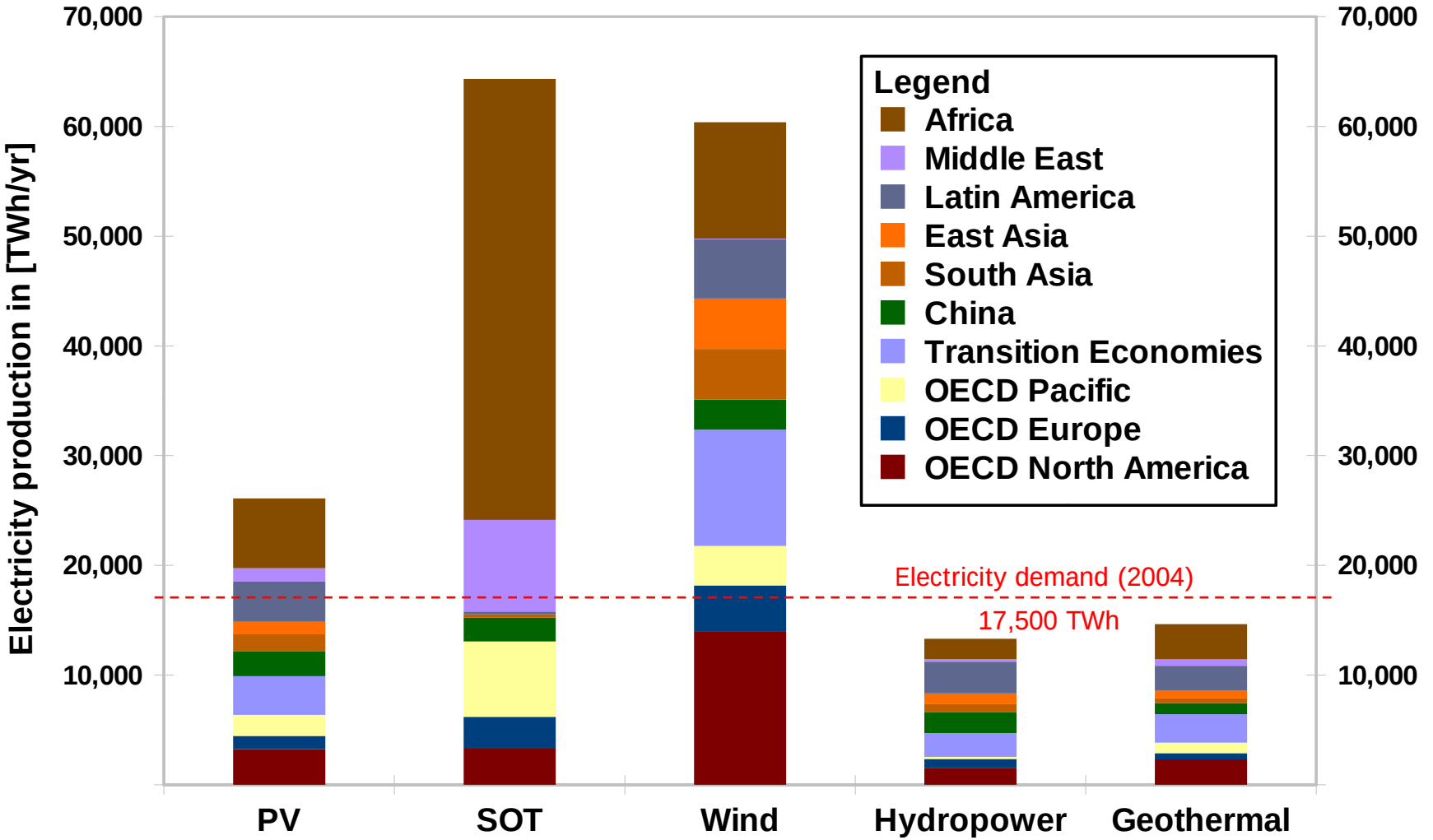
