TRENDS 2015 –
Transition to Renewable Energy Devices and Systems

Detlef Stolten, Ralf Peters (Eds.)

Energie & Umwelt / Energy & Environment
Band / Volume 350
ISBN 978-3-95806-195-8

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FORSCHUNGSZENTRUM

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment Band / Volume 350

Forschungszentrum Jülich GmbH
Institute of Energy and Climate Research
Electrochemical Process Engineering (IEK-3)

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ISSN 1866-1793 ISBN 978-3-95806-195-8

Bibliographic information published by the Deutsche Nationalbibliothek.
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Publisher and Distributor:	Forschungszentrum Jülich GmbH Zentralbibliothek 52425 Jülich Tel: +49 2461 61-5368 Fax: +49 2461 61-6103 Email: zb-publikation@fz-juelich.de www.fz-juelich.de/zb
Cover Design:	Grafische Medien, Forschungszentrum Jülich GmbH
Source Cover Image:	Forschungszentrum Jülich; © fotolia.com: diyanadimitrova (photovoltaic), W.Scott (wind farm), Jürgen Fälchle (field), chalermchai k (refinery), striZh (waves), Arcady (drops), Gudellaphoto (aircraft), Jaroslav Pachý Sr. (truck), Thaut Images (cars)
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Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment, Band / Volume 350

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Preface

The round table discussion, TRENDS 2015, Transition to Renewable Energy Devices and Systems took up relevant topics in the area of the transformation of the energy system. The concept of the conference was to highlight Game Changers and to look into Missing Links in order to achieve the G8 goals of reducing 80% of the CO_2 emission by 2050 and realize a major share of renewable energies by 2030.

This round table discussion focused on fuels for transportation and the respective technology in propulsion and auxiliary power provision. On the fuel side a realistic quantitative assessment of the potential of alternative fuels and their production paths was discussed as well as the cost issues associated with the transformation. The interaction of these two threads will be also emphasized in the proceedings.

On the first day of the TRENDS 2015 delegates discussed about global biomass potentials, alternative fuel strategies and the integration of biomass feed stocks into refinery processes. The second day was designed to bring out and discuss up-to-date technologies in detail.

We have compiled most of the presentations of TRENDS 2015 together with a short abstract to a proceedings book. We would like to thank all participants for their valuable presentations and their contributions to the discussion once again. In regard to a follow-up we invite interested readers of this compilation to send your comments to the editors. We would be glad to implement new aspects in a future event.

Detlef Stolten, Ralf Peters,

Forschungszentrum Jülich GmbH
Institute of Energy and Climate Research
IEK-3: Electrochemical Process Engineering

Hydrogen as a Future Energy Carrier

Detlef Stolten,
Jülich Research Centre, Institute of Energy and Climate Research
IEK-3: Electrochemical Process Engineering
Jülich, Germany

The presentation covers main stream hydrogen production and use for the transformation of the energy system with a focus on the German goals for 2050 to cut greenhouse gas emission by 80 % or more based on 1990 values. The focus is on the proof-of-concept whether hydrogen can contribute quantitatively and cost effectively as a future energy carrier.

Whereas for power production renewable energy from wind and solar are proven to provide a potential high enough to comply with the quantitative and cost requirements, it is much less clear how to cut out the CO_2 emissions of transportation.

This study shows that hydrogen can be produced from renewable energy in Germany at a level which is sufficient to provide 70 % of the vehicle transportation, i. e. 30 mn cars, providing enough fuel based on today's annual mileage. The study outlines the concept, which is to install about 270 GW of renewable peak power. This is necessary to gain enough energy to fully furnish the grid requirements most of the times. The electrical demand was assumed to be at today's level in 2050. If more peak capacity is installed the peak level naturally increases, yet the width of the peaks particularly at its feet increases as well. This means that less stored energy needs to be reconverted in times of weak renewable input. On the other hand it results in notable power production exceeding the grid requirements in times of high renewable power input. Hence, this energy needs to be systematically used for economic reasons, otherwise the installation of a high overcapacity is not a viable option. Insofar, it is no option to leave the excess production to the stock market driving the power price down or even into the negative. This is the point where cross-sectoral energy exchange comes into play. The hydrogen produced can effectively be used in transportation with fuel cell cars, driving tail pipe CO_2 emissions down to zero and limited emission as well. The advantage of fuel cells is the high efficiency at relatively small units (1 - 100 kW) and their low operating temperature at which no NO_x is inherently produced. The strong volatility of renewable energy necessitates significant curtailment of power which results is only a small energy sacrifice; e. g. 37 % of power curtailment sacrificed just 2 % of energy in this study. The constraint of curtailing is owing just to economic considerations. It would be too expensive to provide a technology making use of the high tops of the peaks, which rarely occur.
Based on these assumptions, simulations with a locally and hourly resolved power model for Germany were performed. Thereby it could be proven that enough renewable energy input can be installed to secure Germany's needs for power and 75 % of the vehicular road transportation.

As for fuel cell vehicles, an overview shows that nearly all big automakers are somehow active in fuel cells. Hyundai and Toyota are in an early market entry phase, both having established dedicated small scale manufacturing lines. The beauty of fuel cell propulsion is, that owing to easier fuel storage and refilling, bigger cars for higher speed and longer cruising ranges can be designed. Other than battery cars, fuel cell vehicles are one to one substitutes for existing vehicles with the great advantage that they can run on renewables. The presentation looks into the viability for the essential components for hydrogen for transportation and storage. It also provides cost data on hydrogen for transportation and gives a brief insight how a hydrogen infrastructure can be made cost-competitive at an early stage of market introduction.

Mitglied der Helmholtz-Gemeinschaft

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Hydrogen as a Future Energy Carrier

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TRENDS2015
Transition to Renewable Energy Devices – Transportation Concepts
Aachen, Germany
December 03 - 04, 2015

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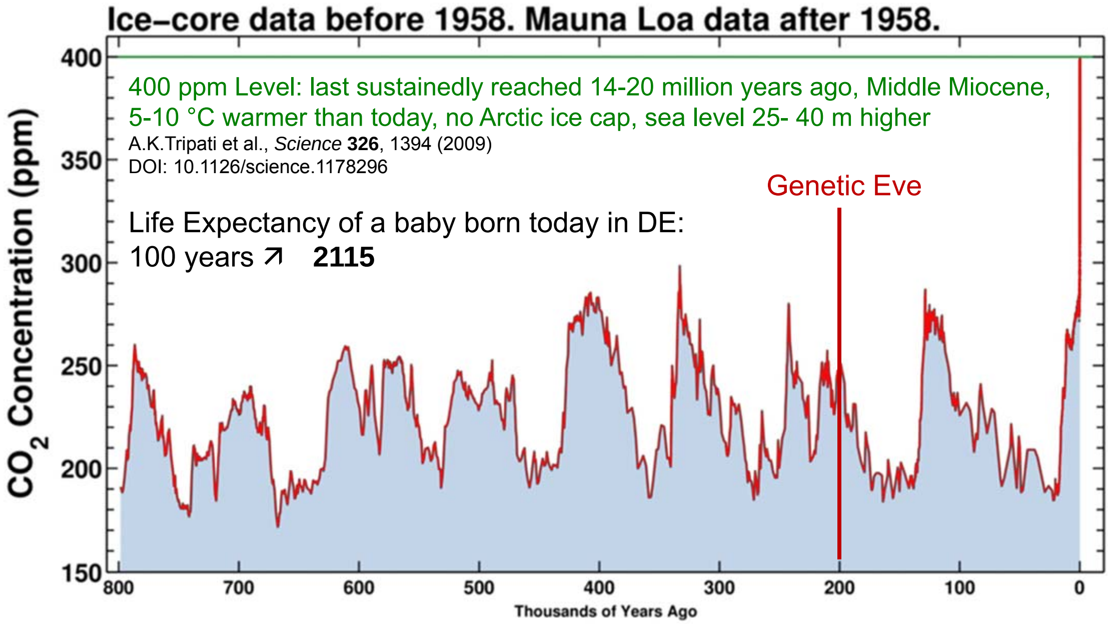
Vectors for Energy Transformation

This presentation aims at identifying major vectors for mass markets and technologies

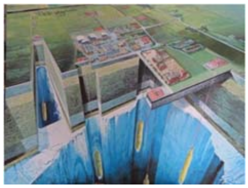
Results may be different in niche markets

Cost considerations are pre-tax and hence internationally valid

Modern CO_2 Level Rise is Unmatched in Human History



Future Energy Solutions need to be Game Changers



Drivers

- Climate change
- Energy security
- Competitiveness
- Local emissions

Grand Challenges

- Renewable energy
- Electro-mobility
- Efficient central fossil power plants
- Fossil cogeneration
- Storage
- Transmission
- **Interconnect the energy sectors to leverage synergies**

Goals

- 2 degrees climate goal requires .... 50% ….by 2050 worldwide
- G8 goal ………………………………………..80% ….by 2050 w/r 1990
- Germany to reduce GHG emissions by …….80-95% by 2050 (w/o nuclear)
- Local emissions reduction in developing countries

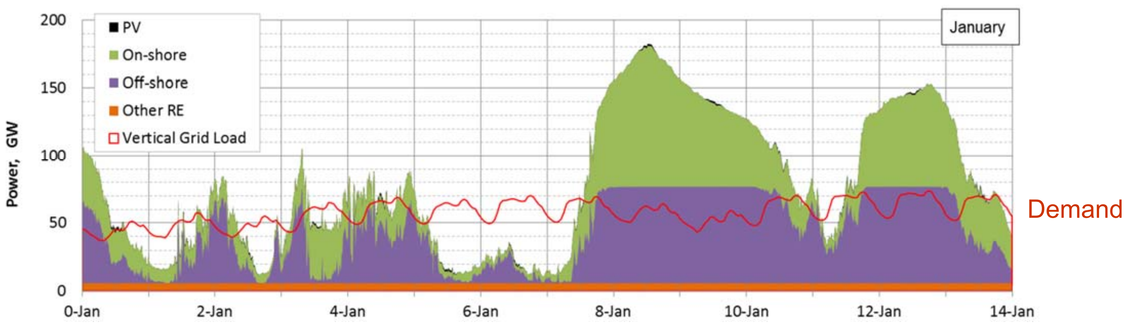
GHG Emissions Shares by Sector in Germany (2010)

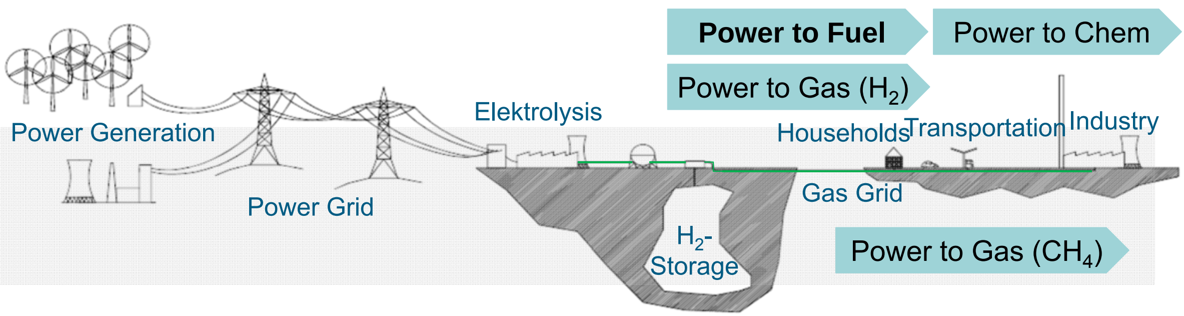
	Emissions		Remedies (major vectors)	
Energy sector		37%		
• Power generation	30%		→ 22.5 % Renewables	✓
Transport (90% petroleum-based)		17%		
• Passenger vehicles	11%		→ 8.3 % **Hydrogen** / renewable power	✓
• Trucks, buses, trains, ships, airplanes	6%		→ 4.5 % Liquid fuel substitutes (biomass/ CO_2-based; **hydrogenation**)	?
Residential		11%		
• Residential heating (electricity in power generation)	11%		→ 8.3 % Insulation, heat pumps etc.	Likely ✓
Industry, trade and commerce		23%		
• Industry	19%		→ 9.5 % CO_2-capture from steel, cement, ammonia; **hydrogen** for CO_2-use	??
• Trade and commerce	4%		25 % already cleaned-up since 1990	
Agriculture and forestry		8%	78.1% clean-up	
Others		4%		
Total		100%		

Source: Emission Trends for Germany since 1990, Trend Tables: Greenhouse Gas (GHG) Emissions in Equivalents, without CO_2 from Land Use, Land Use Change and Forestry Umweltbundesamt 2011

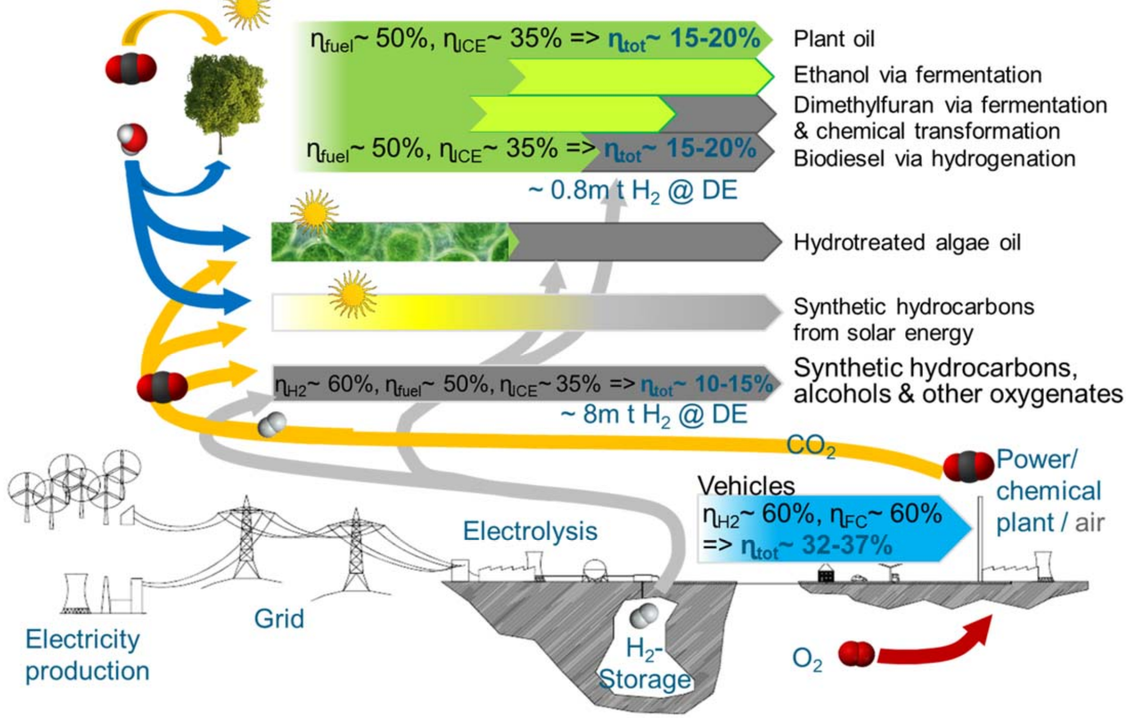
Transport-related values: supplemented with *Shell LKW Studie – Fakten, Trends und Perspektiven im Straßengüterverkehr bis 2030*.

