



Germany – Taking the Fast Lane to Hydrogen Infrastructure Development



Linde

Patrick Schmidt

Ludwig-Bölkow-Systemtechnik GmbH (LBST)

Munich-Ottobrunn · Germany

schmidt@LBST.de



1. LBST Profile
2. Political Background
3. Hydrogen Infrastructure in Germany
 - H₂ Pipelines
 - By-product H₂
 - H₂ Refuelling Stations



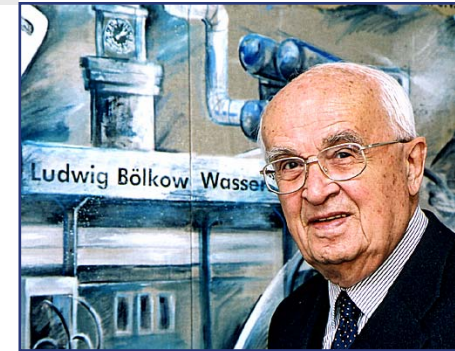
ludwig bolkow
systemtechnik

-
1. **LBST Profile**
 2. Political Background
 3. Hydrogen Infrastructure in Germany
 - H₂ Pipelines
 - By-product H₂
 - H₂ Refuelling Stations



Strategy and technology consultants for sustainable energy and transport systems

- ▶ Founded in 1982
25 years of experience in sustainability issues
20 years with fuel cells, hydrogen and infrastructure
10 years with fossil resource analyses
- ▶ Global, long term and system perspective
- ▶ Focus on technologies for sustainability
- ▶ Clients from industry, politics and NGOs worldwide
- ▶ Interdisciplinary team with high continuity
- ▶ Shareholders: TÜV SÜD (47%), LBST staff (29%), Ludwig Bölkow Foundation (12%), Private person (12%)



Dr. Ludwig Bölkow, † 2003
Founder of LBST and MBB (today EADS)



ludwig bolkow
systemtechnik

-
1. LBST Profile
 - 2. Political Background**
 3. Hydrogen Infrastructure in Germany
 - H₂ Pipelines
 - By-product H₂
 - H₂ Refuelling Stations



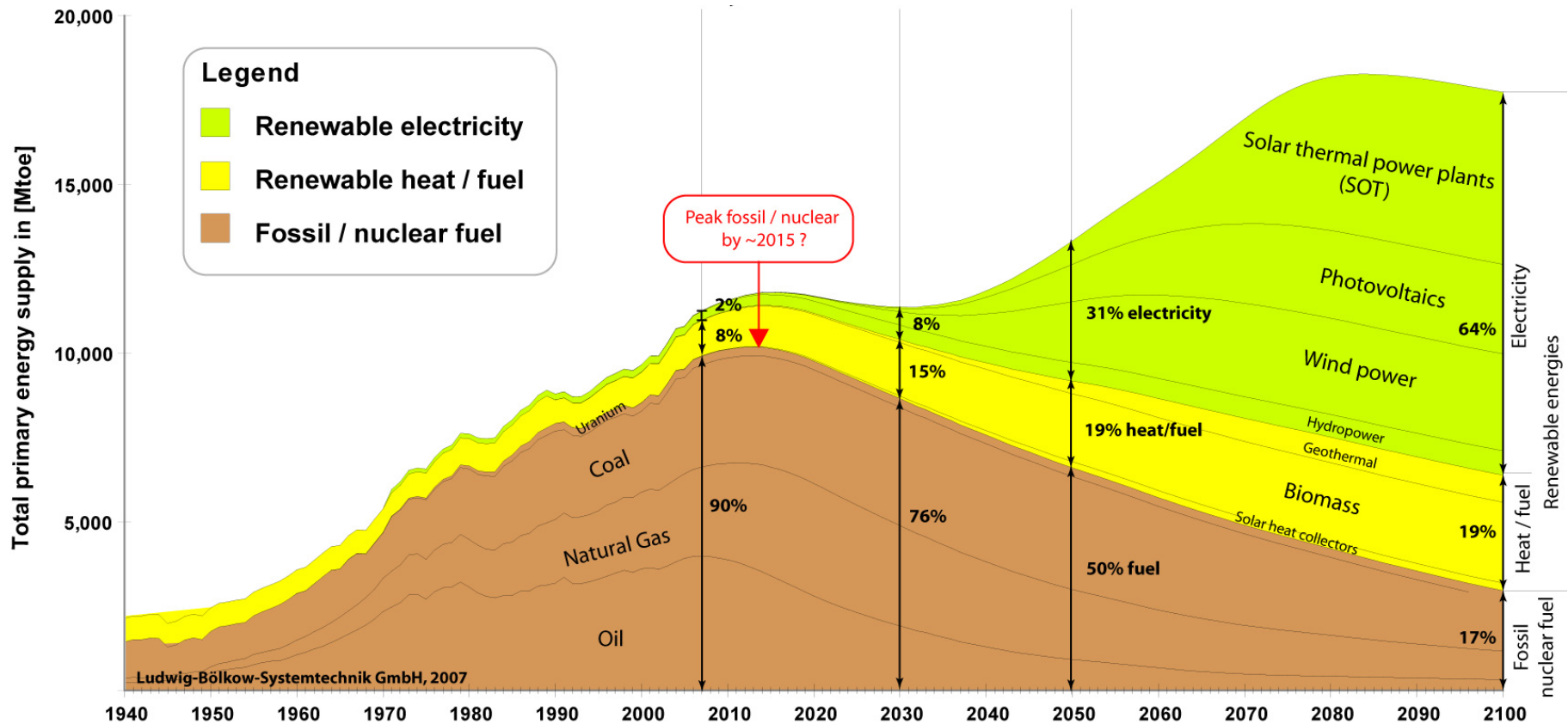
- FT's Tuesday edition
- Impressed vs disappointed
- Peak oil? – Peak everything!?

World “peak oil” is now – “Peak conventional” to follow soon



ludwig bolkow
systemtechnik

- Managing the transition is the mid term challenge
- Near term decision will have long term impacts
- Mind ‘collateral damages’



- Resources (declining fossil energy baseline) – lately
- Environment (climate, pollution, noise)
- Energy (towards an electricity based primary energy system)
- Technology (foster innovation and securing economic competitiveness)

» The risk [when investing in hydrogen and fuel cells] is offset by the likely loss of jobs and value added that would follow if the fuel cell came to dominate the market without the German industry playing a leading role in transport and stationary applications and the establishment of infrastructure. «

German National Innovation Programme (NIP), 8 May 2006

National Hydrogen and Fuel Cell Technology Innovation Programme (NIP)



ludwig bolkow
systemtechnik

- Programme duration: 2007 to 2015
- Funding sources:
 - EUR 500 million from German Federal Ministry of Transport (BMVBS)
 - EUR 2xx million from German Federal Ministry of Research (BMBF) and Economy (BMW*i*)
- ~50% co-financing required
- Additional/complementary financing from state bodies seeken
- Leveraging overall investments of up to EUR 1.4 billion
- Alignment foreseen with European “Implementation Plan” to become a Fuel Cell and Hydrogen Joint Technology Initiative



Minister Tiefensee and European
Commissioner Verheugen

National Organisation Hydrogen and Fuel Cell Technology (NOW)



ludwig bolkow
systemtechnik

- **NOW** GmbH, programme office of the German National Innovation Programme incorporated beginning of 2008
- **Infrastructure** development focus on reforming, biomass-to-H₂, by-product H₂, liquefaction, storage, pipelines, filling stations
- **Demonstration** in two phases

Phase I (2007-2010)

- Advancing technologies
- Focus on key regions
- Car and bus fleets + infrastructure

Phase II (2010-2015)

- Techno-economic validation
- Fleet + infrastructure extension

- Range of H₂ **supply pathways** pursued

- Lead-project “**GermanHy**” to prepare baseline for decisions making



Source: NOW-GmbH.de

Major regional activities in Germany



ludwig bolkow
systemtechnik



CEP – Clean Energy Partnership [CEP-Berlin.de]

- CUTE



HH₂ – Hamburg Hydrogen [HH2Wasserstoff.de]

- CUTE bus demo
- Forklift airport Hamburg
- H₂ ship Alster



H₂FC-Initiative Hessen [H2BZ-Hessen.de]

- Zero Regio



HyCologne – Hydrogen Region Rhineland [HyCologne.de]

Munich (BMW, Linde)



NRW – North Rhine Westphalia [Brennstoffzelle-NRW.de]

- HyChain Minitrans
- HyRaMP Hydrogen Regions Initiative

- Stuttgart (Daimler, Linde)



ludwig bolkow
systemtechnik

-
1. LBST Profile
 2. Political Background
 3. Hydrogen Infrastructure in Germany
 - H₂ Pipelines
 - By-product H₂
 - H₂ Refuelling Stations



Image: Air Liquide

Rhine/Ruhr (AirLiquide)

- 240 km network of H₂ pipelines
- supplying large industry consumers
- Marl is biggest H₂ commissioning centre in Europe

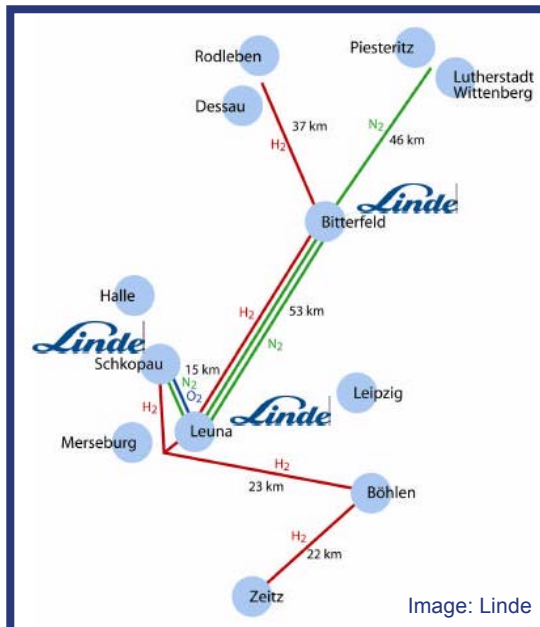


Image: Linde

Leuna/Bitterfeld (Linde)