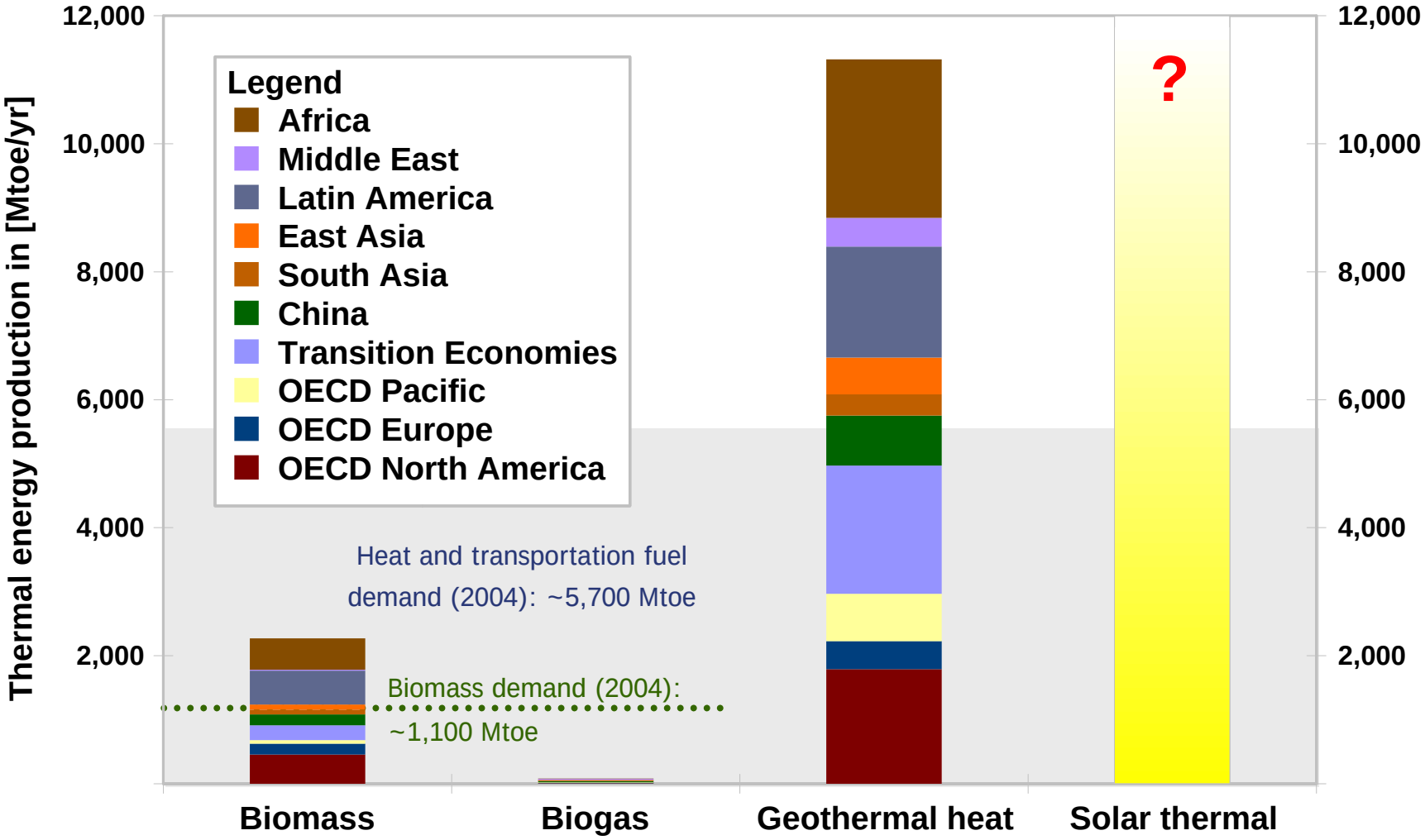