Usage of Renewable Excess Power Production





Liquid Fuels: The Option for Heavy Transportation



Timeline for CO_2-Reduction and the Implication of TRL Levels

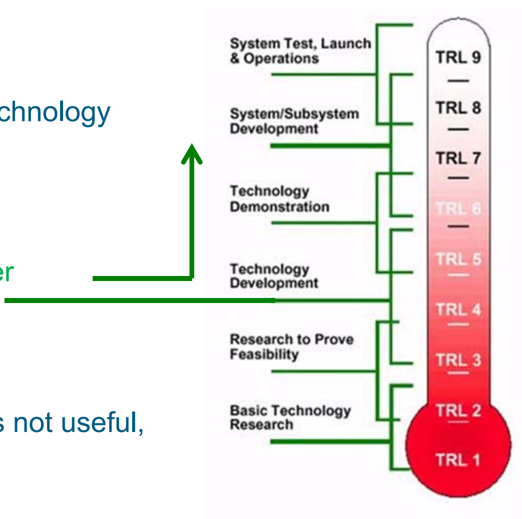
- **2050:** 80% reduction goal fully achieved
- **2040:** start of market penetration
- **2030:** research finalized for 1st generation technology

Development period: unil 2040

Research period: until 2030

⇒ 15 years left for research => TRL 5 and higher

TRL 4 at least



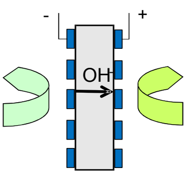
This is not to say research at lower TRL levels is not useful, it will just not contribute to the 2050 goal

For PEM fuel cells infrastructure will determine the timeline

Hydrogen Generation from Electric Power

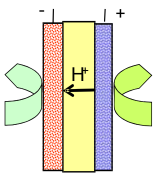
Options for Water Electrolysis

Alkaline electrolysis



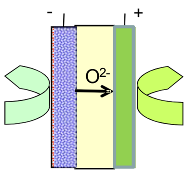
- Mature technology
- <3.6 MW stacks
- Plants <156 MW
- Ni catalysts
- 750 €/kW - 1000€/kW

PEM - electrolysis



- Development stage
- < 1 MW in development
- Pt and Ir as catalysts
- Simple plant design
- €1500@ 2015
- € 500@ 2030 (FZJ)

Solid Oxide Electrolysis



- Laboratory stage
- Very high efficiency
- Brittle ceramics
- Hence, slow scale-up
- Just cost estimations

Hydrogen Storage and Transmission Technology

Decouple Power and Energy for Long-term Storage

Assumption: storage may add about the same price tag to the energy delivered, be it
- Short-term storage, or
- Long-term storage

	Storage cycles / a [1/a]	Relative allowable invest / kWh* [%]	Energy required [GWh]	Energy specific investment cost [€ / kWh]	Power required [GW]	Additional cost for conversion units (electrolyzer) [€/kW]
Short-term	100 - 1000	100%	some GWh	Batteries 100-200	some 10GW	none
Long-term	1 - 10	1%	some 1000 GWh	Salt cavern << 1 (approx. 0.25)	some 10GW	500 €/kW

Disjunction of Power and Energy

Batteries : Power and energy scale linearly with unit size
Hydrogen: **Power** scales less than **energy for loading; quick unloading feasible**

Power ↓ **Electrolyzers**

Energy ↓ **Gas caverns**

Geologic Gas Storage Facilities

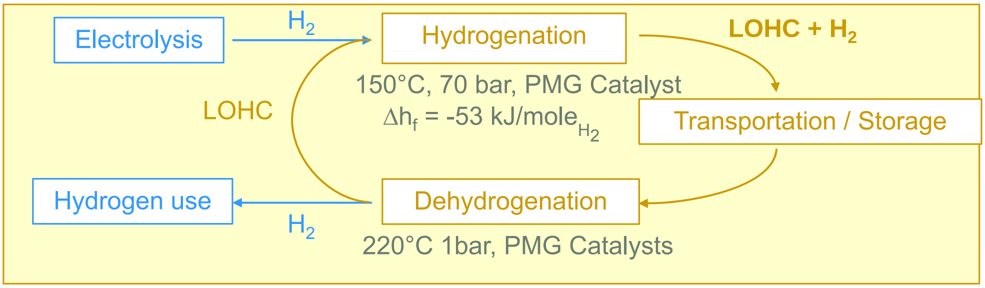
	Depleted oil / gas fields	Aquifers	Salt caverns	Rock caverns / abandoned mines
Working volume [scm]	10^{10}	10^{8}	10^{7}	10^{6}
Cushion gas	50 %	up to 80 %	20 - 30 %	20 - 30 %
Gas quality	reaction and **contamination** with present gases, microorganism and minerals		saturation with water vapor	
Annual cycling cap.	only seasonal		seasonal & frequent	

Investment for geologic storage facilities < 1 €/kwh installed capacity

Investment für storage in containers about 20-50 times higher

Liquid Organic Hydrogen Carriers for Mass Storage (LOHC)

- Liquid, heterocyclic, aromatic hydrocarbon as carriers
- Hydrogenation: saturation of aromatic rings with hydrogen
- **Chemicals:** N-ethylcarbazole, toluene and other aromatics
- Degradation by formation of unintended by-products



- Hydrogen storage density: 6 - 8 wt% [1,2]
- Transportation cost ≈ 0.2 €/kg_{H_2} via ship (5000 km) [3]
- Japan seeks produce H_2 in Patagonia and transport it home (distance ≈ 20,000 km)

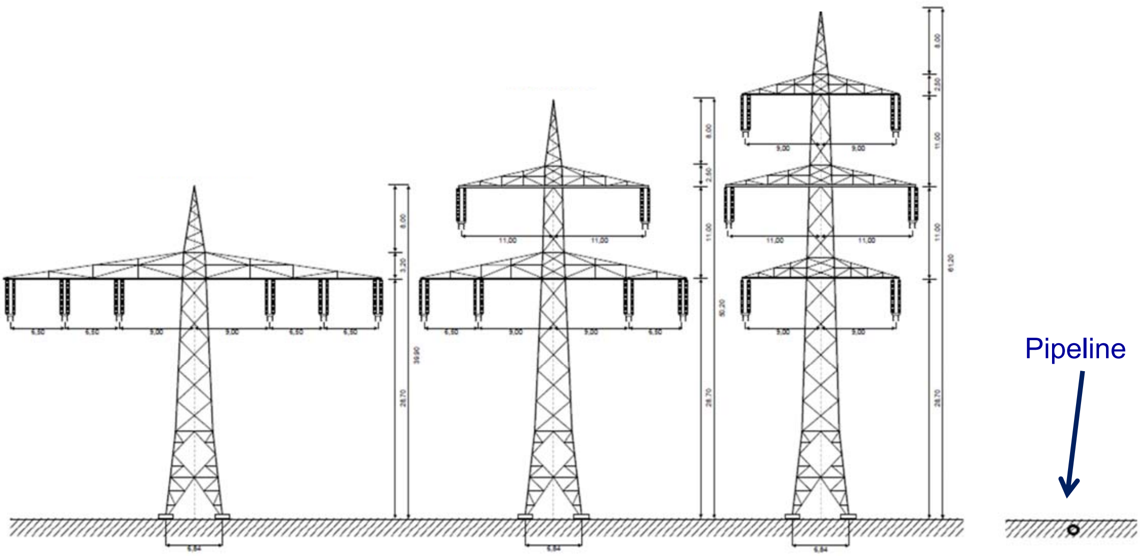
Power Line and Gas Pipelines Compared

	380 kV overhead line	Natural gas pipeline §	Hydrogen gas pipeline
Type	4 x 564/72 double circuit	DN 1000 p_{in} = 90 bar	
Energy transport capacity	1.2 GW_{el}	16 GW_{th}	12 GW_{th}
Investment cost in M€/km	1 - 1.5	1 - 2	1.2 - 3

Spatial Requirements for Transmission

Width of protective strips

70 m 57 m 48 m 10 m

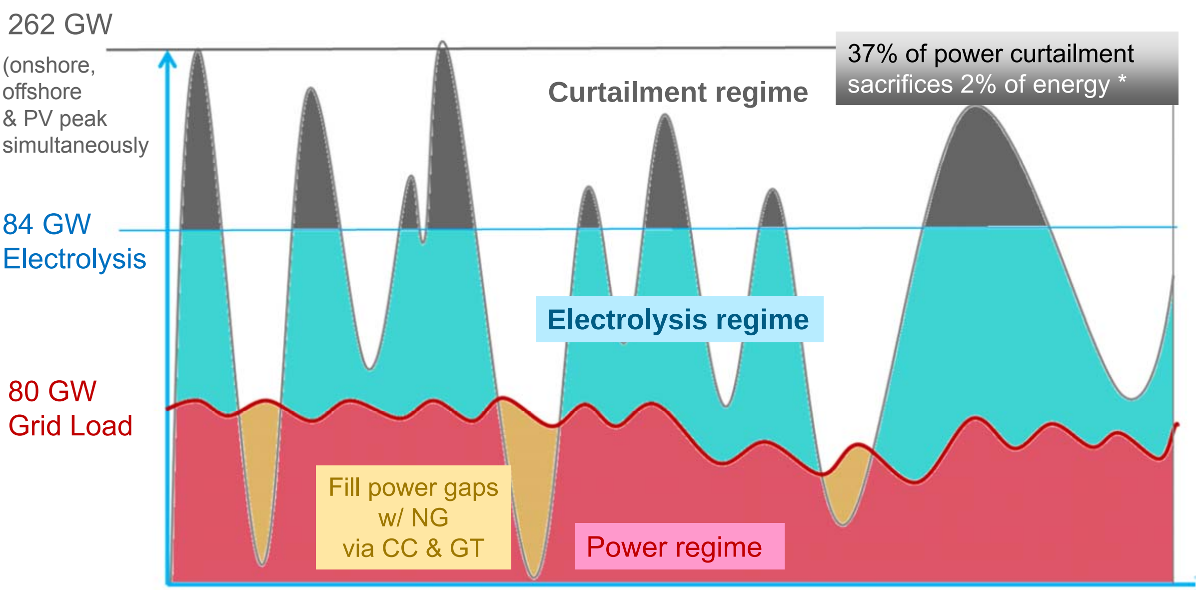


Picture of power poles from Hofman: Technologien zur Stromübertragung, IEH, http://nvonb.bundesnetzagentur.de/netzausbau/Vortrag_Hofmann.pdf

An Energy Scenario Coupling Power and Transportation

Principle of a Renewable Energy Scenario with Hydrogen

Hydrogen as an Enabler for Renewable Energy



* modeled for DE based on inflated input of renewables w/ weather data of 2010

Energy Concept for Germany v1.0

Onshore Wind Power	Same number of wind mills as of end 2011 (22500 units) Repowering from Ø 1.3 MW to 7,5 MW units => Σ 167 GW Average nominal operating hours: 2000 p.a. [1]
Offshore Wind Power	70 GW (potential according to BMU 2011[2], Fino => 4000 h)
Photovoltaik	24,8 GW as status of 12/2011[3], volatility considered
Other Renewables	Constant as of 2010[4]
Excess Energy	Water electrolysis η_{LHV} = 70 %[5]; > 1000 operating hours Pipeline transport + storage in salt caverns
Transpor-tation	Hydrogen for fuel cell cars: cruising range 14900 km/a[6], consumption 1kg/100km
Residential Sector	50% savings on natural gas as of 2010
Back-up Power	Open gas turbines; combined cycles > 700 operating hours/a Part load considered by 15% reduction on nominal efficiency

Results v1.0

Total amount of electricity produced: 745 TWh

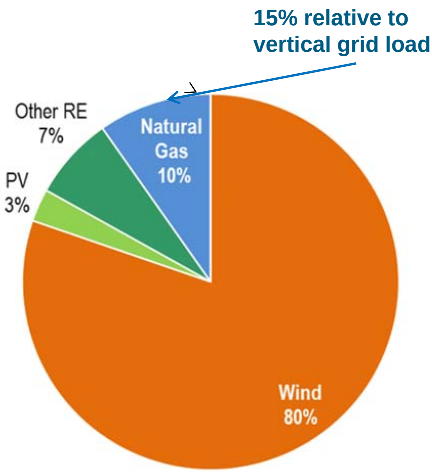
Vertical grid load fully funished: 488 TWh

Electricity for hydrogen production: 257 TWh => **5.4 mn tons H_2**

Hydrogen fuel for about 30 mn cars @ 1kg H_2/100 km

Installed power capacity = 3.3 x max. grid load

Harnessed electricity = 1.5 x vertical grid load



The Locally Resolved Model – Facts and Methodology

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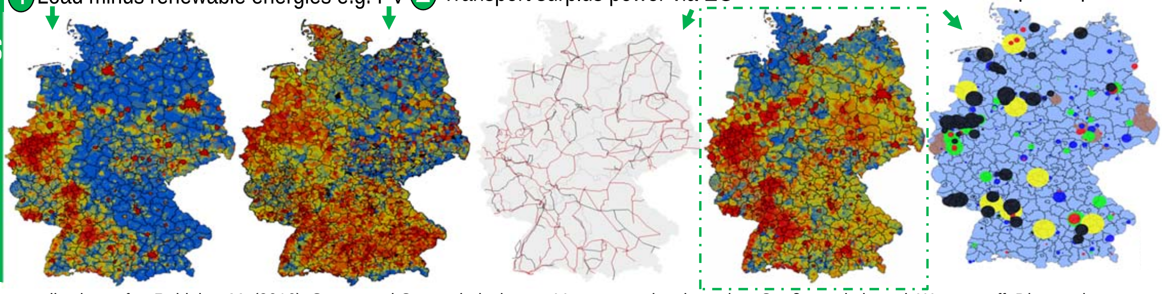
Facts

Spatially resolution:	11,768 municipalities in Germany – onshore even longitude and latitude resolution
Temporal resolution:	Hourly
Electrical Energy Transport:	Current high voltage grid – 380 and 220 kV – implemented, further grid developments can be considered
Conventional Power Plants:	All conventional power plants with their individual efficiency coefficient and generation cost are implemented, further developments e.g. shutdown of the nuclear power plants in 2022 can be considered
Market models:	Current market regime – merit order – as well as zonal pricing
LCOE:	Detailed optimization model which takes e.g. individual investment cost and power curves in consideration