- 150 km network of H₂ pipelines
- serving industrial clients
- 2 newly built liquefiers with 5 t_{LH₂}/d capacity each



ludwig bolkow
systemtechnik

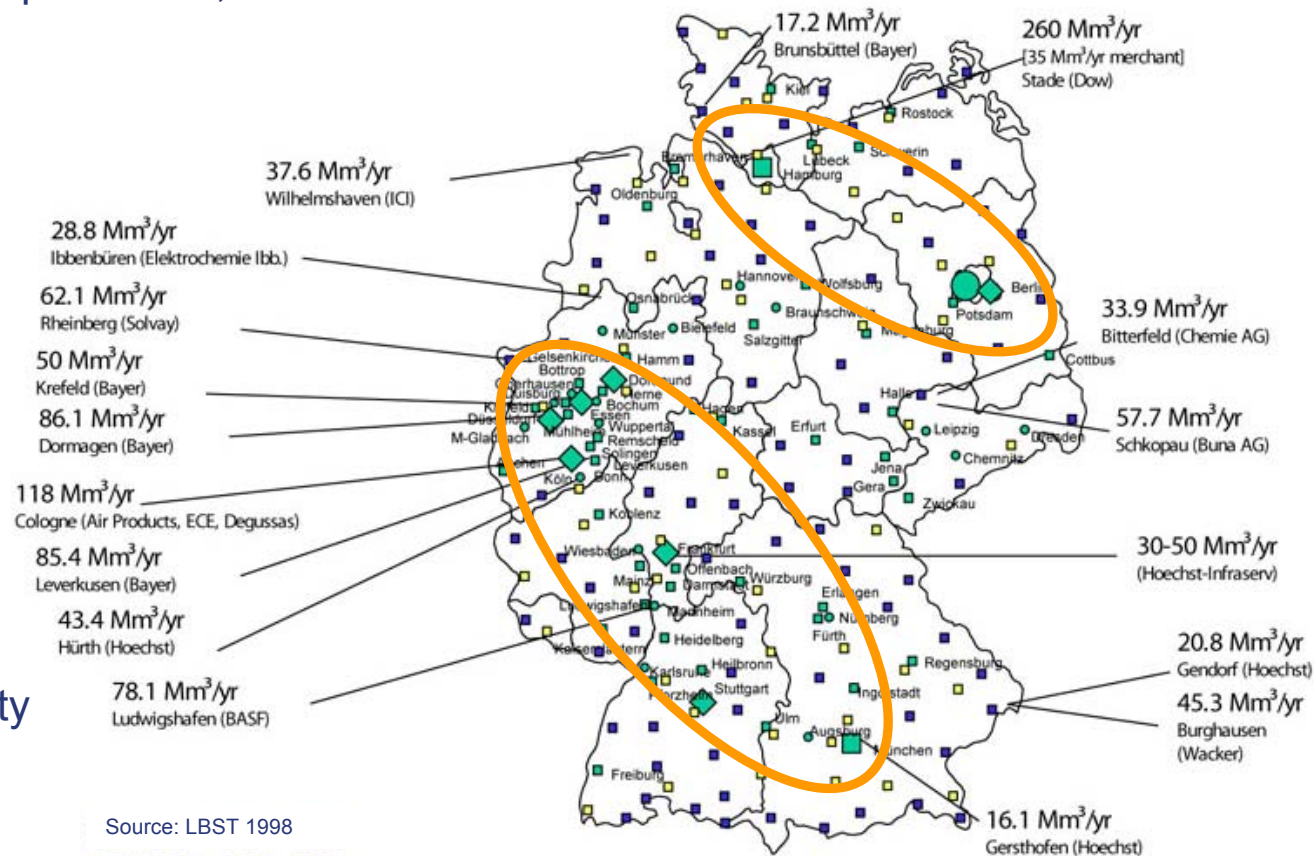
-
1. LBST Profile
 2. Political Background
 3. **Hydrogen Infrastructure in Germany**
 - H₂ Pipelines
 - **By-product H₂**
 - H₂ Refuelling Stations

By-product hydrogen in Germany



ludwig bolkow
systemtechnik

- Potential of **800-1,000 million Nm³/yr** identified [LBST 1998, HyWays 2007]
- Equivalent to 2.5-3 TWh/yr or 9-10.8 PJ/yr
- By-product **sources** are chemical processes, such as
 - chlorine electrolysis
 - sodium hydroxide production
- So far, excess H₂ is **utilised** for
 - heat and steam production
 - electricity generation
- Typical **locations** are Cologne, Frankfurt, Hamburg, Leverkusen and the region of North Rhine Westphalia
- The two geographical clusters correspond with population density





ludwig bolkow
systemtechnik

-
1. LBST Profile
 2. Political Background
 3. Hydrogen Infrastructure in Germany
 - H₂ Pipelines
 - By-product H₂
 - H₂ Refuelling Stations

Hydrogen refuelling stations in Germany



ludwig bolkow
systemtechnik



Status Germany
as of April 2008:

- in operation: **21**
- in planning: **4**
- discontinued: **10**

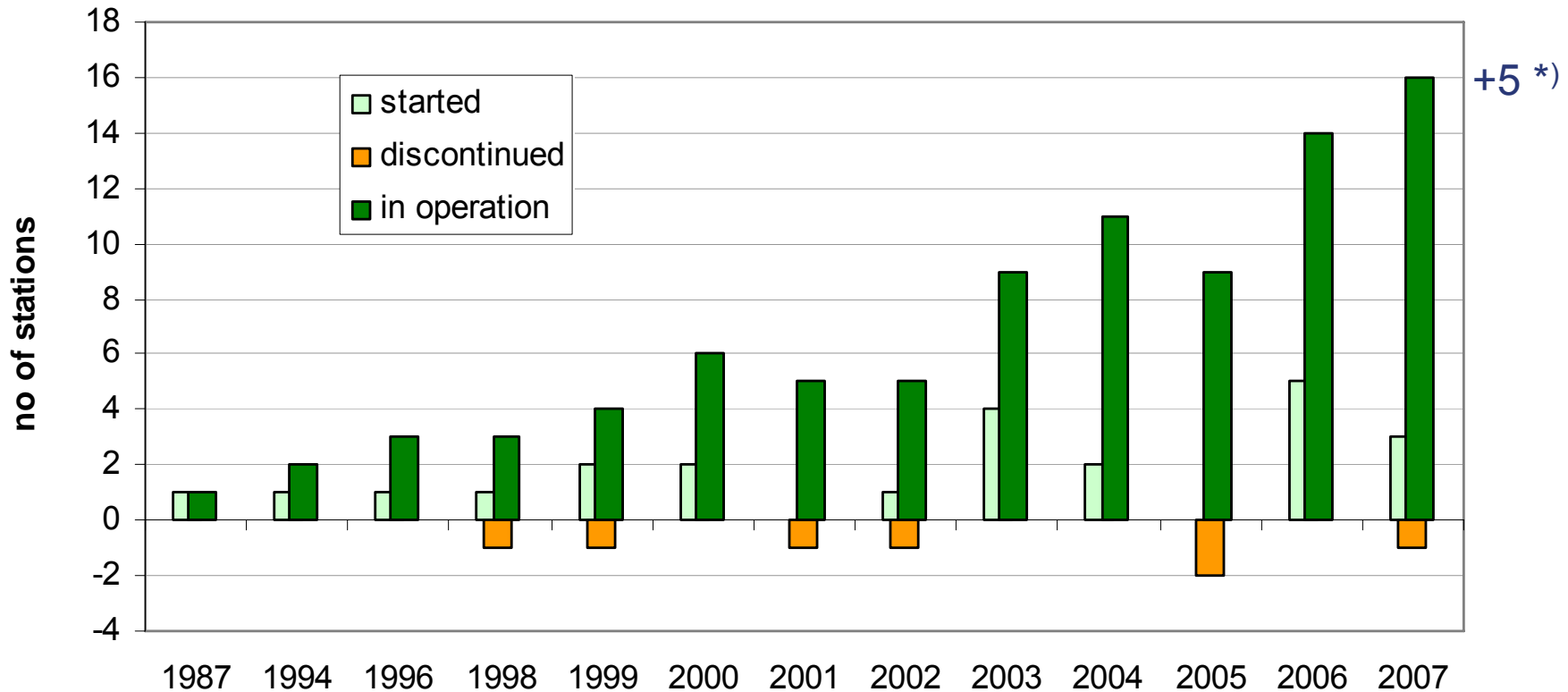
 in operation  planned  out of operation

Currently, the H2stations.org database contains **303** unique entries (past, current, and planned)

Hydrogen refuelling stations in Germany



ludwig bolkow
systemtechnik



LBST | H2stations.org, April'08

*) There have been **8** additional hydrogen refuelling stations (HRS) in Germany with no time indication, mostly installations with R&D facilities, thereof likely **5** still in operation $\Rightarrow \Sigma$ **21** HRS

Total (CEP)



- Opened 03/2006
- Serving 14 hydrogen powered city buses with internal combustion engine, thereof 4 having 150 kW and 10 having 200 kW (turbo-charged)
- Serving HyFleet:CUTE buses
- H₂ supply via pipeline and on-site steam LPG reforming
- Dispensing LH₂ and CGH₂

Aral/BP (CEP)