Source: LBST

Cumulative regional growth scenarios based on historic growth rates projected into the future via logarithmic function

Role of hydrogen

Where does the hydrogen come from? – Heat by world region



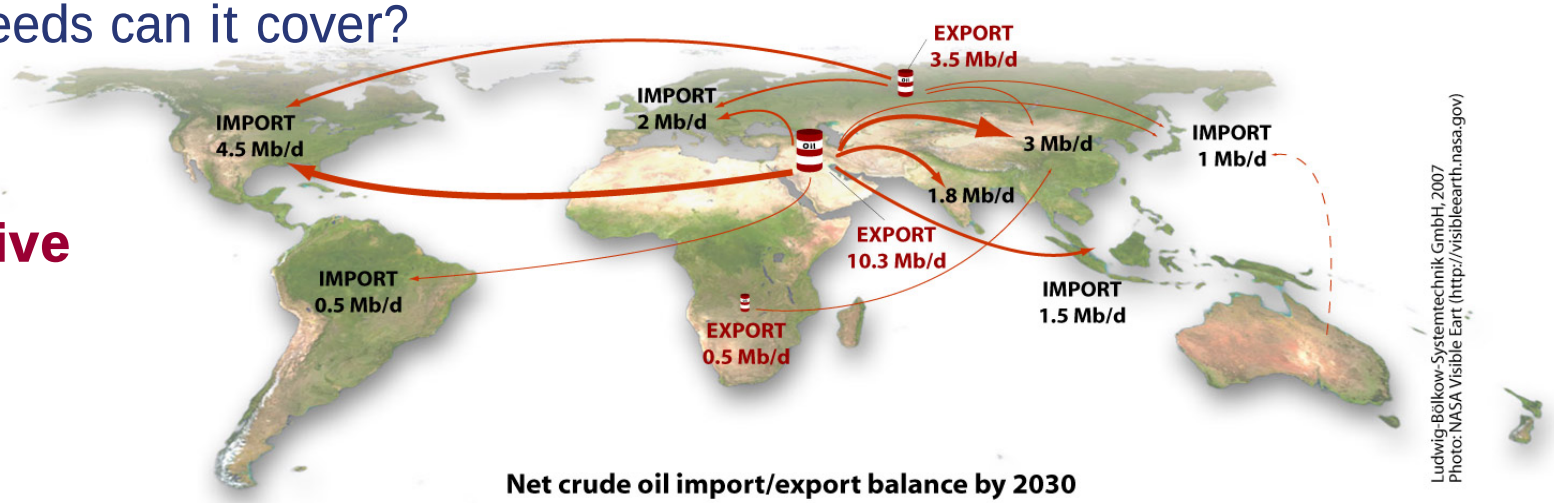
Source: LBST

Cumulative regional growth scenarios based on historic growth rates projected into the future via logarithmic function

Role of hydrogen

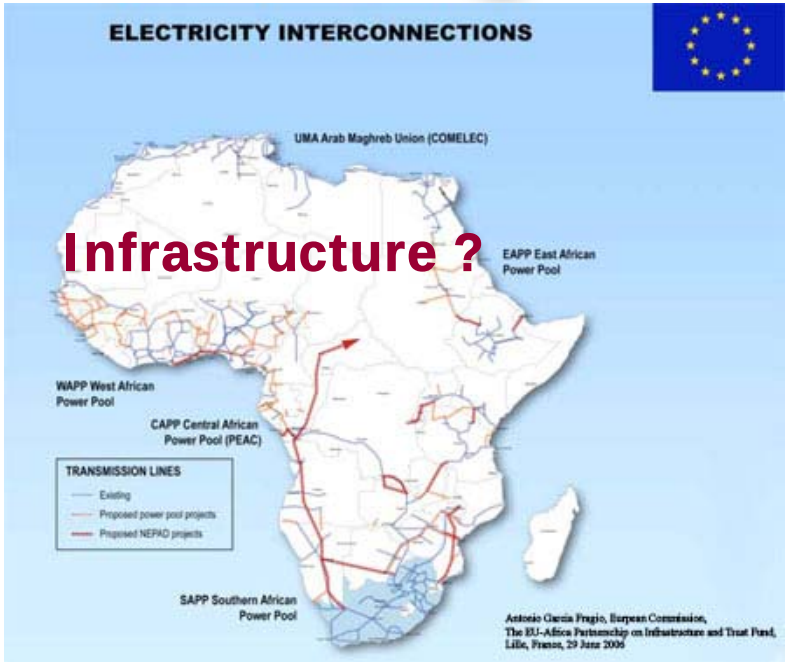
Which needs can it cover?