Methodology

Calculate the residual load for each hour with and w/o electrical grid (EG) :

1. Load minus renewable energies e.g. PV
2. Transport surplus power via EG
3. Still surplus → water electrolysis; Demand: Conventional power plants



Sources: all values after Robinius, M. (2016): Strom- und Gasmarktdesign zur Versorgung des deutschen Straßenverkehrs mit Wasserstoff. Dissertation RWTH Aachen University, to be published in 2016. LCOE: Levelized cost of electricity

The Locally Resolved Model – Selected Results

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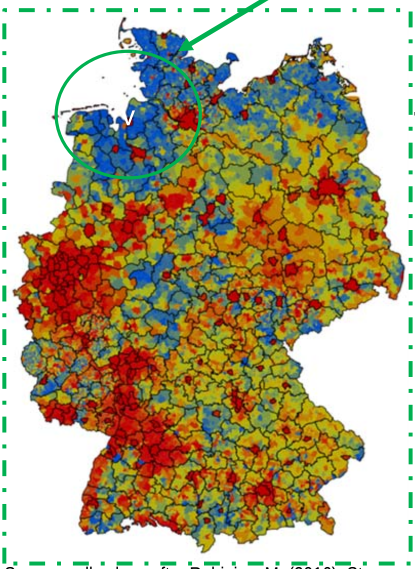
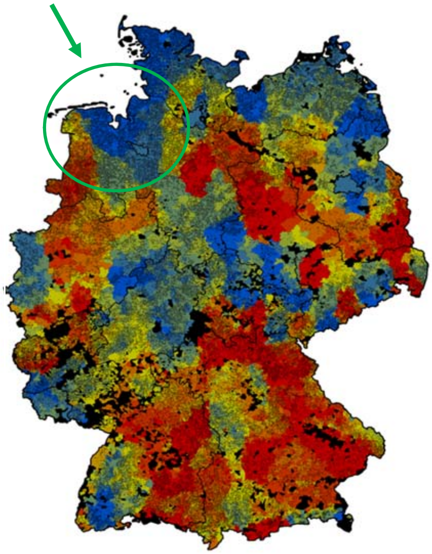
Possible residual energy in 2050 | **LCOE onshore wind**

High surplus energy for water electrolysis

Low levelized cost of electricity onshore wind



Residual energy [MWh/km²]	LCOE[1] [€ct/kWh]
-3.000.000 - 2.500	2,3 - 6,7
-2.500 - -1.700	6,7 - 7,5
-1.700 - -1200	7,5 - 8,5
-1.200 - -830	8,5 - 9,5
-830 - -460	9,5 - 10,5
-460 - -120	10,5 - 11,5
-120 - 175	11,5 - 13
175 - 545	13 - 15
545 - 1.535	15 - 106
1.535 - 50.600	



Sources: all values after Robinius, M. (2016): Strom- und Gasmarktdesign zur Versorgung des deutschen Straßenverkehrs mit Wasserstoff. Dissertation RWTH Aachen University, to be published in 2016. LCOE: Levelized cost of electricity [1] WACC = 8 %

IEK-3 Energy Concept 2.0 (Based on Locally Resolved Model)

Production

Renewable electricity: [GW | TWh]	onshore: **170** | 350 hydro: **6** | 21	offshore: **59** | 231 bio: **7** | 44	PV: **55** | 47
Further assumptions:	Grid electricity: **528 TWh**	imports: 28 TWh	exports: 45 TWh
Excess electricity:	**293 TWh** (grid considered)	**191 TWh** („copper plate“ & 40 GWh pumped hydro)	
H_2 production (η = 70 %):	**6.2 million t**	**4.0 million t**	

Demand

H_2 use in German districts:	
FCV [kg/100 km]:	**0.92** (2010) → **0.58** (2050) [1], linear decrease
FCV fleet:	curve fit; until 2033 according to [2]; maximum share in 2050: 75 % of German fleet
Further assumptions:	**14,000** km annual mileage **12 years** lifetime; total vehicle stock: 44 million cars
Peak annual H_2 demand:	**2.93 million t (2052)**

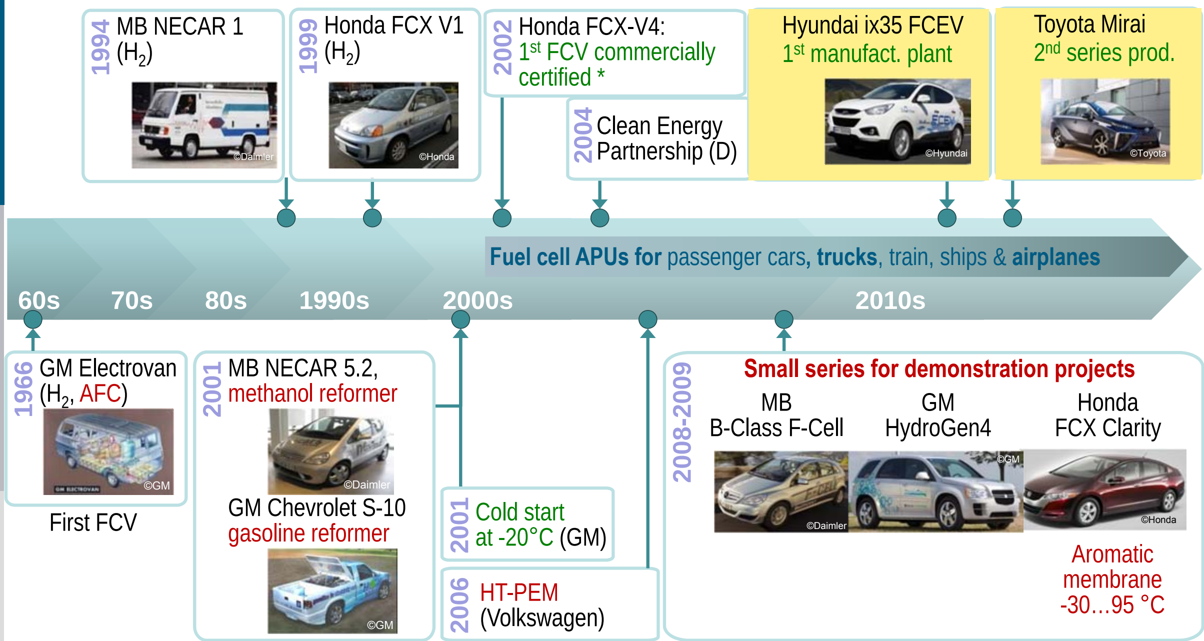
Results

H_2 sources:	**28 GW** electrolysis power in 15 districts in Northern Germany
H_2 sinks:	**9,968 refueling stations** with averaged daily sales of 803 kg
H_2 storage:	**8 billion €** (48 TWh, 60 day reserve)
Pipeline invest (Krieg 2012)**:**	**6.7 billion €** (12,104 km transmission grid); **12 billion €** (29,671 km distribution grid)
Electricity cost:	LCOE Onshore: **5.8 ct/kWh**; WACC: 5.8 %
H_2 cost distribution (pre-tax)**:**	Energy: 8.5 ct/kWh. invest: 3.4 ct/kWh. capital charge: 2.3 ct/kWh. OPEX: 2.3 ct/kWh
Total H_2 cost (pre-tax)**:**	**16.5 ct/kWh** (energy concept 1.0: 19.6 ct/kWh)

Sources: all values after Robinius, M. (2016): Strom- und Gasmarktdesign zur Versorgung des deutschen Straßenverkehrs mit Wasserstoff. Dissertation RWTH Aachen University, to be published in 2016; except [1] GermanHy (2009), Scenario “Moderat”, [2] H_2-Mobility, time scale shifted 2 years into the future
LCOE: Levelized cost of electricity

Viability Check on the Components

FCV Market Introduction has Started



* First fuel-cell vehicle certified by the U.S. EPA and California Air Resources Board (CARB) for commercial use

MB: Mercedes-Benz; GM: General Motors

All cars with PEFC except GM Electrovan with AFC

Commercial FC Vehicles

	Toyota Mirai	Hyundai iX35	Hyundai Tucson (2016)
Vehicle type	front-motor, front-wheel-drive, 4-passenger, 4-door sedan, one-speed direct drive	Electric reducer FWD, 5-seater [planetrary type mechanical varaible speed tranction drive]	Compact SUV, 5-seater, single-speed transmission FWD
Motor Power	115 kW Synchronous AC	100 kW	100 kW Induction motor
Torque	335 Nm (247 lb-ft)	300 Nm (30.6 kgm)	221 lb-ft or 300Nm
Fuel Cell Power	144 kW	-	100 kW
Range (NEDC)	502 km	594 km (144 liter H_2 tank)	424 km (265 mi)
Consumption (NEDC)	5.8/5.0 l/100km eq. (56/58 MPGe)	0.8896 kg H_2/100km city 0.9868 H_2/100km highway	-
Battery	NiMH	Lithium polymer 24 kW	Li-pol. 60 Ah, 24 kW, 0,95 kWh
Top speed	177 km/h	160 km/h	160 km/h
Acceleration	9 s 0-97 km/h (0-60 mph)	-	12,6 s 0-62 mph
Curb weight	1860 kg (4100 lb)	-	-
Base price	58,395 US$	-	Lease: 2,999 down; 499 monthly @36 months (incl. fuel & maintenance)

- http://www.caranddriver.com/toyota/mirai
- http://worldwide.hyundai.com/WW/Showroom/Eco/ix35-Fuel-Cell/PIP/index.html
- https://www.hyundaiusa.com/tucsonfuelcell/

Options for Hydrogen Transport

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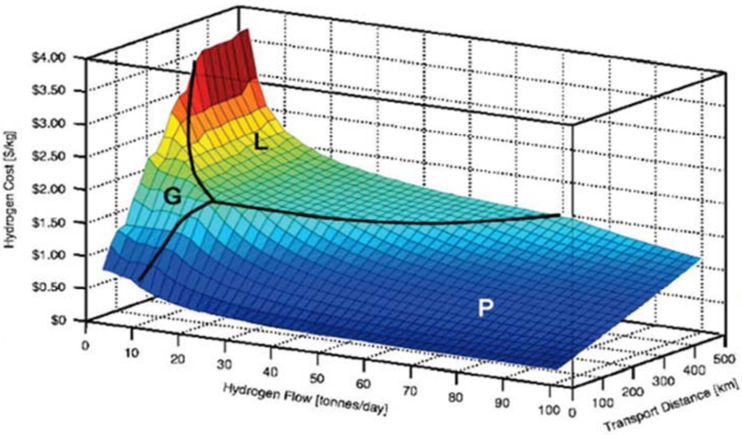

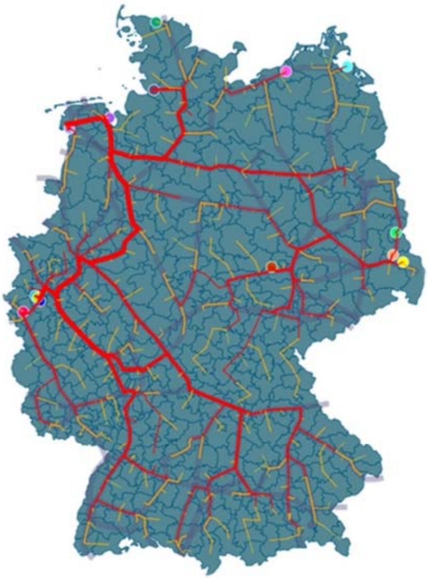

Minimum H_2 transmission costs as a function of H_2 flow and transport distance

Yang, C. and J. Ogden, *Determining the lowest-cost hydrogen delivery mode.* International Journal of Hydrogen Energy, 2007. 32(2): p. 268-286

Infrastructure: Electrolysis & Large Scale Storage

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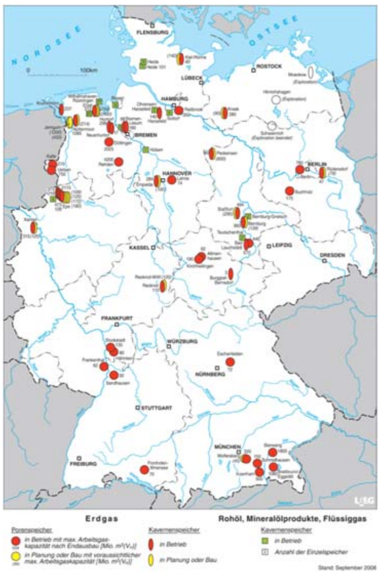

Estimated seasonal storage capacity	**27 TWh_{LHV}**
Storage capacity 60 day reserve	**90 TWh**
Storage capacity until 2040	**40 TWh**

regularly over weeks and months;

DB research, Josef Auer, January 31, 2012

(Pumped Hydro Power in Germany: 0.04 TWh_e)

Seasonal storage capacity required:	9 bn scm
Existing NG-storage in Germany :	20.8 bn scm
thereof salt dome caverns in use:	8.1 bn scm
Salt cavern in construction/planned :	12.9 bn scm

Source: Sedlacek, R: Untertage-Gasspeicherung in Deutschland; Erdöl, Erdgas, Kohle 125, Nr.11, 2009, S.412–426.