Mobility partners: Vehicle demonstration

Partner	Vehicles	Drive train	Tank
BMW	2 BMW 7 series	H ₂ ICE	LH ₂
Daimler Chrysler	10 A-Class F-Cell	Fuel Cell (Ballard)	CGH ₂
Ford	3 Ford Focus FCEV	Fuel Cell (Ballard)	CGH ₂
Opel	1 Opel HydroGen3	Fuel Cell (GM/ Opel)	LH ₂

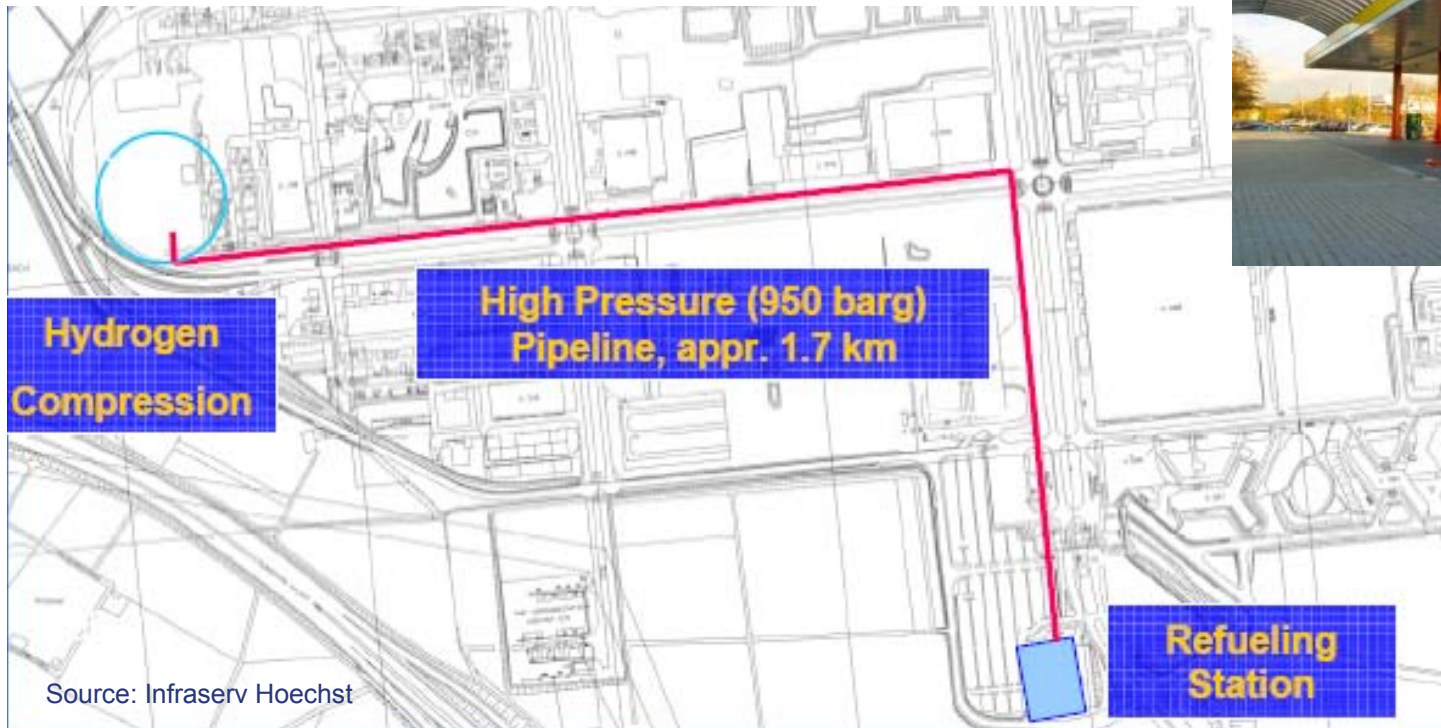
Mobility partners and BVG:

Operation of maintenance workshops for passenger cars and buses

Infrastructure partners: Demonstration of on-site production and supply of hydrogen

Partner	Task
ARAL/ BP	Planning, approval and construction of the site, Operation of H ₂ -station incl. GH ₂ -compression
GHW Hydro	Supply of GH ₂ by on site electrolysis
Linde	Supply and storage of LH ₂ from central production (reforming), LH ₂ -filling technology
Vattenfall	Supply of regenerative electrical power

Infraserv Hoechst (ZERO REGIO)



Source: Infraserv Hoechst



- Opened 11/2006
- Infrastructure and Vehicle Demo Project
- Fully-integrated HRS
- LH₂ and CGH₂
- High-pressure H₂ pipeline
- Serving Daimler F-Cell

Vattenfall / Hamburg (CUTE)



- Opened 09/2003
- On-site water electrolysis
- CGH₂
- Serving three CUTE buses
- New: Hamburg Airport to serve forklift

Aral/BP / Stuttgart (CUTE)



- Opened 2003
- Steam methane reforming
- Serving three CUTE buses

Linde (Linde Hydrogen Centre)



- Opened 10/2006
- Serving BMW L7 and MAN buses
- Linde's test facilities, technology show room
- Public access

Total (Detmoldstrasse)



- Opened 03/2007, serving BMW L7
- Fully integrated with underground LH₂ storage

Aral/BP (H2argemuc)



- LH₂ and CGH₂
- Filling robot
- Open from 05/1999–01/2007
- LH₂ supply, steam reforming and electrolysis
- Serving BMW 7'series LH₂, MAN buses and a forklift

- Transportation sector totally dependant from oil
- Electrification of the drive train is consent among majors in the automotive industry
- Fuel cells are efficiency measures when times are getting tough resource-wise
- Hydrogen is a key enabler, allowing for an uptake of high shares of renewable energies in our energy system [EHA, June 2008]
- Demonstration activities are indispensable exercises to validate technology and allow learning to relevant stakeholders (industry, public bodies, safety authorities, not least the public)
- Long lead times of infrastructure developments impose timely action
- 'Change management' needs careful upfront planning, common goal, firm commitment,
 - and delivery.
- In Germany, concrete steps to go forward will be decided in 2008.

LBST hydrogen and fuel cell information online



ludwig bölkow
systemtechnik



[H2stations.org](https://www.h2stations.org)

All hydrogen filling stations worldwide



[H2mobility.org](https://www.h2mobility.org)

All hydrogen cars, buses, trucks, ships, aviation, and speciality vehicles



[HyWeb.de](https://www.hyweb.de)

News bits, calendar of events



[LBST.de](https://www.lbst.de)

Projects, reports, presentations

Thank you!



ludwig bolkow
systemtechnik

...and looking forward to a fruitful discussion



Patrick Schmidt · Ludwig-Bolkow-Systemtechnik GmbH · Daimlerstr. 15 · 85521 Munich-Ottobrunn · Germany
schmidt@LBST.de



GM WTW Study – "Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study" [2001 - 2002]

BStMLU Study – "Comparison of Different Propulsion Systems in Private Transport in Terms of Energy Saving and Reduction of Greenhouse Gases" [2001 - 2002]

FCSHIP – "Fuel Cell Technology in Ships" [2002 - 2004]

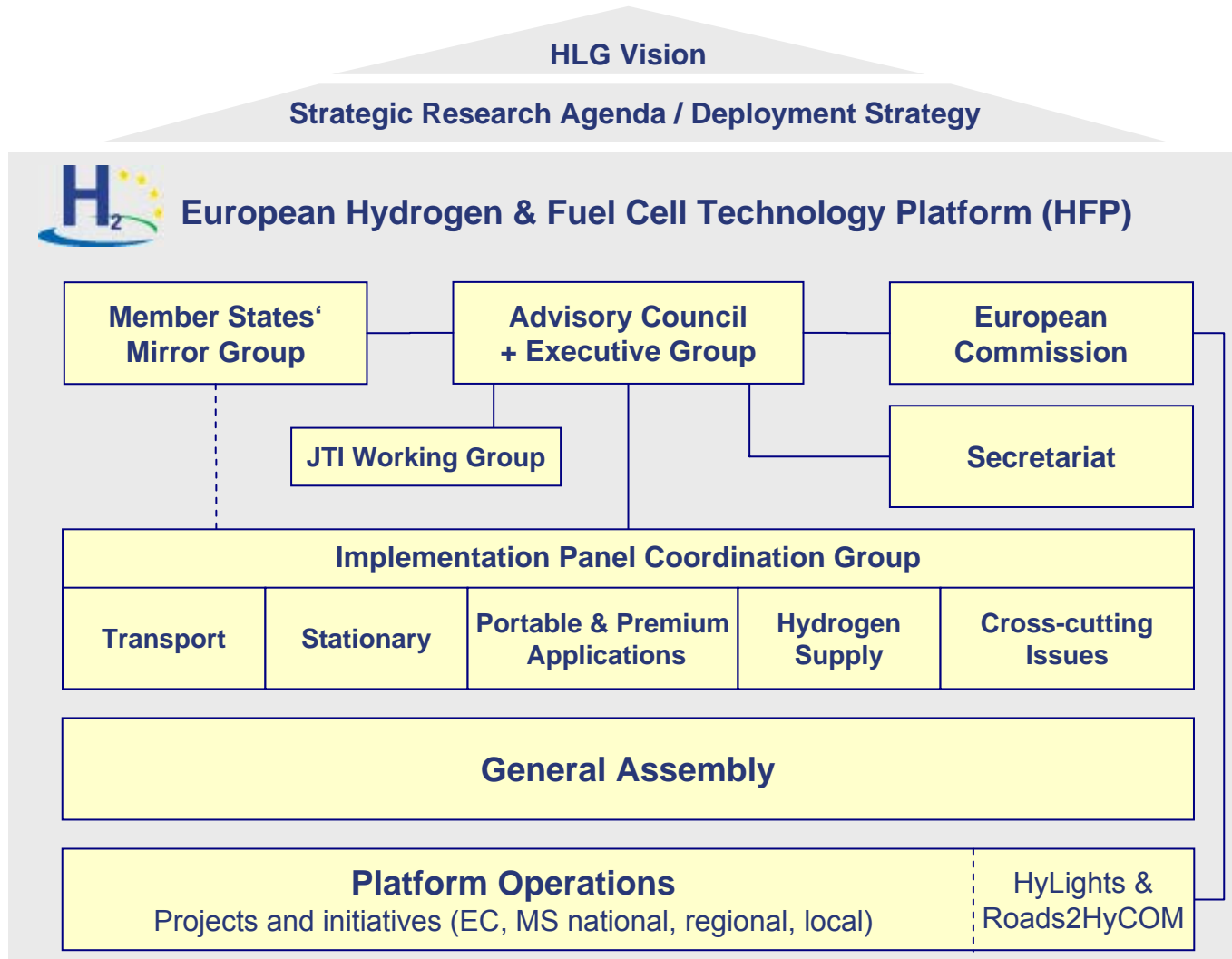
HyWays – European Hydrogen Energy Roadmap Activity [2004 - 2007]