Alternative Fuels ?



Net crude oil import/export balance by 2030

Infrastructure ?



Transport sector:

Local production of hydrogen

(*reduction of oil import dependency, long-term growth will not be feasible with fossil fuels nor with biomass-derived fuels respectively through imports*)

Stationary sector:

Supply of back-up power via fuel cells (*hospitals, telecom, data processing, manufacturing processes, refrigeration, etc.*)

Remote /re-electrification for electrical islands

(*compensation for infrastructure deficits*)

Load levelling of fluctuating electricity production

Source: LBST

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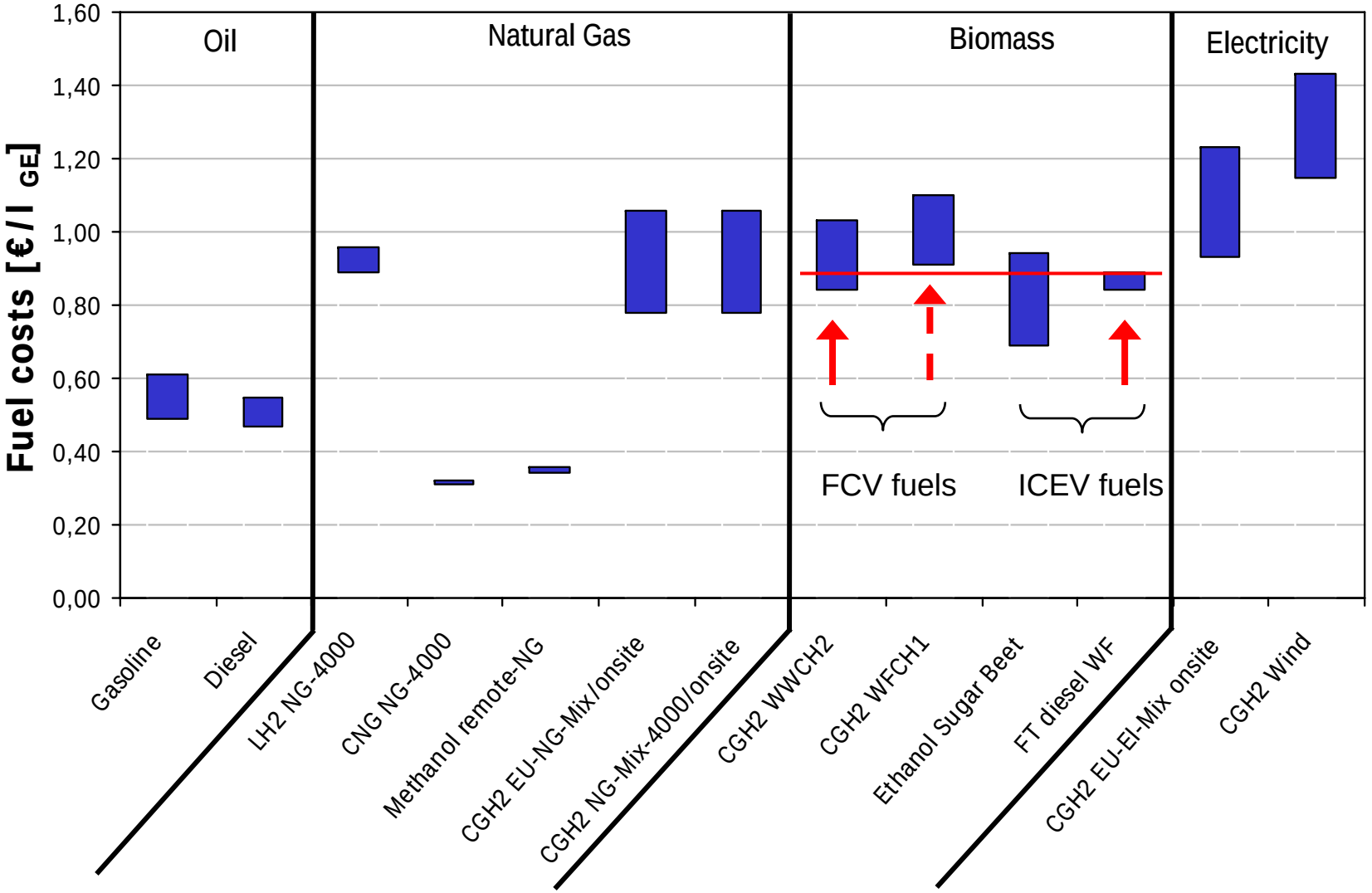
Cost of Hydrogen as Transport Fuel Compared to Other Alternative Fuels