Overview of Cost v1.0
for a Renewable Hydrogen Infrastructure for Transportation

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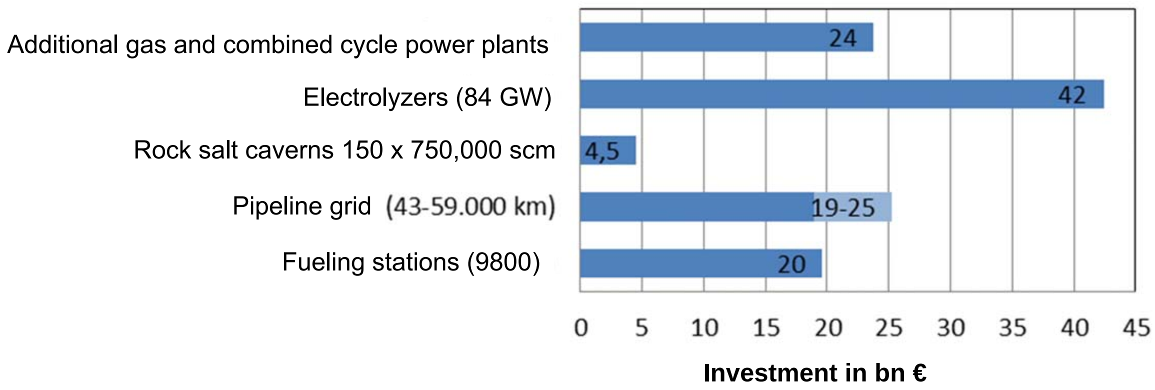
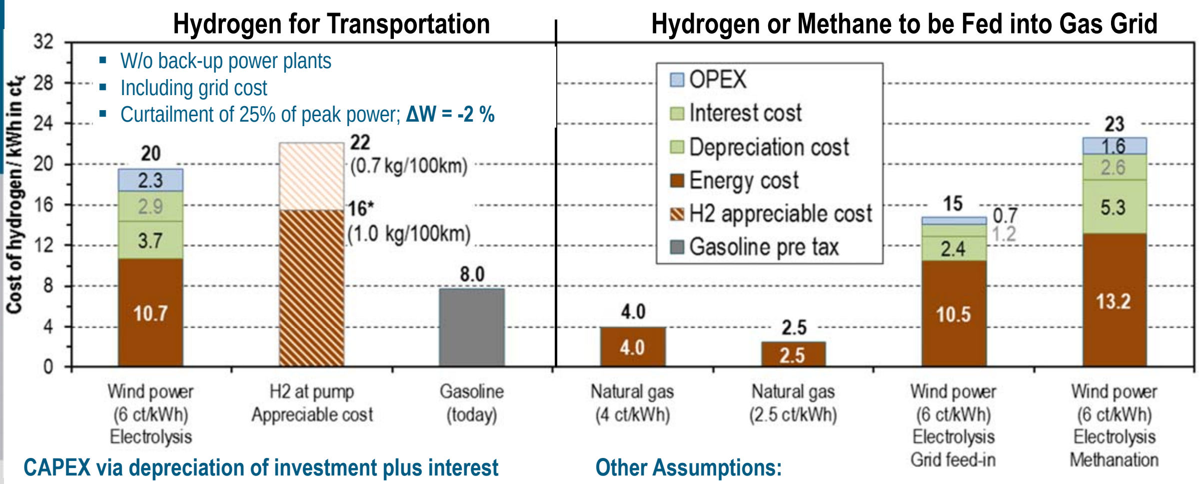


Cost Comparison of Power to Gas Options – Pre-tax

JÜLICH FORSCHUNGSZENTRUM



CAPEX via depreciation of investment plus interest

- 10 a for electrolysers and other production devices
- 40 a for transmission grid
- 20 a for distribution grid
- Interest rate 8 % p.a.

Other Assumptions:

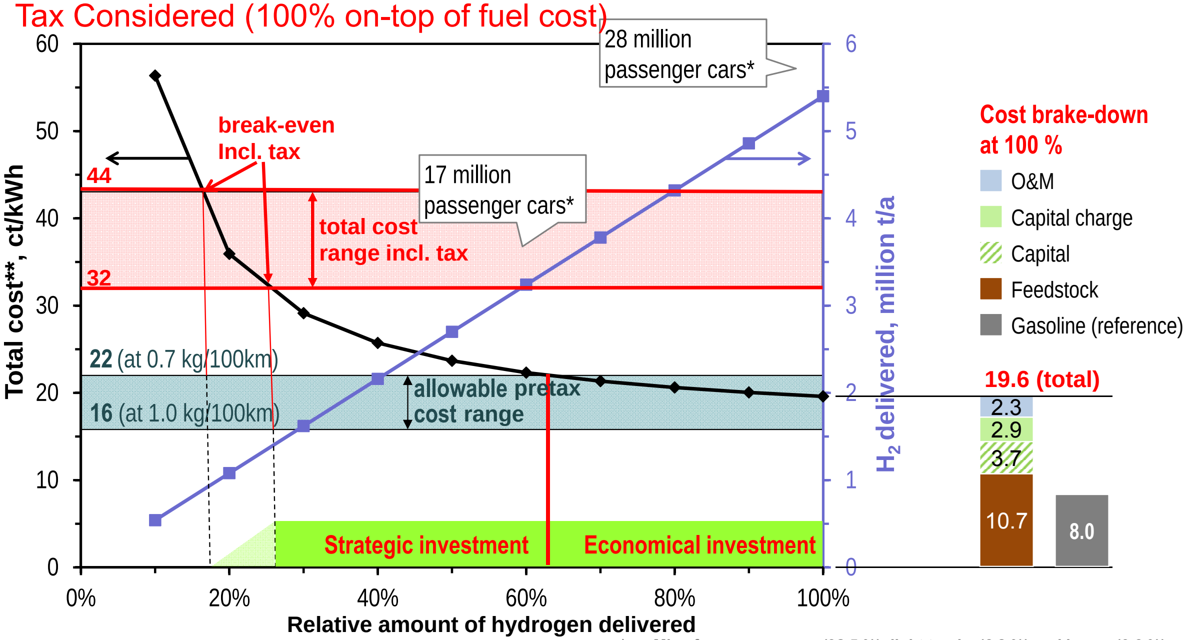
- 5.4 million t_{H2}/a from renewable power via electrolysis
- Electrolysis: η = 70 $\%_{LHV}$, 84 GW; investment cost 500 €/kW
- Methanation: η = 80 $\%_{LHV}$
- Grid fee for power transmission: 1.4 ct/kWh_e [1]

* Appreciable cost @ half the specific fuel consumption

[1] **EWI (2010)**: *Energiekosten in Deutschland - Entwicklungen, Ursachen und internationaler Vergleich (Projekt 43/09); Endbericht für das Bundesministerium für Wirtschaft und Technologie*. Frontier Economics/EWI, 2010.

Market Introduction:
Cost Evolution for Full-fledged Pipeline Grid and Fueling Stations w/ Incremental Installation of Electrolyzers and Storage Capacities

Tax Considered (100% on-top of fuel cost)



* Mix of passenger cars (92,5 %), light trucks (6,8 %) and buses (0,6 %)
** Total cost = feedstock + capital depreciation + capital interest + O&M
*** Wind energy input 6 ct/kWh, 8% capital interest rate

Some Concluding Remarks

Why are There so Many Contradictory Assessments on Storage?

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The necessity of storage depends on:

- The time-line
  The shorter the time-line the less storage will be needed. The need of storage at an earlier time might not be in line with the lead-time needed for furnishing later storage requirements.
- The energy sectors included
  If only the power sector gets considered, storage will be necessary much later compared to scenarios which look into a comprehensive CO2 clean-up of whole energy sector, including transportation and industry. Households might not have that a strong impact on the storage scenarios.
  Scenarios considering just the power sector at 2030 consistently report that no storage will be needed. That does not take into account that additional electrical energy will be needed for transportation and industry, currently fueled by fossils.
- The level of penetration of renewable energy
  If only intermediate levels of RE penetration is envisaged / imagined there is little need for storage. Yet , that is not in line with the political goals.
- Whether the political goals (of the German Energy Strategy) are accepted / taken seriously

The assessments depend on the assumptions to an unusual extent

Conclusions

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- An overwhelmingly renewable energy supply entails overcapacity in installed power and hence entails “excess power”
- 80% of CO_2 reduction requires interconnection of the energy sectors
  - Hydrogen as fuel for automotives
  - Hydrogenation steps in liquid fuel production from biomass and CO_2
- Conversion of excess power to hydrogen and storage thereof is feasible on the scale needed (TWh)
- Over long distances mass transportation of gas is more effective than that of electricity
- Fuel cell vehicles are being introduced to the market by asian automakers
- Hydrogen as an automotive fuel is cost effective other than feed-in to the gas grid or reconversion to electricity

Storage gets necessary if CO_2 is to be cleaned up beyond the power sector; i.e. if and when the energy sectors get interconnected

The Team

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Thank You for Your Attention!

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HVO Technology For Mobile Application

Sebastian Dörr,
Lubtrading GmbH on behalf of Neste

Mobility is an essential desire of the modern society – today fossil fuels are playing a dominant role in the transport sector as well as combustion engines. Due to climate change concerns and the fact of limited fossil resources alternatives are needed:

In the longer term future mobility based on BEV (Battery Electric Vehicles) or FCEV (Fuel Cell Electric Vehicles) are seen as the most promising solution. Open Questions are:

Battery weight, cost, space and LCA and related the range of Battery cars as well as charging time.

Loading Infrastructure for Battery or Hydrogen is needed – as well as related mobility concept taking shareconomy, connectivity, autonomous drive etc into account to avoid wrong investment.

Long distance transportation, deep see transportation and aviation will require liquid fuels still for a long time due to the advantage of very compact chemical storage of energy with relative low mass.

HVO = Hydro treated Vegetable Oil can be seen as bridging technology to more sustainable mobility:

It can be produced from various different oil and fat sources like plant oils, side streams of food production, waste materials and is already today produced in significant volumes (> 2.5 mio t)

Quality is pure paraffinic fuel like GTL and enables engine manufacturer even to build more efficient low emission diesel engines.

The quality has been proofed in various field tests with millions of kilometres in trucks, buses, passenger cars, locomotives and even airplanes.

It can be blended with fossil fuel in any ratio and is a real drop in fuel with no harm within the whole logistic chain.

HVO is produced in sustainable manor and reduces GHG emissions significantly. It can be implemented in any mobility strategy easily and brings immediate effect for reasonable cost.

It can play various roles in different applications:

Today:

- Blending component for Diesel Fuel
- Component for Premium High Quality Diesel
- Component for High Bio EN 590 regular diesel fuel (Diesel R33)
- Cetan Booster for pure plant oil (Tractor Oil Program)
- Need Fuel for off road and fleet application (pr EN 15940)

In 10 year’s time:

Due to increasing number of BEV and bridging PHEV HVO can be used:

- Ultra Clean Diesel Fuel for City applications (with additional oxygen carriers)

  for PEHV, High Energy Consuming City Vehicles (Garbage Truck)
- Off road applications
- Long distance transportation
- Aviation

In 25 years’ time:

If Fuel Cell and BEV develop according to estimates, still applications for ultra clean liquid renewable fuel remain:

- Off road applications in regions with difficult power supply
- HVO as Hydrogen Carrier for FCEV
- Long distance transportation (partial)
- Aviation

Key question for acceptance of HVO is the availability of enough sustainable produced feedstock!

Improvements in agriculture standards and productivity,

better monitoring and control mechanisms for sustainability,

increased use of side streams and waste materials,

new technologies like yeast, algae,

better waste treatment and new process technologies for waste

show, that HVO can support the way to more sustainable mobility and is already now available.

While some of today’s application will run out and be replaced by more efficient electric options,

other applications are developing and will require renewable, clean and compact chemical energy storage what HVO can offer.

Hydrogenation of Plant Oils for Future Fuels

Dipl. Ing. Sebastian Dörr
Lubtrading GmbH für Neste

Aachen Trends 2015

NESTE

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NESTE

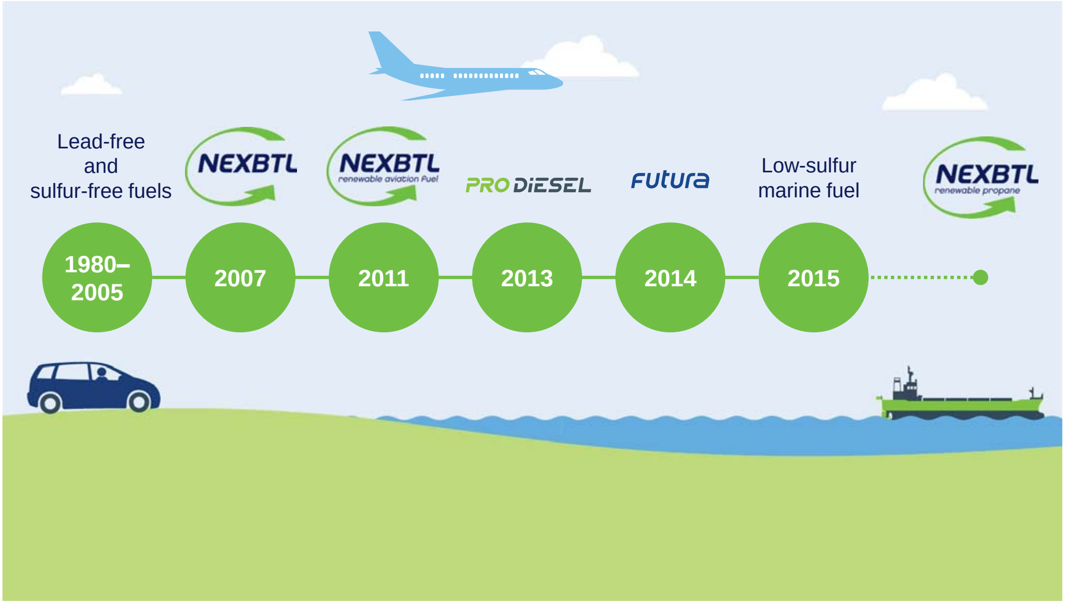
Neste in brief

A refining and marketing company focused on **low-emission, high-quality traffic fuels**

- Operations in 14 countries
- 5,000 employees
- Global HQ in Helsinki, Finland

- 15 million t/a of **petroleum products**
- 2.4 million t/a of **renewable diesel**

Cleaner solutions through the years



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Our ambition

Growth in global renewable feedstock-based markets

- Become the global leader and the most profitable player in the renewable diesel market
- Develop significant business from non-traffic fuel markets by end of the decade

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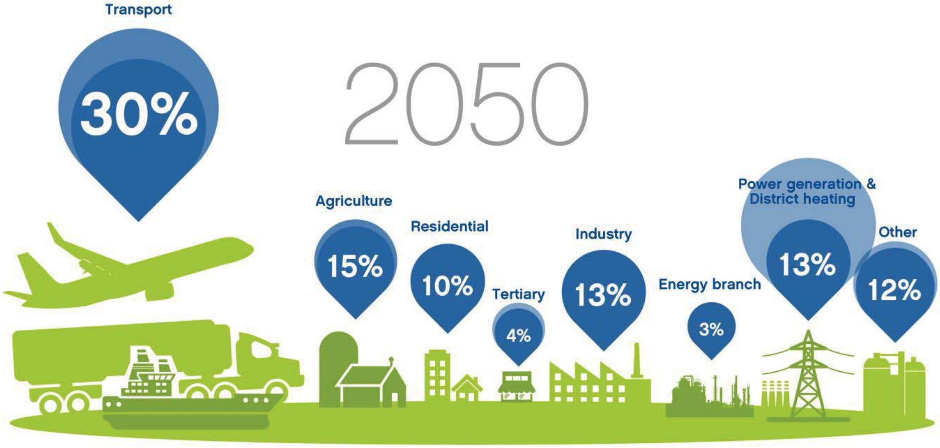
Carbon reduction in transport is vital

Anticipated EU-28 shares of total GHG emissions 2050



Source: EC 2013 Trends to 2050 Reference scenario

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NEXBTL Renewable Diesel: Process and product performance