CONCAWE/EUCAR/JRC – "Well-to-Wheel Assessment of Alternative Road Transport Fuels – Well-to-Tank" [2002 - 2008]

European Hydrogen & Fuel Cell Technology Platform (HFP)



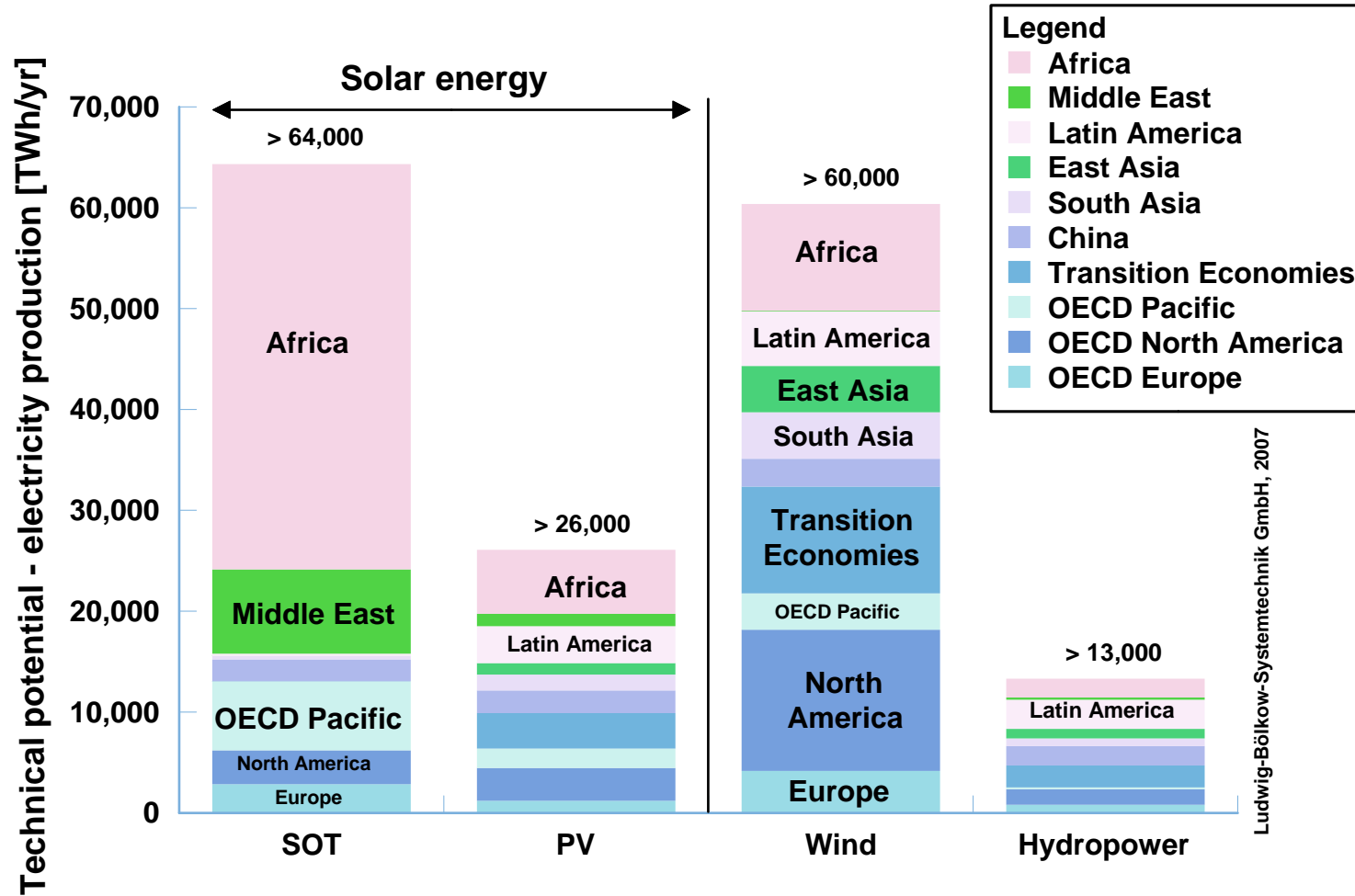
ludwig bolkow
systemtechnik



Technical Potentials for Renewable Electricity Worldwide



ludwig bolkow
systemtechnik



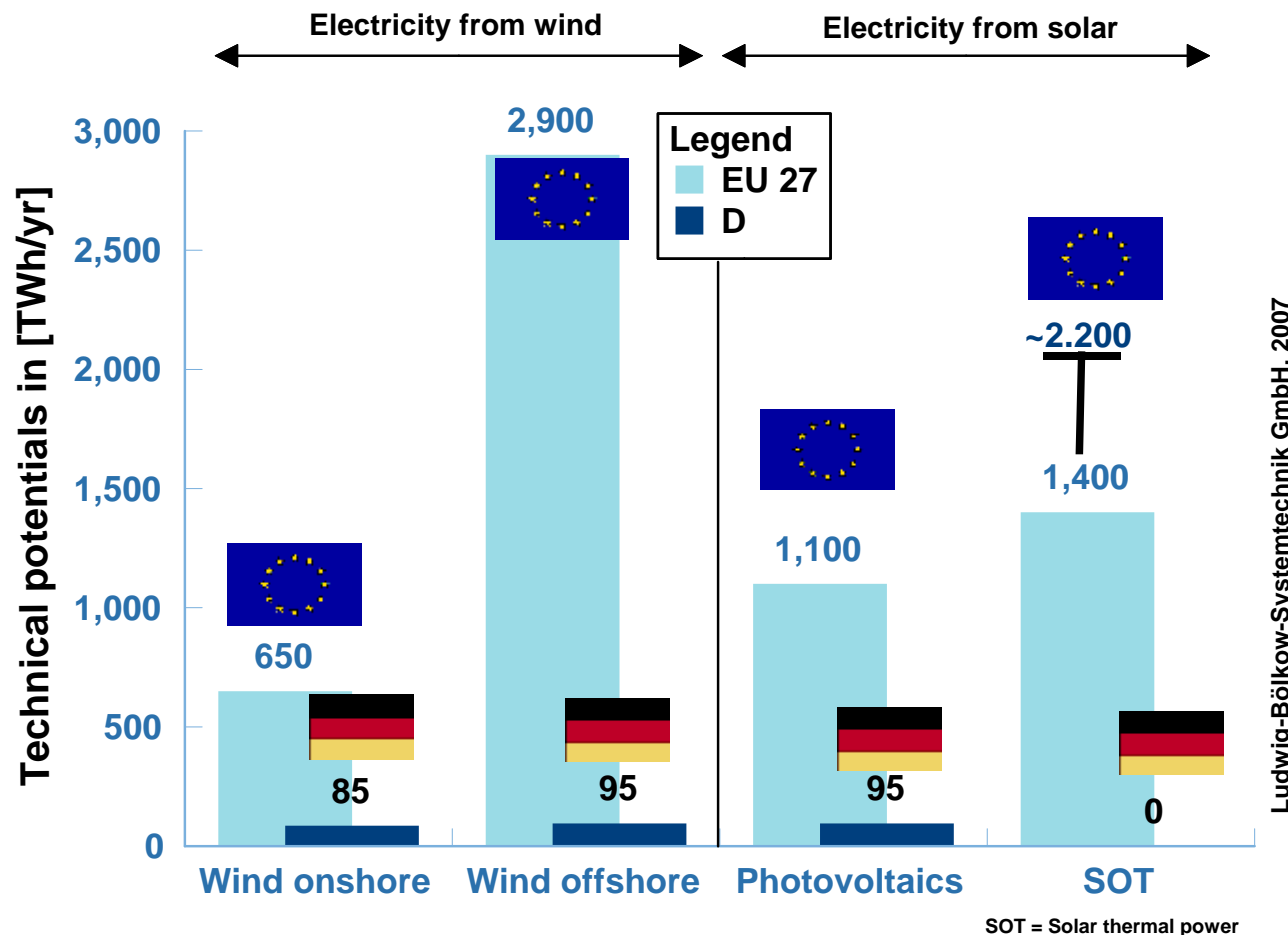
Ludwig-Bölkow-Systemtechnik GmbH, 2007

For comparison: Electricity demand of EU-27 had been **3,250 TWh** in 2004

Technical Potentials for Wind and SOT in Europe (EU) and Germany (D)