Fuel costs “Well-to-Tank”



Crude oil based gasoline and diesel: price ex filling station without taxes in June 2006

Source: LBST

Fuel costs versus GHG emissions “Well-to-Wheel” - hybrid powertrain

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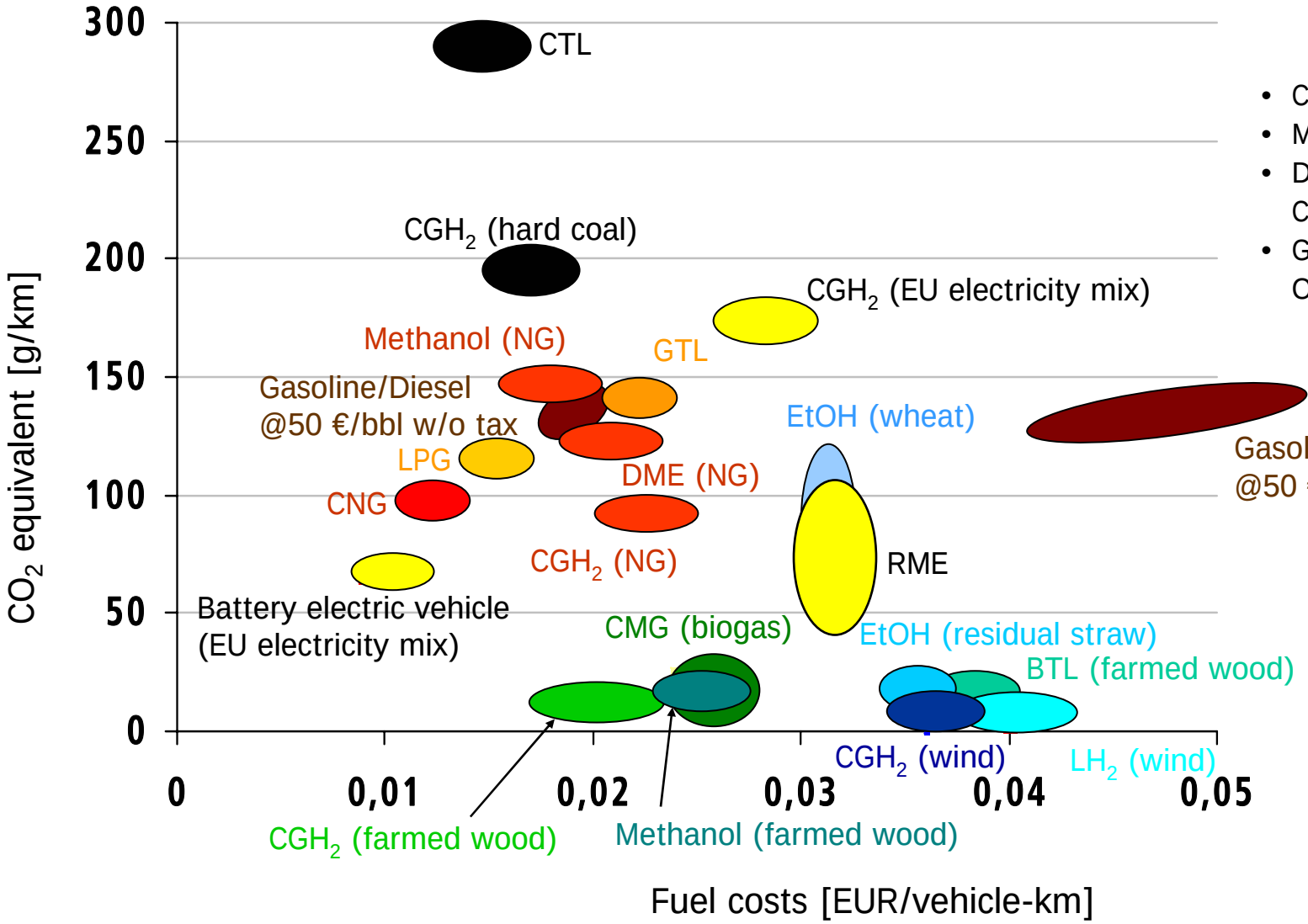