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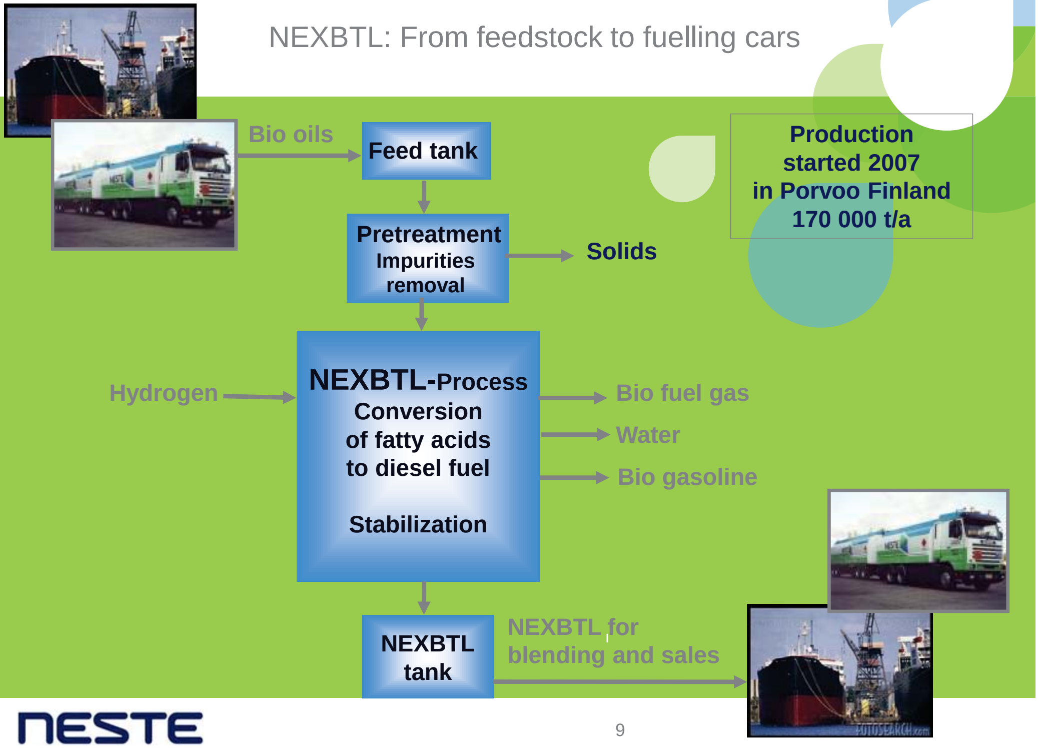
NEXBTL: From feedstock to fuelling cars



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HVO - Superior Quality

Fuel Properties Typical values	EN590 diesel fuel	HVO
Cetane number	53	75-99
Cloud point (°C)	0 - -12	-5...-30
Heating value (lower) (MJ/kg)	43	44
Heating value (lower) (MJ/l)	36	34
Density at +15 °C (kg/m3)	835	780
Sulfur content (mg/kg)	< 10	0
Distillation range °C	180-360	180 - 320

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Fully compatible with fossil diesel

	Biodiesel (FAME / RME)	Fossil diesel	Renewable diesel (HVO) e.g. NEXBTL	Fischer-Tropsch (BTL)
Raw material	Vegetable oils & animal fats (mainly rapeseed oil)	Crude oil (mineral oil)	Flexible mix of raw materials (vegetable oils & waste fats)	Biomass
Technology	Esterification	Traditional refining	Hydrotreating	Gasification & Fischer-Tropsch
End product	Ester-based, conventional biodiesel	Hydrocarbon (gasoline, jet fuel, diesel)	Bio-based hydrocarbon (renewable diesel, jet fuel, bionaphta, biopropane)	Bio-based hydrocarbon (renewable gasoline, jet fuel, diesel)
Chemical composition	O II H_3C-O-C-R	C_nH_{2n+2} + aromatics	C_nH_{2n+2}	C_nH_{2n+2}

FAME = Fatty Acid Methyl Ester, conventional biodiesel
RME = Rapeseed Methyl Ester, conventional biodiesel

HVO = Hydrotreated Vegetable Oil, advanced biofuel i.e. renewable fuel
BTL = Biomass to Liquid

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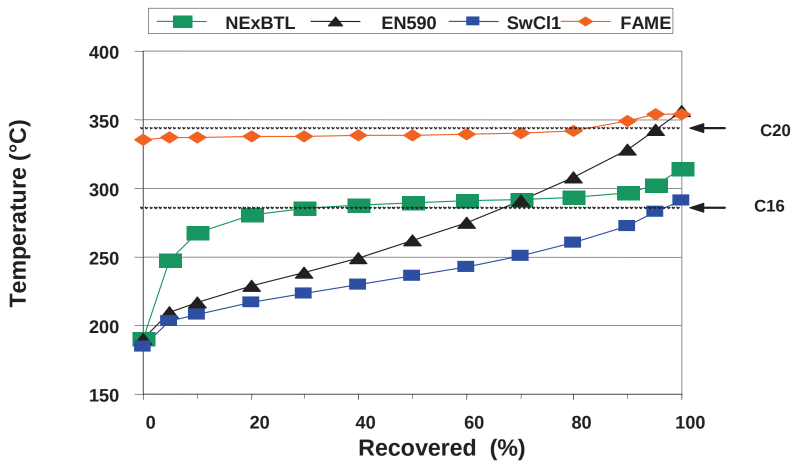
Distillation curves



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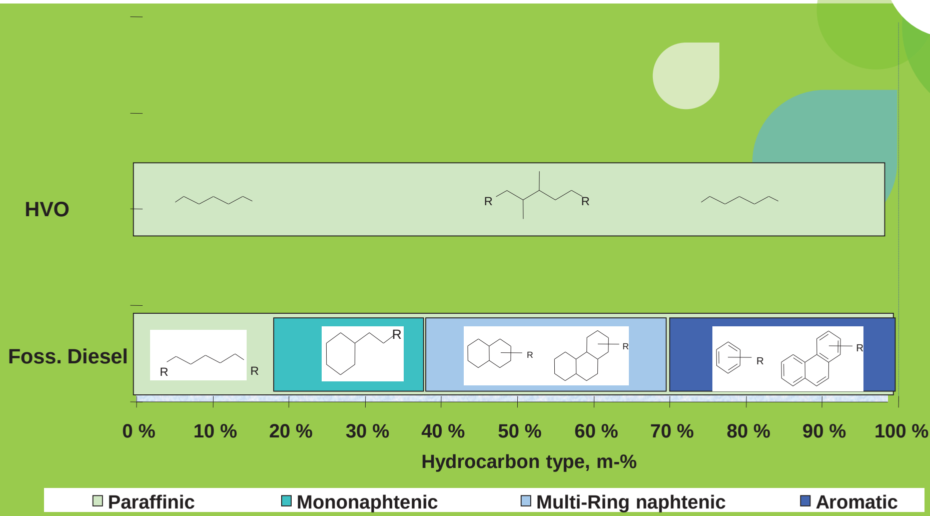
Chemical structure by MS-FI



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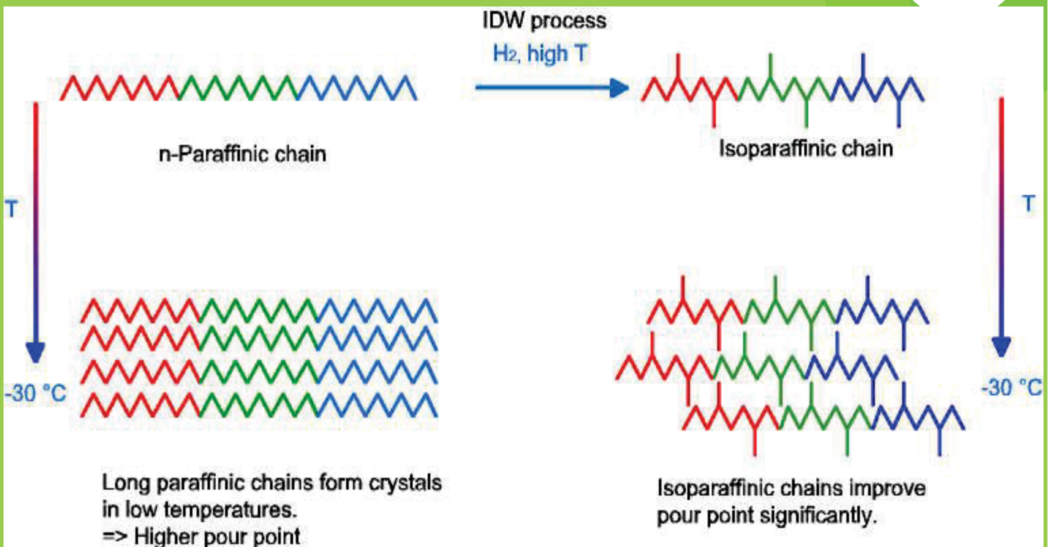
IDW process
Low temperature properties



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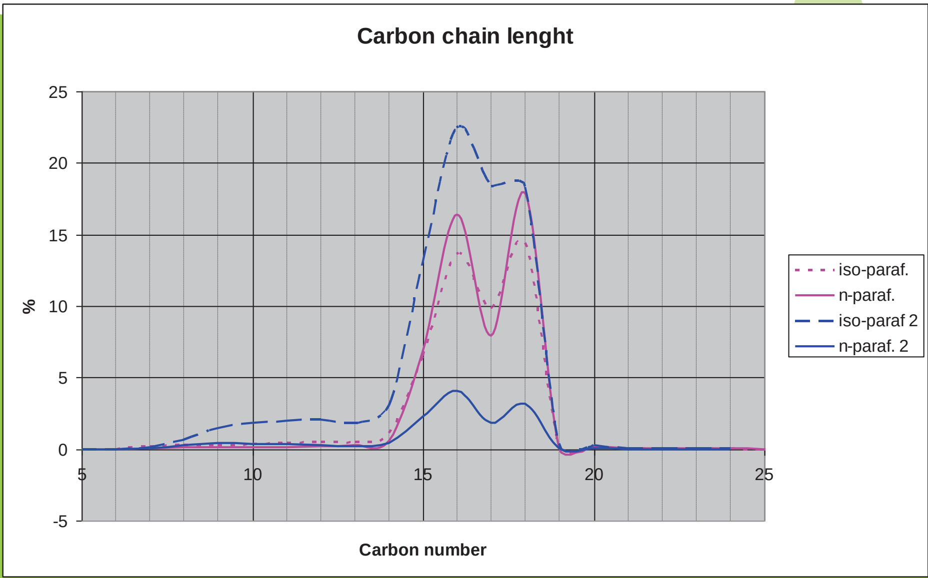
Carbon distribution



HVO - diesel

- Next step from traditional Biodiesel
- Improved Technology and Product
- Pure Hydrocarbon, fully compatible with Mineral Diesel
- No compromises on Fuel Quality or Vehicle Performance
- In Commercial Production

NEXBTL – reduced emissions

NEXBTL production capacity of 2.4 Mt/a

Unit	Capacity	Year
Finland #1	200 000 t/a	2007
Finland #2	200 000 t/a	2009
Singapore	1 000 000 t/a	2010
Rotterdam	1 000 000 t/a	2011

All Neste's NEXBTL plants are ISCC-EU and EPA-approved.
Neste's aim is to increase production capacity to 2.6 million t/a by 2017.

Field tests and experience

HVO100 - from fleet tests to commercial operations

- **Helsinki bus fleet test**, 2007-2010, 300 vehicles of different makes and emission classes
- **DHL-Daimler-Stuttgart Public Transport**, 2008-2011, semitrailers, vans, buses, 3 million km
- **Scania 60 ton fuel tankers**, 300,000 km
- **Volvo- DHL-Renowa**, Euro V and Euro VI trucks in Sweden
- **Swebol Logistic**, Volvo and Scania trucks in Sweden

- **Commercial use of 100% NEXBTL started about 2 years ago**

- **Austria:** around 5000 vehicles run daily on NEXBTL (semitrailers, trucks, agricultural machinery, snow cats)
- **USA:** more than 5,000 vehicles (trucks, busses, construction machinery, i.e. for mines)
- **Sweden:** over 30 fleets with more than 1000 vehicles
- **Netherlands:** several fleet operations and free sales to end consumers as well as off-road
- **Finland:** Helsinki buses

- **Reliable operations**
- **Similar service intervals**
- **Significantly reduced GHG and tailpipe emissions**

HVO significantly reduces greenhouse gas and tailpipe emissions

50 million kilometers covered in the world's largest biofuel trial (Helsinki 2007-2010)

HVO contributes to a significant reduction in exhaust emissions:

- Nitrogen oxide (NOx) 10% reduction
- Particulates (PM) 30% reduction
- Greenhouse gases (LCA-GHG) >50% reduction

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Project burnFAIR : Facts

Duration: 15th July – 27th December 2011, 8 flights/day

Route: Hamburg – Frankfurt – Hamburg (1h flight time)

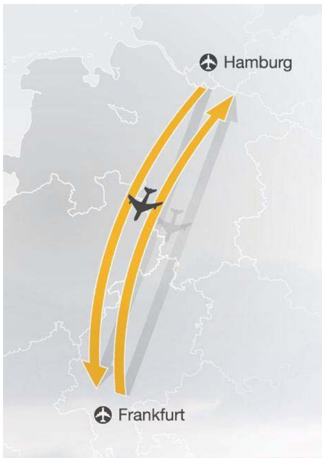
Aircraft: Airbus A321

Biofuel quantity: 800 tons

Biofuel ratio: 50% in one engine

Total cost: 8.4m USD

Emission savings: approx. – 1,500 tons CO_2



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Use in the aircraft – The „Drop In“ Concept

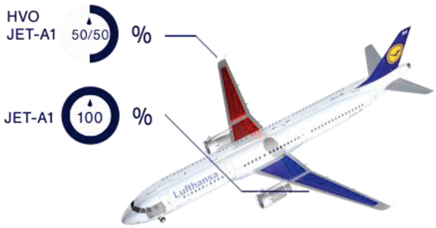
Research of engine performance:
One engine to operate with 50% blend of HVO kerosene

First truck supplies bioblend to the starboard wing tank

Second truck supplies conventional JET A-1 to the backboard wing tank

No major changes in normal cockpit procedures

“Bio-Engine” shows expected data and operates normal



First Results of the Project Aviation Biofuel

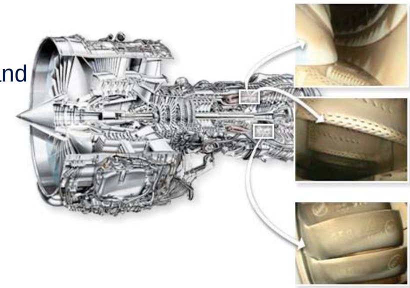
Bottom line

On December 27th 2011, the aircraft D-AIDG completed its last flight with biofuel

Total number of flights: 1187
Biofuel blend [volume in tons]: 1557
Emission saving [CO_2 in t]: 1471

Perfect fuel for aviation

1. During the operation
Aircraft and engine performed excellently
1% lower fuel consumption due
to the higher energy content
2. Inspection after the program
Fuel system, combustion chamber and
turbines in a perfect condition
Normal function and tightness of
fuel bearing parts
3. Storage stability
Density steady at 783 kg/cbm
No microbial issues



Source of the picture: Lufthansa

Whats possible today?