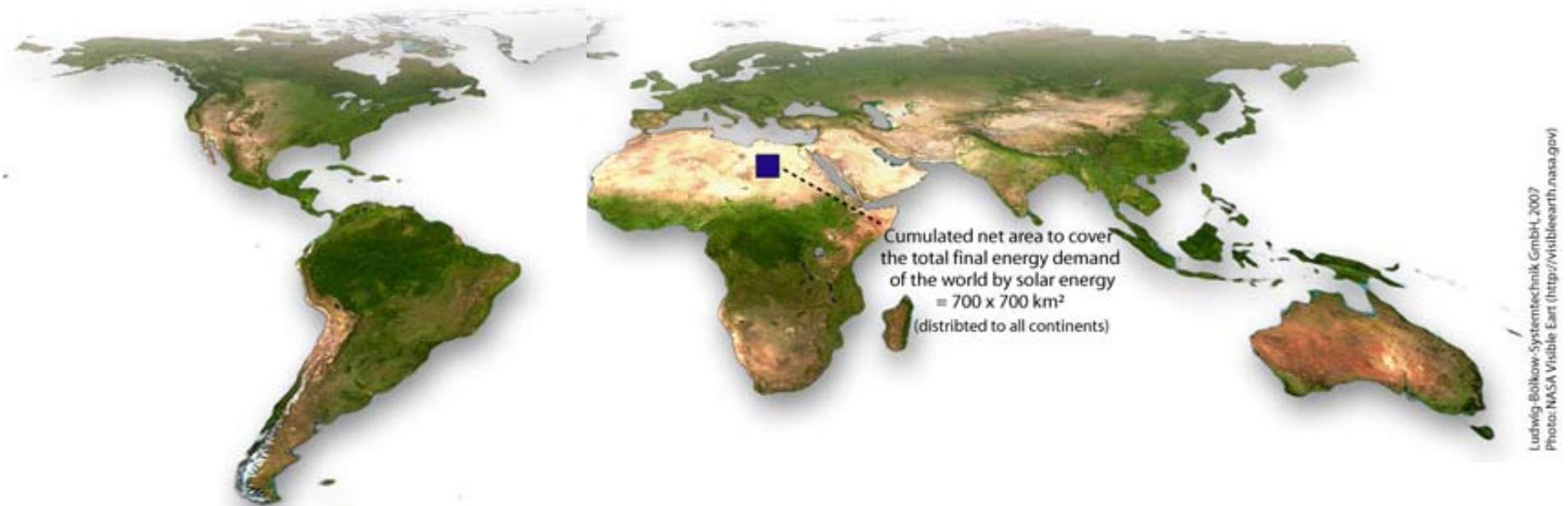


ludwig bolkow
systemtechnik



For comparison: Electricity demand of EU-27 had been **3,250 TWh** in 2004

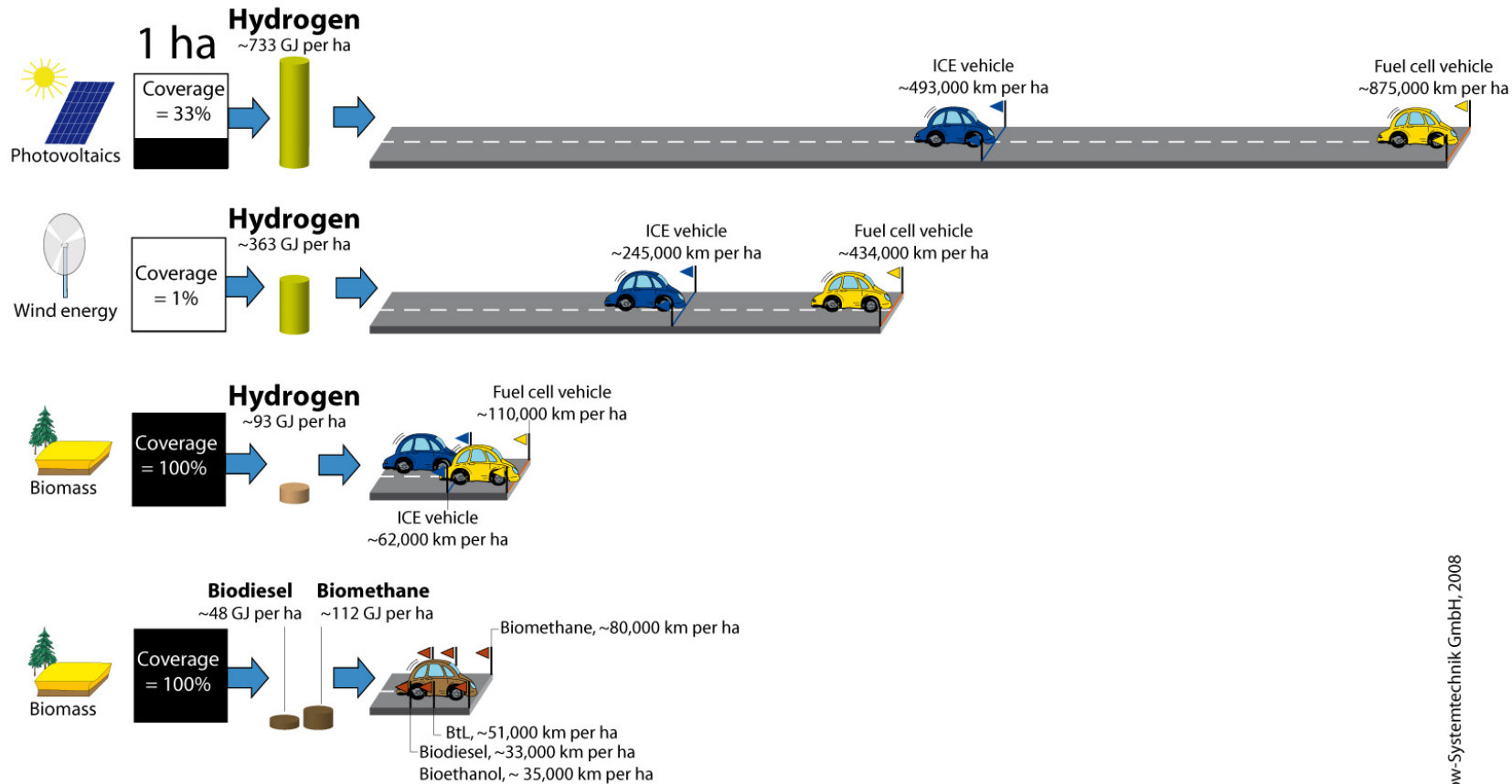
■ Land requirements to cover today's world electricity demand



Use of one hectare of land for fuel production...



ludwig bolkow
systemtechnik



Primary energy	Land covered	Fuel production per ha
----------------	--------------	------------------------

Well-to-Wheel efficiency
(vehicle km per ha)

ha = hectare
ICE = internal combustion engine

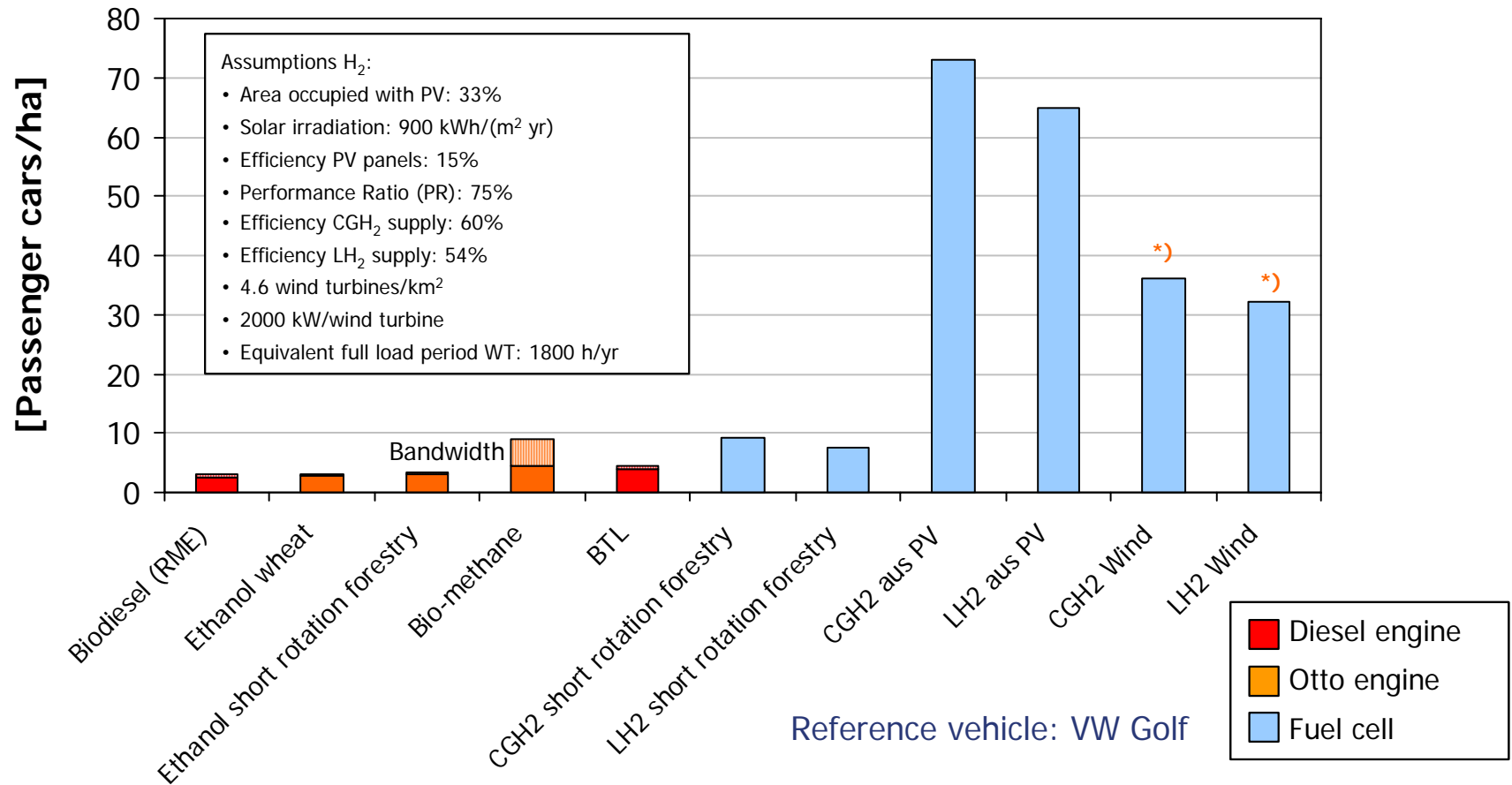
Reference vehicle: VW Golf [Concawe/EUCAR/JRC 2006], average driving performance = 12,500 km per year