- CGH_2, LH_2: FC
- Methanol: FPFC
- Diesel, RME, BTL, GTL, CTL, DME: Diesel ICE
- Gasoline, ethanol, CMG: Otto ICE

➢ reference vehicle VW Golf
➢ hybrid

Source: LBST

www.lbst.de

Selected Literature Sources – Energy Resources Situation:

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Energy Watch Group:

Oil Report:
http://www.energywatchgroup.org/Oil-report.32+M5d637b1e38d.0.html
http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Oilreport_10-2007.pdf [full report]
http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Oilreport_Summary_10-2007.pdf [executive summary]
http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Press_Oilreport_22-10-2007.pdf [press release]

Uranium Report:
http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Uraniumreport_12-2006.pdf

Coal Report:
http://www.energywatchgroup.org/fileadmin/global/pdf/EWG-Coalreport_10_07_2007.pdf
´

DWV:
"Woher kommt die Energie für die Wasserstofferzeugung — Status und Alternativen“
http://192.168.1.217/www/lbst.de/publications/studies__d/2006/DWV_Woher-H2_NOV2006.pdf
http://www.dwv-info.de/publikationen/2006/woher.pdf

EHA:
EHA H2 Production Brochure April, 2007
http://www.h2euro.org/Publications/studies/EHA_H2Production_brochure_eng_0407.pdf

EC-JRC IPTS:
"Potential of hydrogen as a fuel for transport in the long term (2020 to 2030)“
http://192.168.1.217/www/lbst.de/publications/studies__e/2004ipts__e.html

Selected Literature Sources – Well-to-Wheel and LCA:

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EUCAR, CONCAWE, JRC – Well to Wheel Reports
Well to Wheel Reports 2007, 2006, 2005 and 2003
http://192.168.1.217/www/lbst.de/publications/studies__e/2005eucar__e.html
http://ies.jrc.cec.eu.int/wtw.html

Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study
http://192.168.1.217/www/lbst.de/publications/studies__e/2002gmwtw__e.html

Einordnung und Vergleich biogener Kraftstoffe – „Well-to-Wheel"-Betrachtungen
http://192.168.1.217/www/lbst.de/publications/articles2006/Schindler-Weindorf_LBST_Bio-Kraftstoffe-WtW_TA-TuP_April2006_scwe06a.pdf

Vergleich verschiedener Antriebskonzepte im Individualverkehr im Hinblick auf Energie- und Kraftstoffeinsparung
http://192.168.1.217/www/lbst.de/publications/studies__d/2002_antriebe__d.html
Comparison of different propulsion systems in private transport in terms of energy saving and reduction of greenhouse gases
http://192.168.1.217/www/lbst.de/publications/studies__e/2004propuls__e.html

Thank you for your attention !

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For further information
on hydrogen and fuel cells:

www.HyWeb.de — Basic information on H_2 and fuel cells + newsletter (operative since 1996)

www.h2mobility.org — Overview of all H_2 and fuel cell vehicles worldwide (operative since 2000)

www.h2stations.org — Overview of all H2 refuelling stations (operative since 2000)

www.energiekrise.de — Overview of the availability of fossil energy sources (operative since 2000)