Diesel regenerativ

- Mixture of HVO and Biodiesel
- Has been tested succesfully in car fleet
- 100% bio is possible in modern engine concepts and backwards compatible
- Possible strategy for higher bio blends
- Well accepted by consumers!

OEMs continue to approve NEXBTL renewable diesel

OEMs which have approved NEXBTL:

- **Volvo**
  - All EURO V and less than 8 liter Euro VI
  - All marine engines and non road equipment
- **Scania**
  - All Euro V and Euro VI
- **Daimler**
  - Euro VI for Buses
- **Caterpillar**
- **Agco Power systems**
- **Steyr marine engines**
- **Deutz**, with some reservations

Approved as ASTM D975
Detroit diesel
Liebherr
Komatsu
Perkins*
Hitachi*
MTU*
Mercruiser

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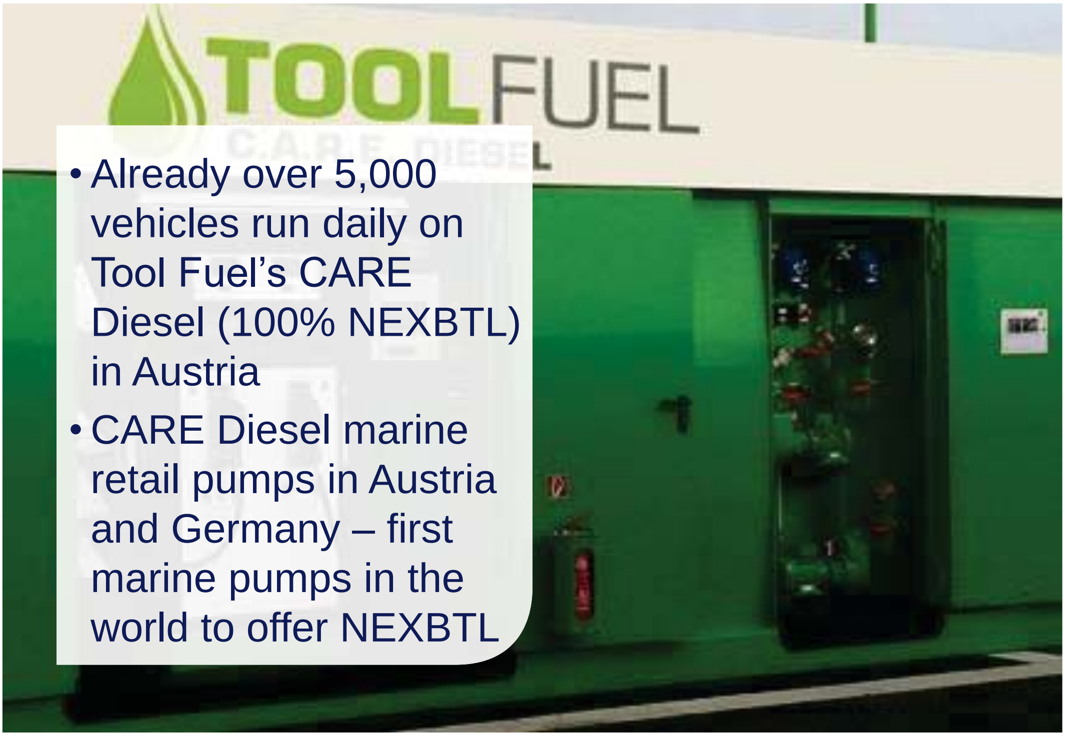
* Manuals say ASTM D975 is ok, but in some documentation or messaging they have limitations for HVO



- Already over 5,000 vehicles run daily on Tool Fuel's CARE Diesel (100% NEXBTL) in Austria
- CARE Diesel marine retail pumps in Austria and Germany – first marine pumps in the world to offer NEXBTL

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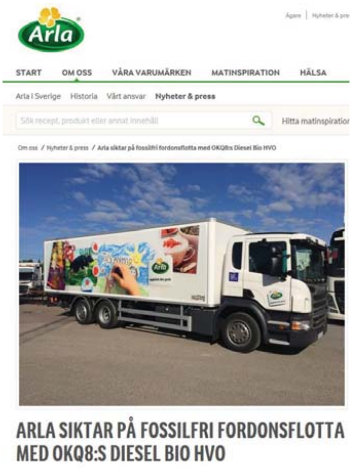
Sweden is quite active now



- Arla has 315 Trucks
- Many makes: Scania, MAN, Mercedes-Benz and Volvo
- Supplied by OKQ8

- Neste provides 100% NEXBTL to bus company Stånga Buss in Linköping, Sweden. The fuel is used e.g. in school buses.
- Stånga Buss opened their filling station also to other companies and private individuals

More news from Sweden

SCANIA PRESS info

8 October 2015

From the leader in alternative fuels:

Green light for HVO-use in Scania Euro 6 range

Scania has given the green light to hydrotreated vegetable oil (HVO) being used to power its Euro 6 range, provided the fuel used meets technical specification TS15940. Vehicles using HVO – which chemically mimics fossil-fuel-based diesel – can under optimal condition achieve up to a 90-percent reduction in CO_2 emissions. HVO does not affect a vehicle's characteristics or its maintenance requirements.

⌂ Home > Megatrends Articles > Freight Efficiency Articles > Volvo Trucks underlines its commitment to HVO

Volvo Trucks underlines its commitment to HVO

By: Automotive World October 6, 2015

Volvo Trucks is gearing up to ensure its Euro VI engines support hydrotreated vegetable oils (HVO)

Just as it did with its Euro V engines, Volvo Trucks is readying its Euro VI engines to be hydrotreated vegetable oil (HVO) compliant. The OEM believes the alternative fuel will play an important role in the commercial vehicle (CV) segment when it comes to meeting future legislation requirements.

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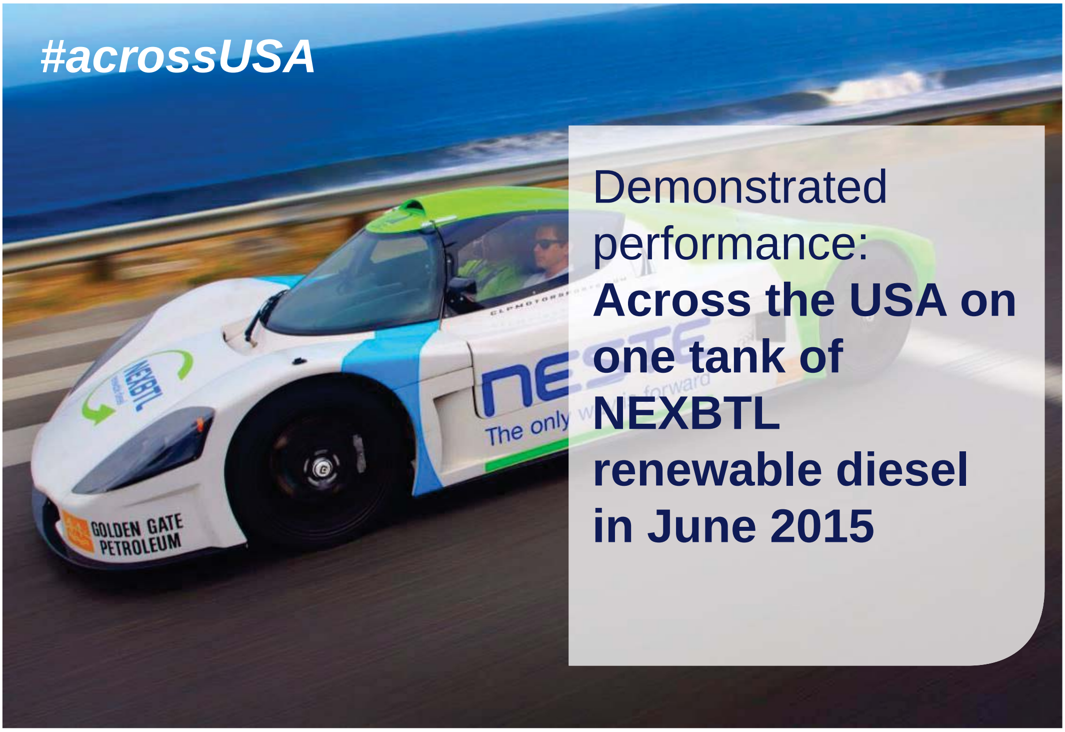

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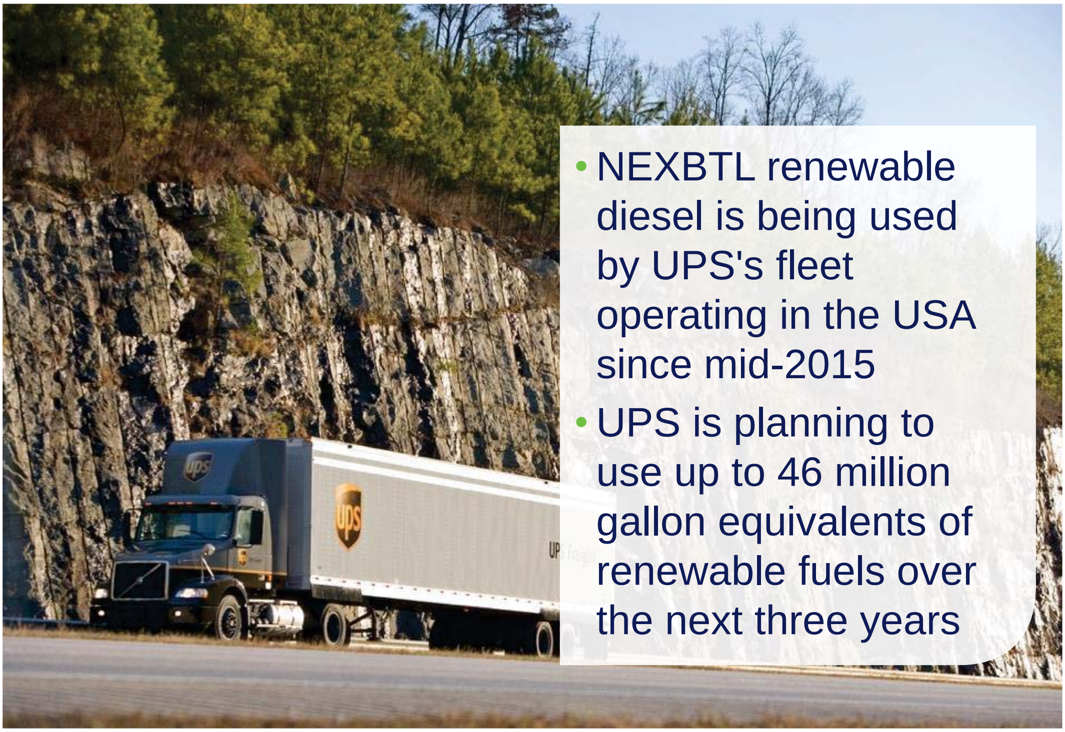
• NEXBTL renewable diesel is being used by UPS's fleet operating in the USA since mid-2015
• UPS is planning to use up to 46 million gallon equivalents of renewable fuels over the next three years

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Google
• Google's gBuses in Silicon Valley, California are running with neat NEXBTL
• gBuses ferry employees from their homes in San Francisco and Oakland to Google's corporate campuses
Neste's customer Golden Gate Petroleum is the distributor of the fuel

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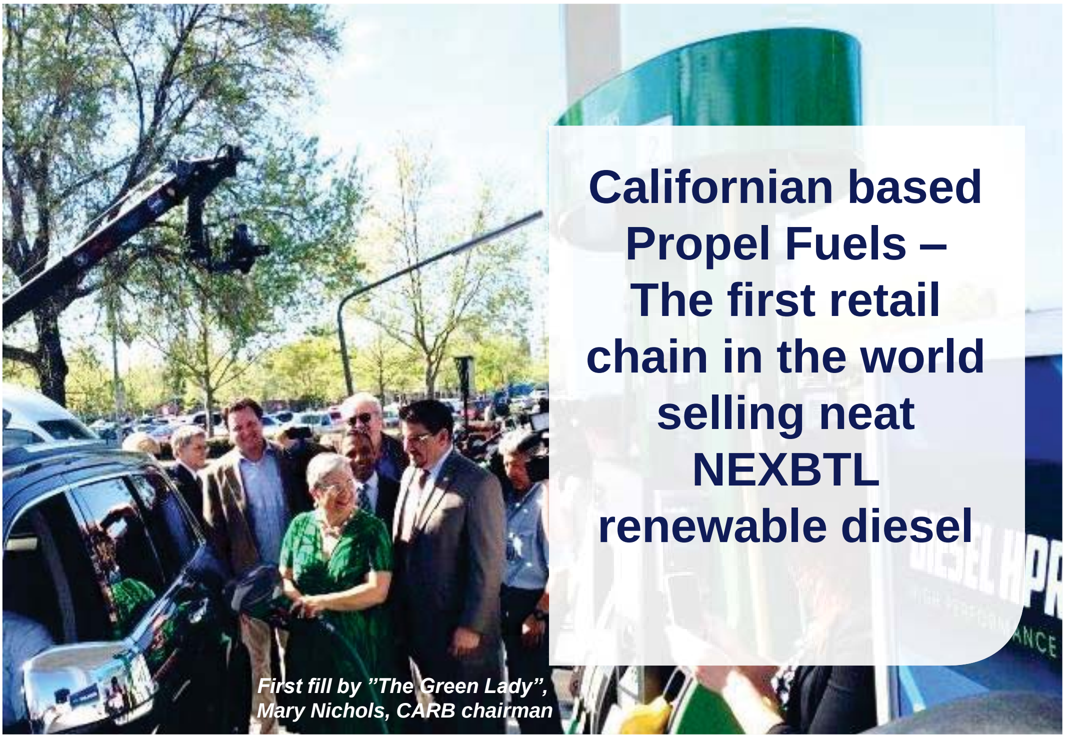
Californian based Propel Fuels – The first retail chain in the world selling neat NEXBTL renewable diesel



First fill by "The Green Lady", Mary Nichols, CARB chairman

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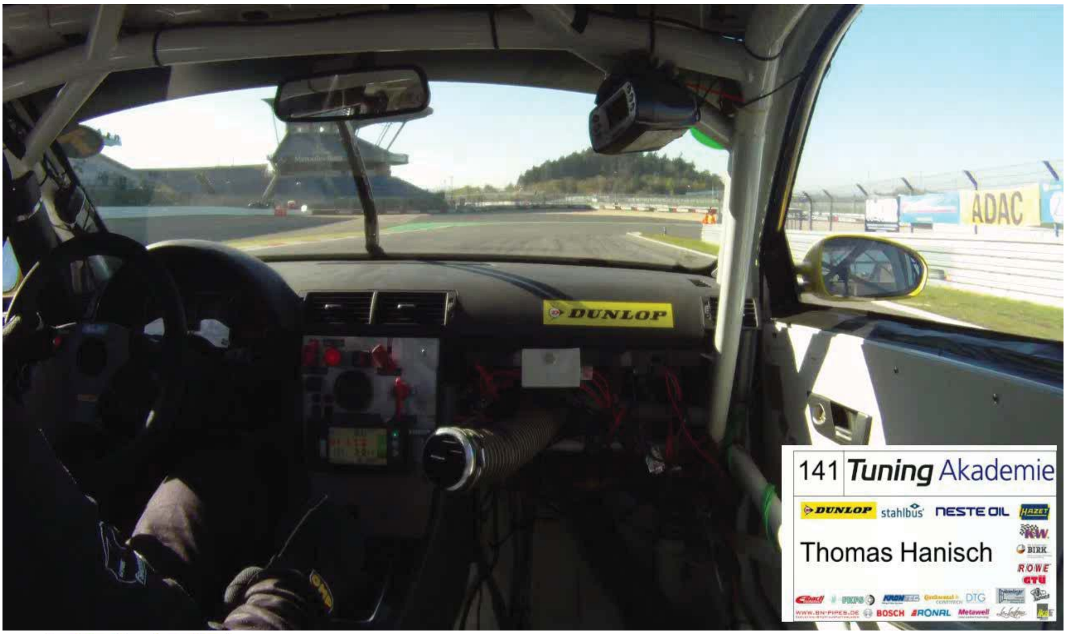
Inboard Video Mercedes-Arena

Tuning Akademie



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Tuning Akademie

Technology platform Audi A4 3.0 TDI quattro

Technical data

- body: Audi RS4 (B7)
- engine: V6 TDI (Generation 1)
- capacity: 2967ccm
- power: 230 kW
- torque: 600 Nm
- tires: Dunlop 265/660 R 18 DTM
- brakes: B7 RS4 original (steel)
- ABS / ESP: Bosch ESP8 optimized
- Permanent recording of CAN bus during testing and races
- Up to 32 analog signals (e.g. temperature) can be recorded

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NEXBTL feedstock

•NExBTL renewable fuel can be produced flexibly from a mix of various vegetable oils and waste animal fats.