Ludwig-Bölkow-Systemtechnik GmbH, 2008

Number of cars that can be fuelled from one hectare of land using...



ludwig bolkow
systemtechnik

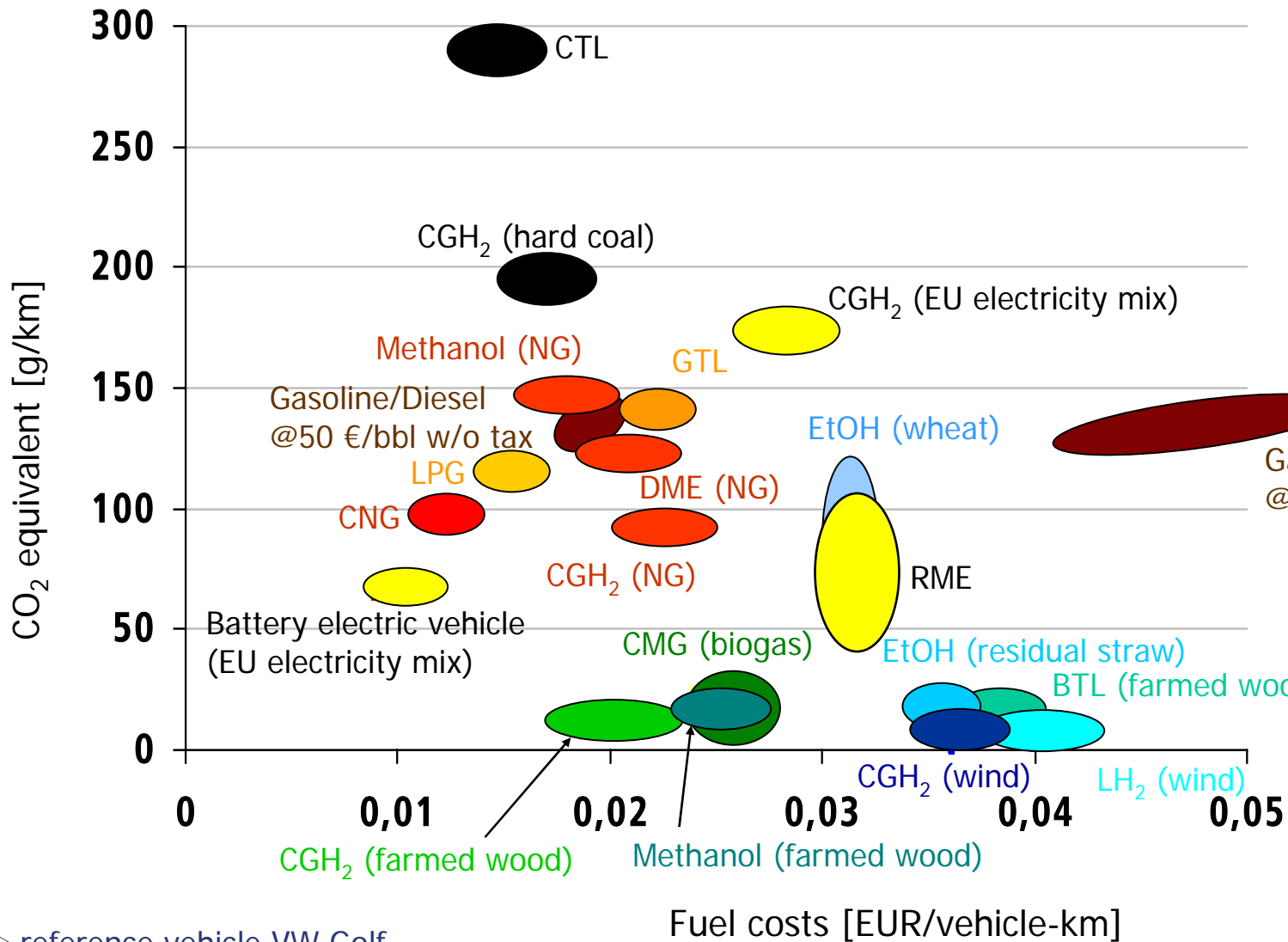


*) more than 99% of the land area can still be used for other purposes e.g. agriculture
 Remark: wind energy convert units of 2 MWe today represent the bottom limit for wind park installation

Fuel costs versus GHG emissions "Well-to-Wheel"



ludwig bolkow
systemtechnik



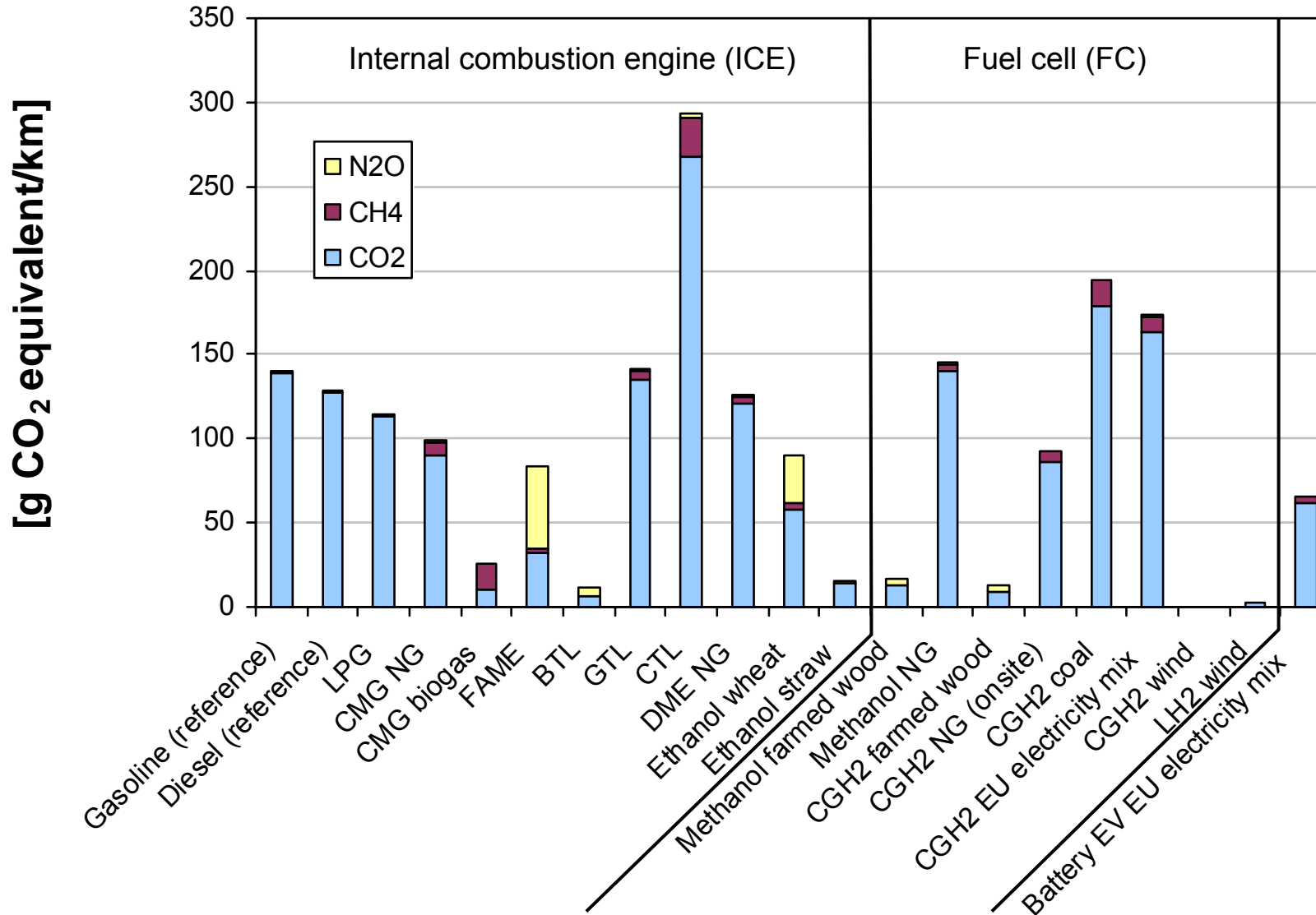
- CGH₂, LH₂: FC
- Methanol: FPFC
- Diesel, RME, BTL, GTL, CTL, DME: Diesel ICE
- Gasoline, ethanol, CMG: Otto ICE