•The fuel has constant high quality independent from

•raw material used.

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Neste’s current feedstock portfolio

100% traceable and certified raw materials


Waste animal fat from the food processing industry


Waste fat from the fish processing industry


Vegetable oil residues (stearin, PFAD, spent bleaching earth oil)


Technical corn oil


Used cooking oil


Tall oil pitch


Crude palm oil


Camelina oil


Jatropha oil


Rapeseed oil

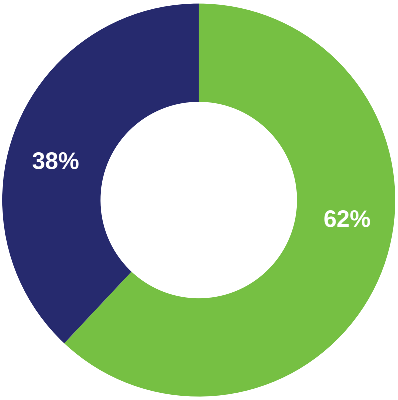

Soybean oil

Neste Oil’s criteria for new raw materials

- Applicability
- Availability for industrial scale production
- Economical perspectives
- Features of sustainable development
  - Carbon footprint (greenhouse gas emission balance)
  - Water footprint
  - Nutrients
  - Land use

More than 60% of our renewable feedstocks are waste and residues

Renewable feedstock mix in 2014

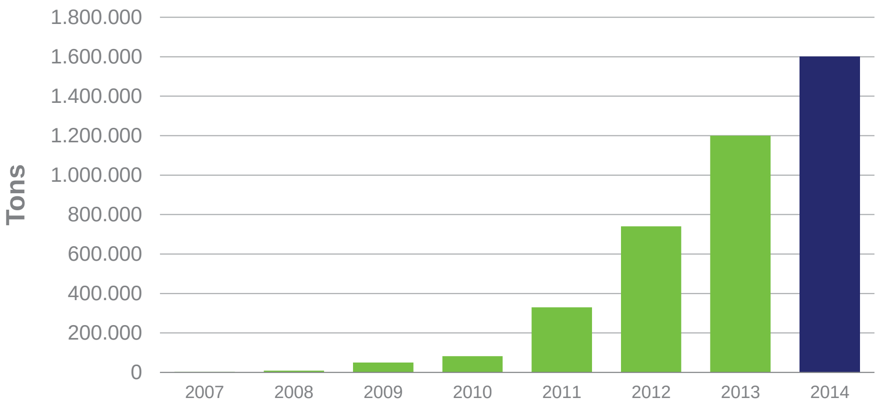


Waste and residues (e.g. waste animal fat, waste fish fat, fatty acid distillates, technical corn oil)

Food crops, 100% certified

100% waste and residue processing capability since 2015

Huge increase in waste and residue usage in couple of years



Sustainability recognition

Dow Jones Sustainability Indexes
Member since 2007/08

Member 2014/2015
STOXX
ESG LEADERS INDICES

FOREST FOOTPRINT DISCLOSURE

SPP Global Topp 100
Lönsamhet och hållbarhet
i en och samma fond
spp fonder

OMXSUSTAIN
NASDAQ OMX
OMX GES SUSTAINABILITY NORDIC
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Biofuels **outlook**

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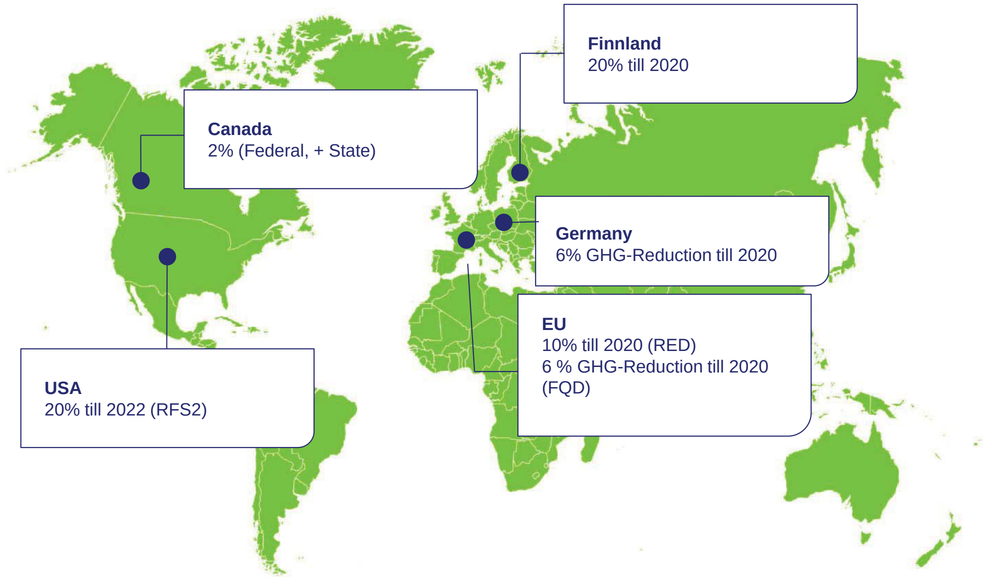
Targets for Biofuels and Renewable Energy in Traffic Sector



Diverse demand for NEXBTL, as blending component and 100% use

Commercial and municipal bus fleets

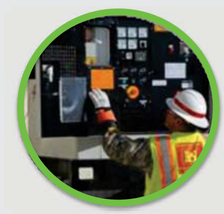
Truck fleets

Construction; Mining

Agricultural machinery

Aviation

Marine



Emergency generators

NEXBTL renewable diesel is ideal for fleet operations

High performance
Free of sulphur, oxygen, and aromatics. Together with a high cetane number of 75-95 the fuel ensures an efficient and clean combustion.

Smaller environmental footprint
Reduces greenhouse gas emissions by up to 90% in addition to sizable reductions in tailpipe emissions.

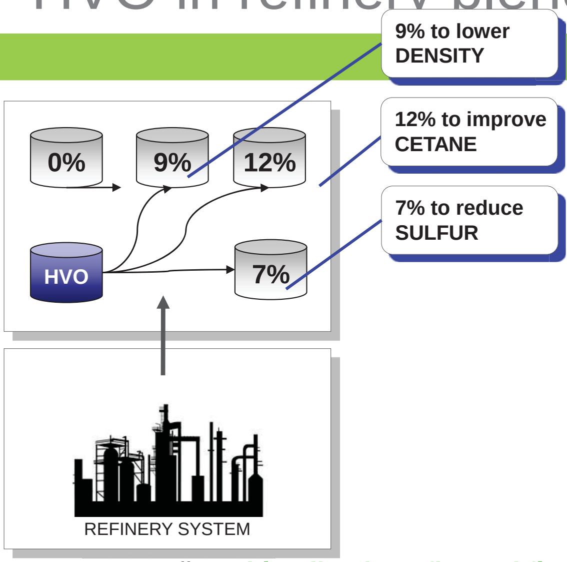
Lower operating costs
Longer service and maintenance intervals than for other alternative fuels.

Superior cold weather performance
Suitable for very cold weather conditions. No matter the raw material, Neste guarantees its fuel will exceed cold temperature requirements.

Long shelf life
Can be stored over long periods of time with no deterioration in quality or water accumulation.

Easy switch; no additional investments
Fleets can switch to NEXBTL renewable diesel overnight without any conversion of vehicles or to logistics systems.

HVO in refinery blending



HVO allows **blending benefits and flexibility**

Emerging local competition offers more support for biofuels

Emerging HVO competitors

ENI

- Conversion of Venice refinery to HVO production plant completed in 2014
- Planned conversion of Gela refinery to HVO production plant

TOTAL

- Conversion of La Mede refinery to HVO production by 2017
- Conversion of Dunkirk refinery by 2017 (not HVO)

PREEM

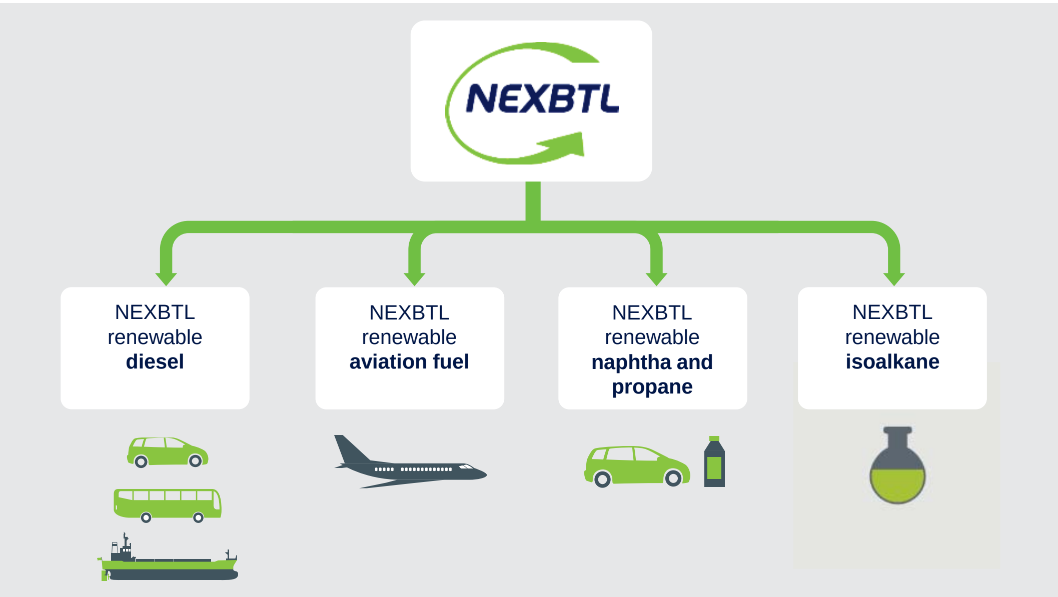
- Plan to double biofuel production in 2015

UPM

- Commercial production of HVO from tall oil in Finland since Q1/2015

Total potential capacity approx. 2 Mton/a

NEXBTL product family, 100% renewable



Official name change 1st June 2015

NESTE

The only way is forward

AACHENER VERFAHRENS-TECHNIK | RWTH AACHEN UNIVERSITY

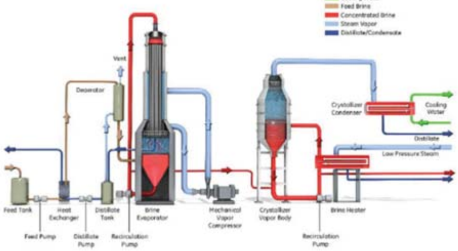
Zero Liquid Discharge Biorefineries

Prof. Dr.-Ing. Andreas Jupke

Zero liquid discharge in general

Application of “zero liquid discharge” (ZLD)?

- Wastewater treatment → reduce waste water streams to dry solids
- Sea water desalination → no brine discharge
- Applied unit operations:
  - Evaporation
  - Crystallization
  - Reverse osmosis
  - Electrodialysis
- Often increased energy consumption
- 2 levels of ZLD
  1. Strict definition:
     NO liquid discharge
  2. Limited definition:
     highly concentrated discharge
     in waste water slurry



Source: GE Water & Process Technologies

Aachener Verfahrenstechnik | RWTH AACHEN UNIVERSITY

Zero liquid discharge discussion paper

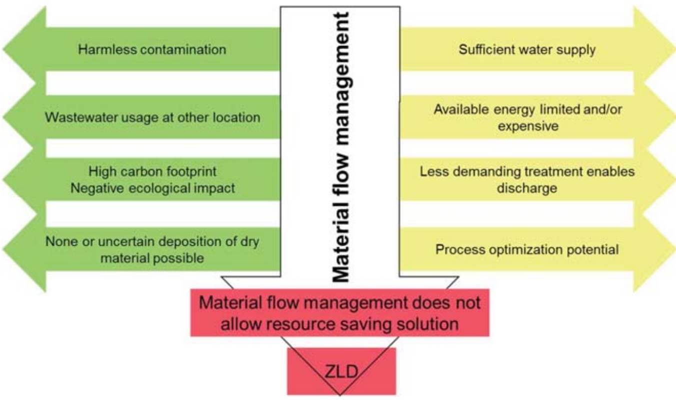
Discussion paper by DECHEMA & VDI (Nov. 2015)

Source: DECHEMA

Zero liquid discharge discussion paper

Discussion paper by DECHEMA & VDI (Nov. 2015)

- ZLD → increased energy consumption & indirect CO_2 emissions
- Alternatives available
- Decision tree for application of zero liquid discharge



Chemical engineering towards renewable feedstocks

Fossil feedstocks → **Renewable feedstocks**

 → 

Chemical engineering towards renewable feedstocks

Fossil feedstocks → **Renewable feedstocks**

Gas phase reactions → Liquid phase reactions (dilute)

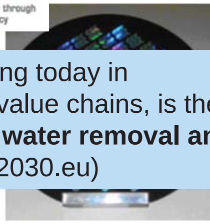
 → 

Chemical engineering towards renewable feedstocks

Fossil feedstocks	→	Renewable feedstocks
Gas phase reactions	→	Liquid phase reactions (dilute)
“Evaporative” separations	→	“Low temperature” separations

PRODIAS
Processing Diluted Aqueous Systems

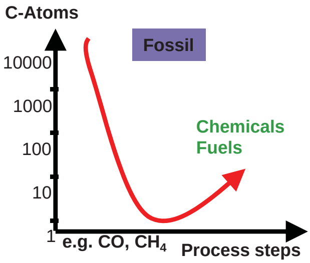
SPIRE
Sustainable Process Industry through Resource and Energy Efficiency

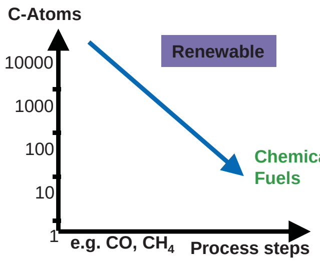


“A main challenge the process industry is facing today in introducing renewable raw material into their value chains, is the **development of cost- and energy-efficient water removal and product-recovery techniques”**. (http://spire2030.eu)

Chemical engineering towards renewable feedstocks

Fossil feedstocks	→	Renewable feedstocks
Gas phase reactions	→	Liquid phase reactions (dilute)
“Evaporative” separations	→	“Low temperature” separations
Structure degradation & build-up	→	Structure prevention





Biorefinery concepts

Definition “biorefinery“

A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, & value-added chemicals from biomass.