- reference vehicle VW Golf
- hybrid

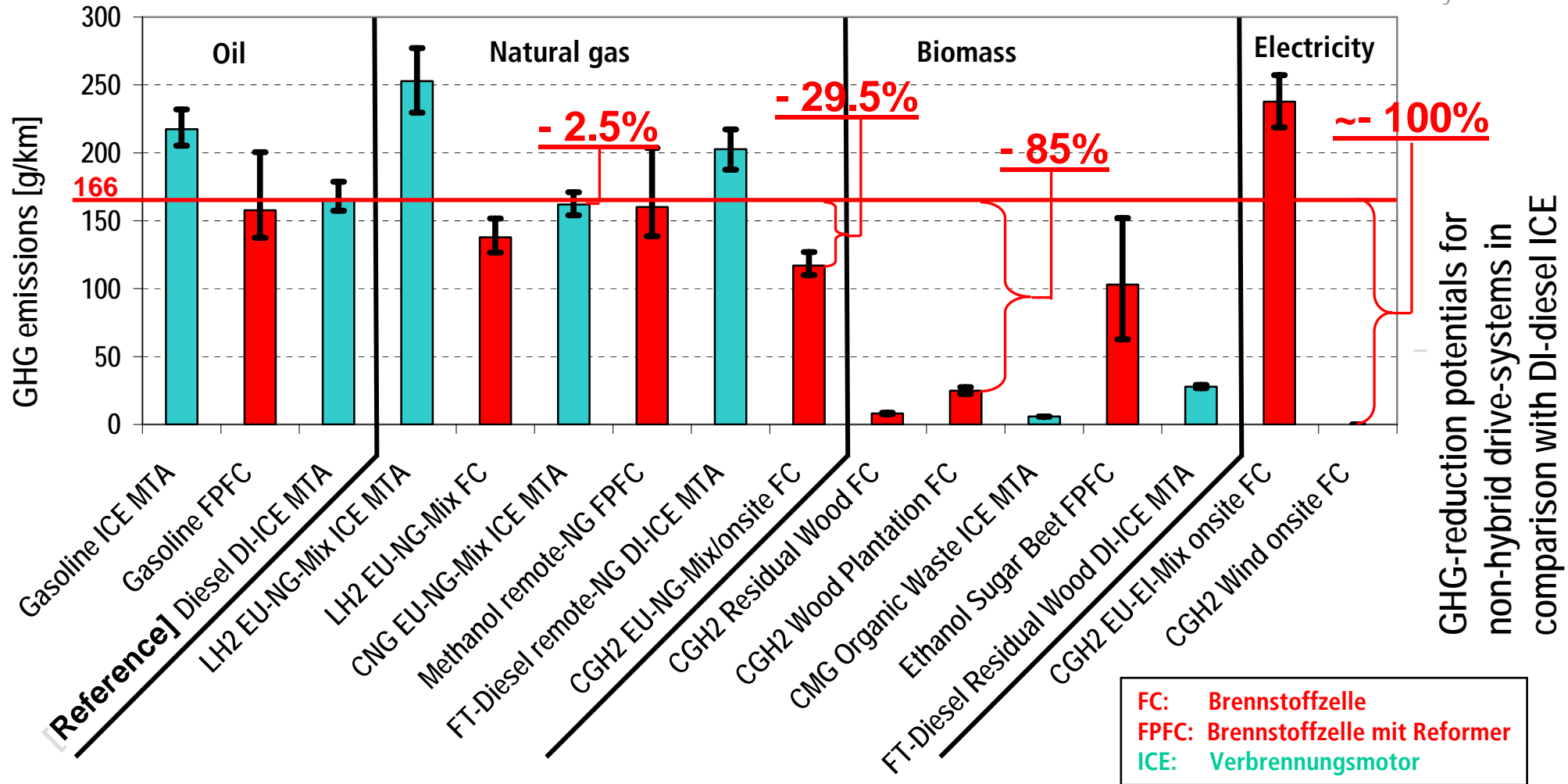
Well-to-Wheel Greenhouse Gas Emissions of Various Pathways



ludwig bolkow
systemtechnik



GHG emissions of alternativ fuels in Europe



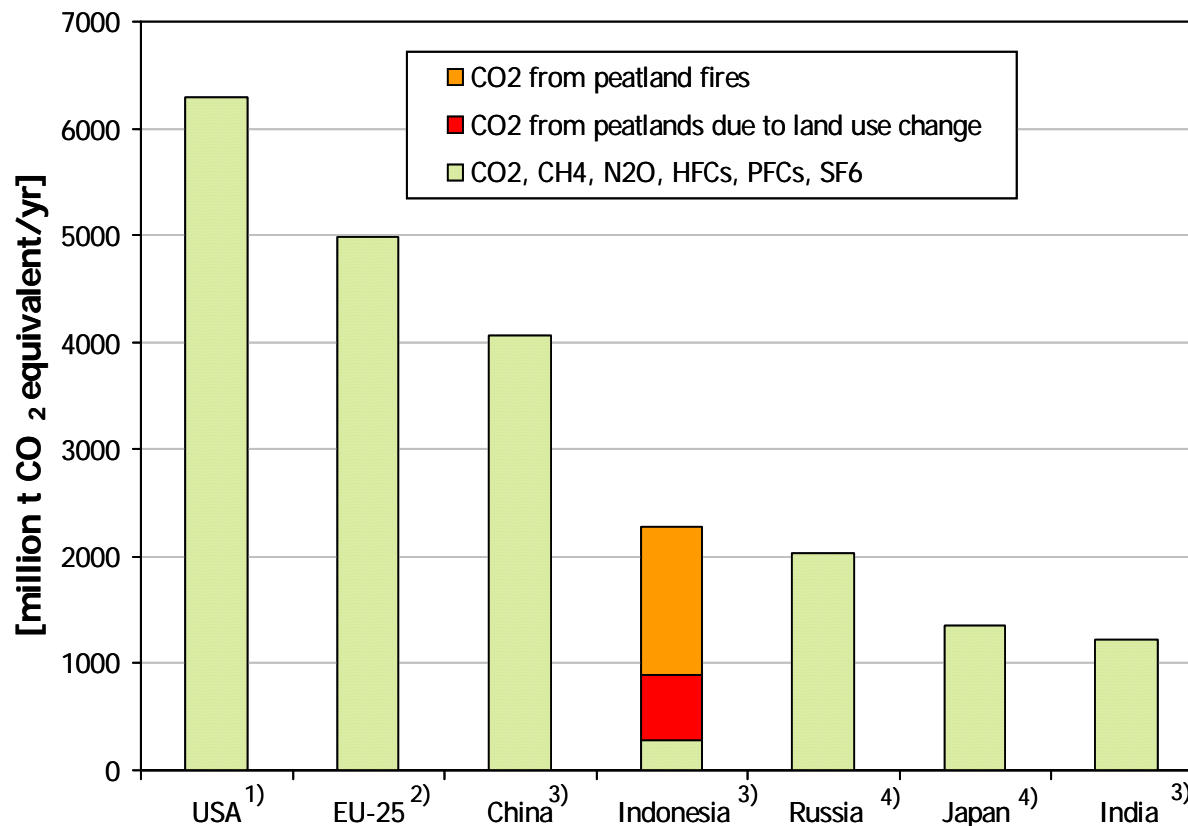
Basis: Opel Zafira

The biofuel case – ‘collateral damage’



ludwig bolkow
systemtechnik

GHG emissions 2004



Sources:

1) U.S. Environment Protection Agency (EPA), April 2006

2) European Environmental Agency (EEA), 2007

3) www.wetlands.org, November 2006

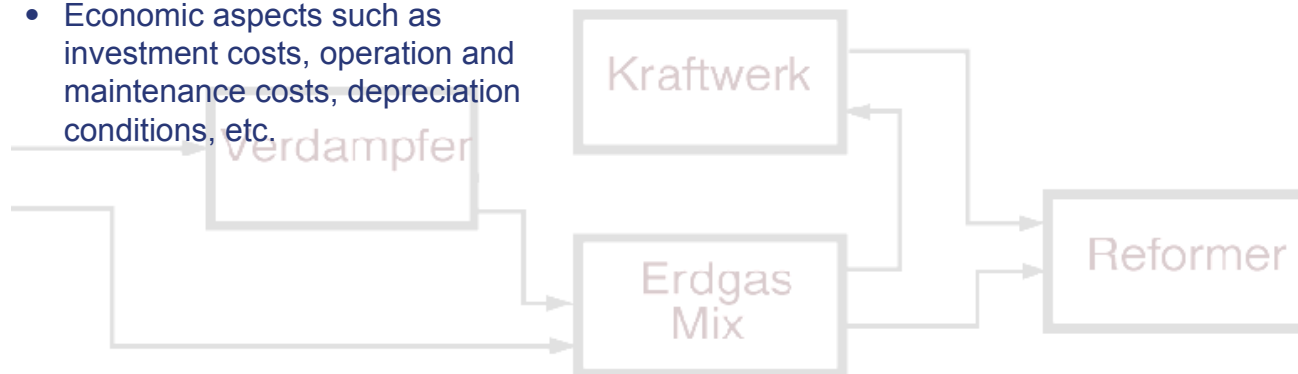
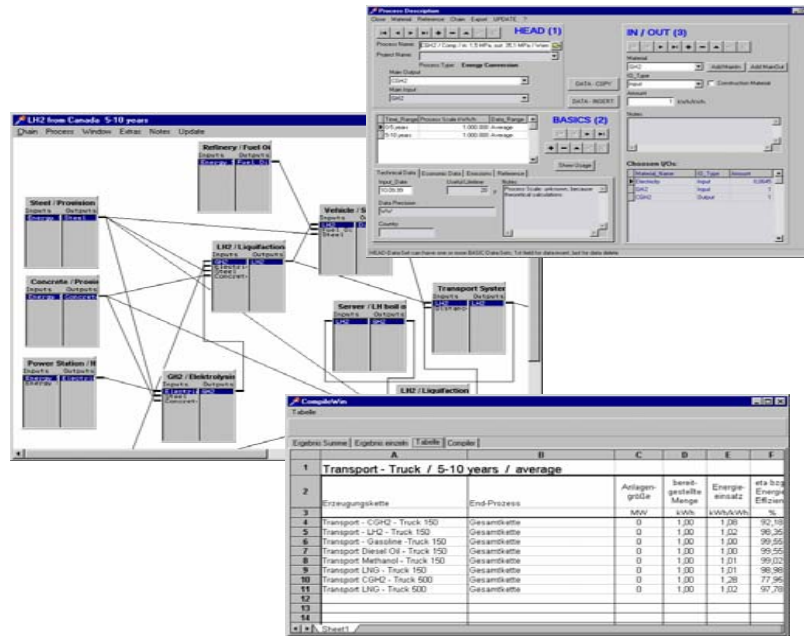
4) UNFCCC, 2006

E3 database

A calculation tool

for the supply and use of energy carriers, products or services:

- Cumulative energy demands
- Material balances, e.g. for the construction of an industrial plant
- Emissions of air pollutants and greenhouse gases (CO₂, CH₄, etc.)
- Economic aspects such as investment costs, operation and maintenance costs, depreciation conditions, etc.





ludwig bolkow
systemtechnik

E3database example simulation:

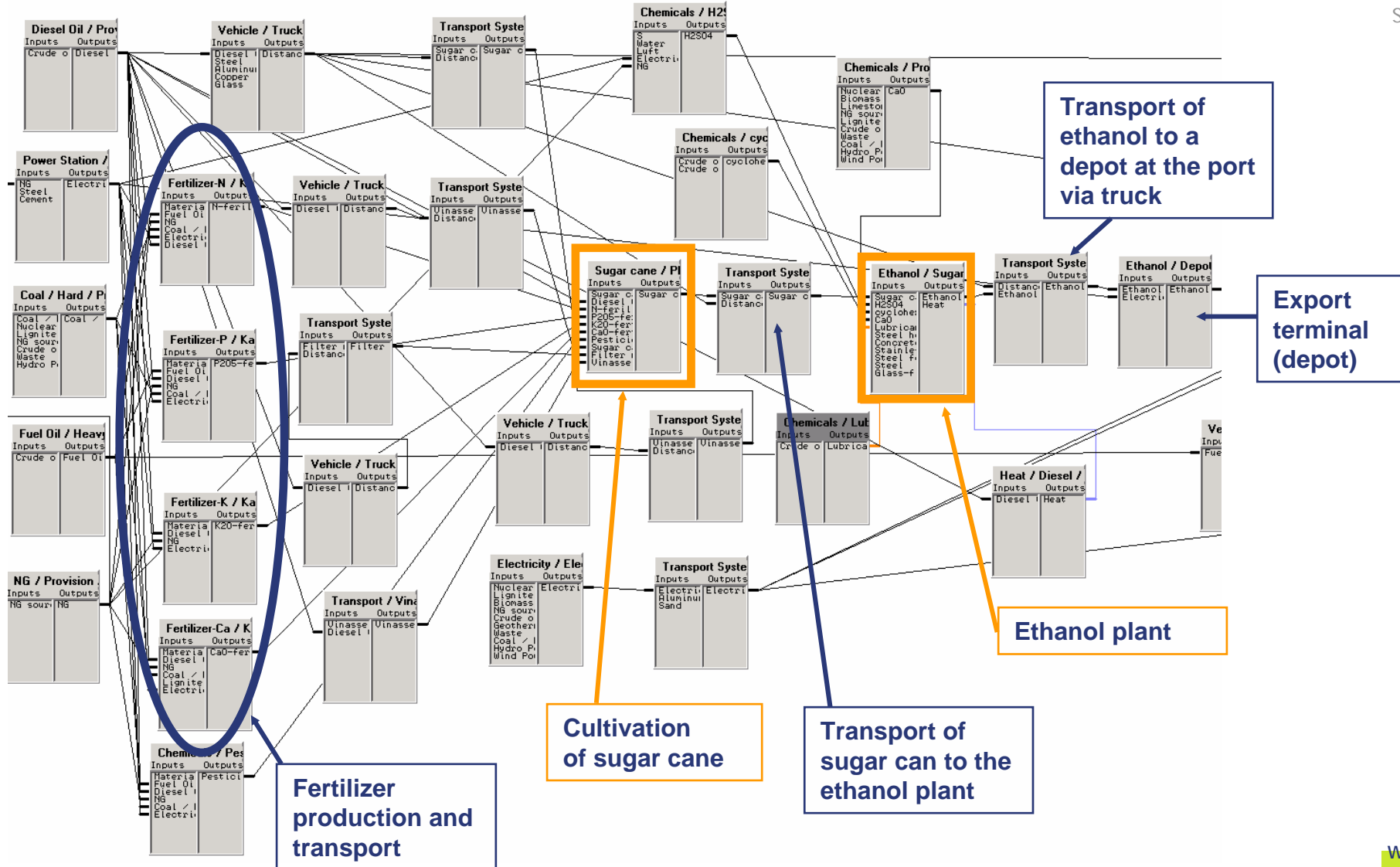
Ethanol from sugar cane produced outside the EU
and consumed in the EU

Part I: Sugar cane plantation, ethanol production, transport to port



ludwig bolkow
systemtechnik

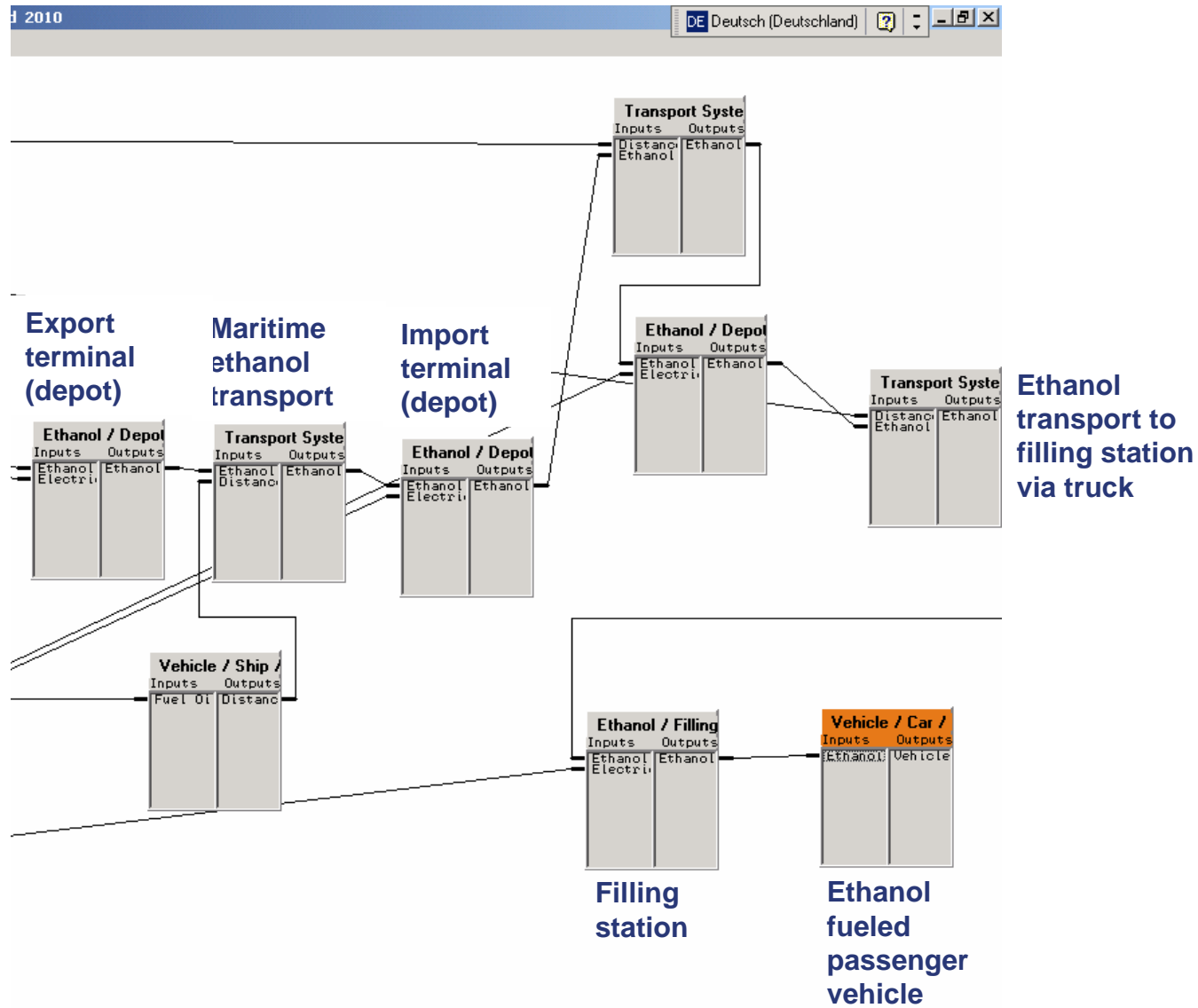
CONCAWE SCET1 / Sugar cane to EthOH (produced in Brazil, used in Europe) / DISI 2010 hybrid 2010



Part II: Ethanol transport to the EU, ethanol use in a vehicle



ludwig bolkow
systemtechnik



Simplified Model of an Agricultural Product and Supply



ludwig bolkow
systemtechnik



Possible outcomes:

- Greenhouse Gases
- Air pollutants
- Energy effort
- Costs

Service unit: 1 kg fruit

Fertiliser
Pesticides
Fuel
Electricity

Material (e.g. paper)
Fuel
Electricity

Shipping mode
Shipping distance
Fuel
Electricity