Lignocellulosic biomass

- 40-45 % Cellulose
- 15-35 % Hemicellulose
- 18-30 % Lignin

Classification of lignocellulosic biorefineries

Structure prevention | Structure degradation

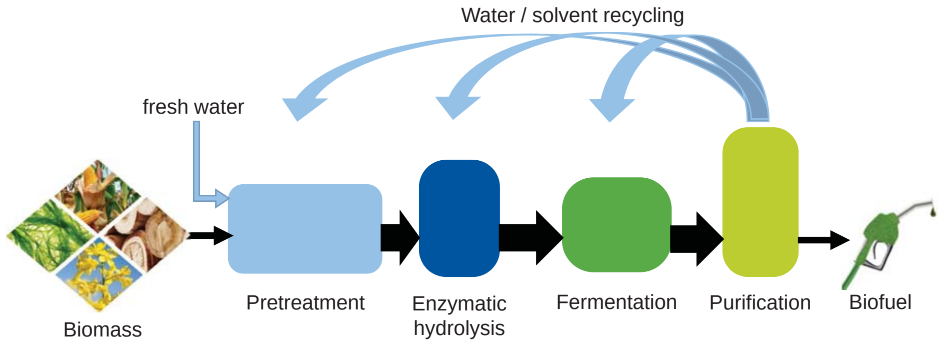
Steam Explosion, dil. Acid, Organosolve, Organocat → **Cellulose Hemicellulose Sugars, Lignin**

Gasification, Thermal-Hydrolysis, Pyrolysis → **Syngas H_2, CO**

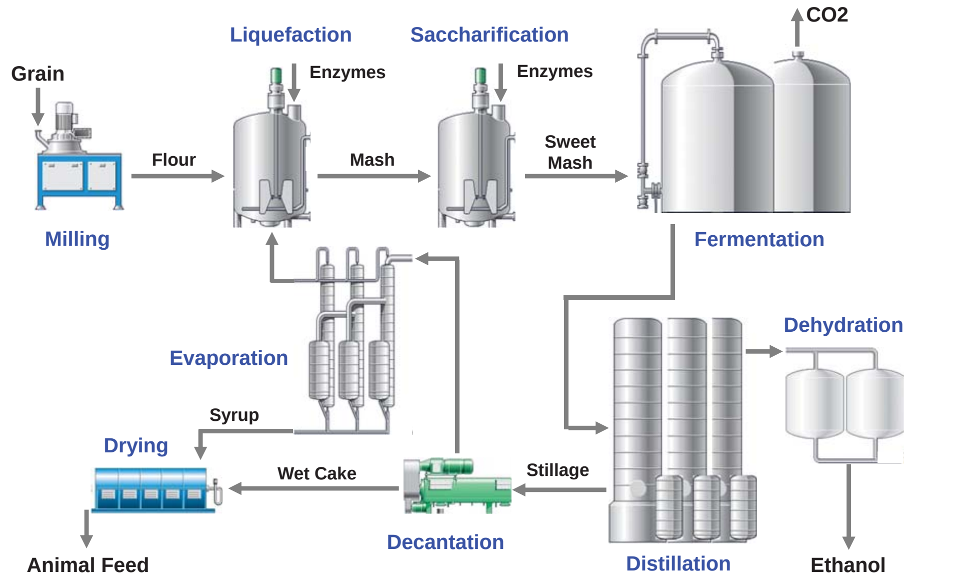
Target of zero liquid discharge biorefineries

Zero liquid discharge biorefineries means

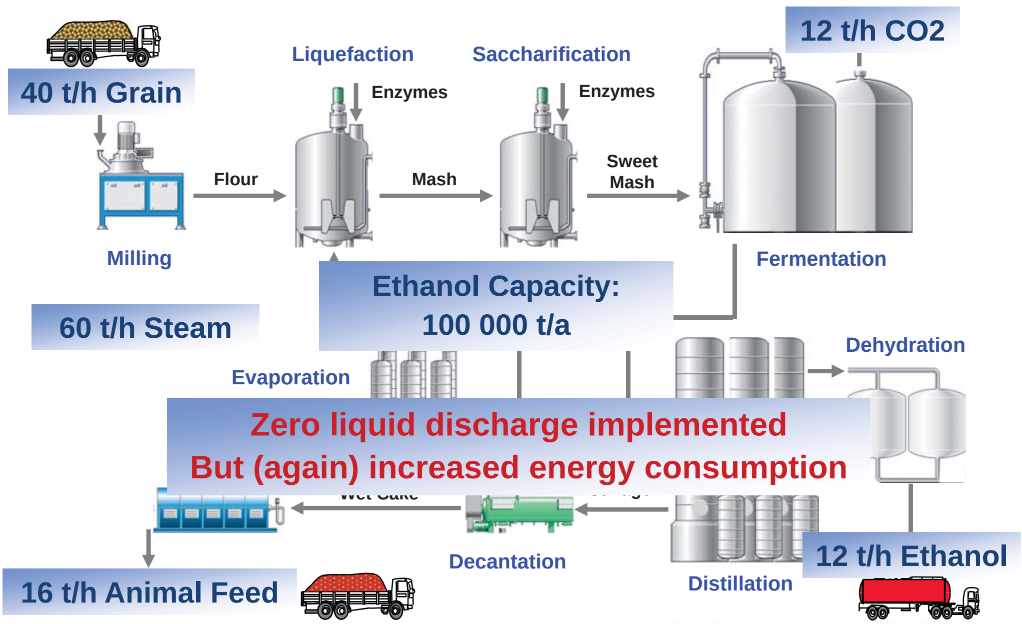
- Water and solvents are recycled
- Purity requirements of recycled water and solvents → separation likely
- Waste streams are concentrated / dried → increased energy consumption



Zero liquid discharge at first generation Bioethanol?

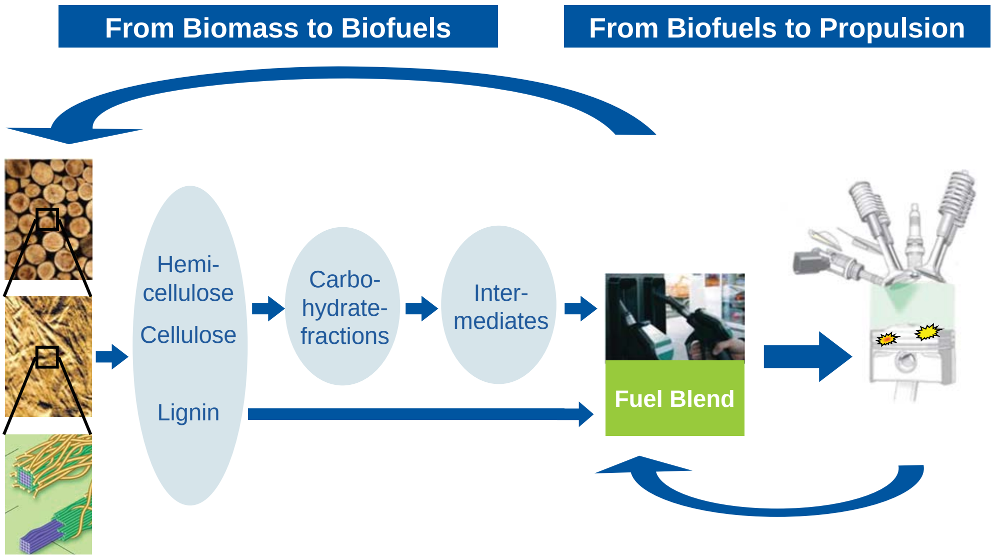


Zero liquid discharge at first generation Bioethanol!



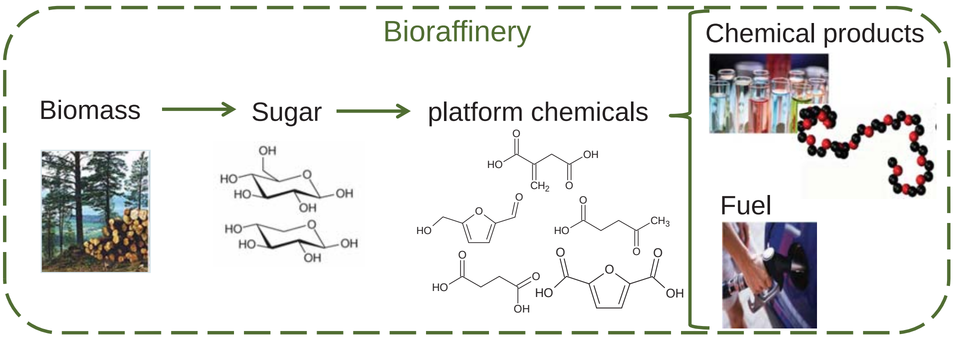
TMFB: Tailor-maid fuels from biomass
Integrated Fuel Design Process

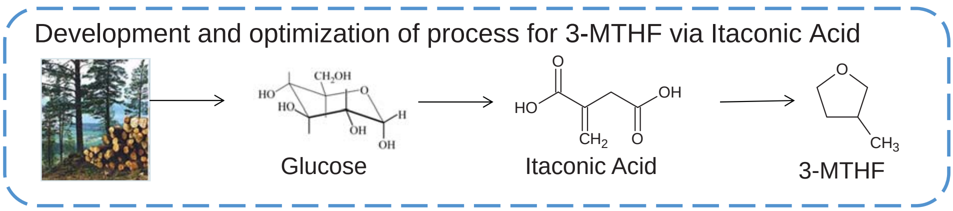
Tailor-Made Fuels from Biomass



Motivation
TMFB: Tailor-maid fuels from biomass

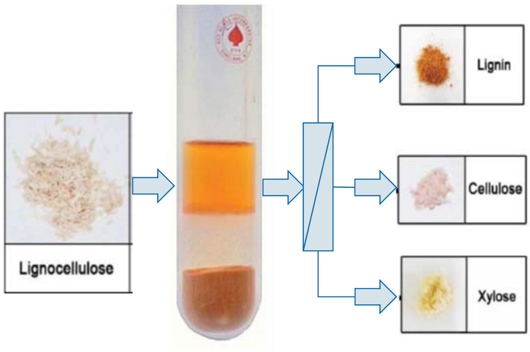
Tailor-Made Fuels from Biomass





Biomass Fractionation: OrganoCat Process

Oxalic acid
2-MTHF
T = 80 -140 ºC

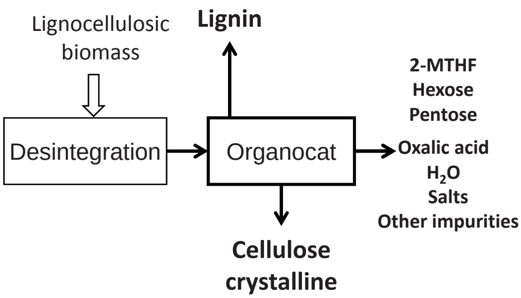


Advantages

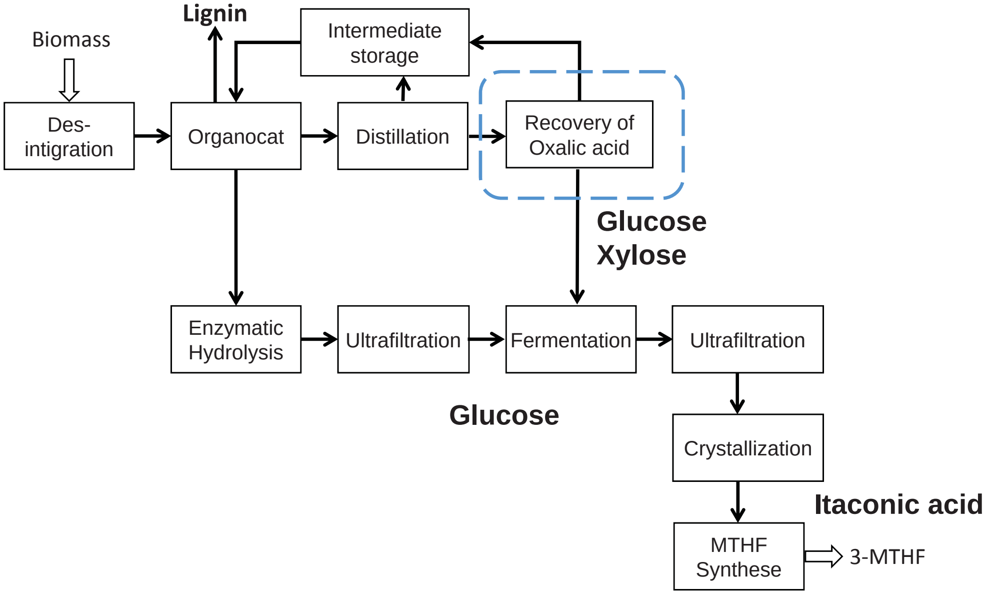
- High-quality lignin solved in organic phase 2-MTHF
- Hemicellulose Xylose solved in aqueous phase
- Pure cellulose for downstream hydrolysis and fermentation

Grande, P. M.; Viell, J.; Theyssen, N.; Marquardt, W.; de María, P. D. & Leitner, W.
Fractionation of lignocellulosic biomass using the OrganoCat process
Green Chem., The Royal Society of Chemistry, **2015**, *17*, 3533–3539

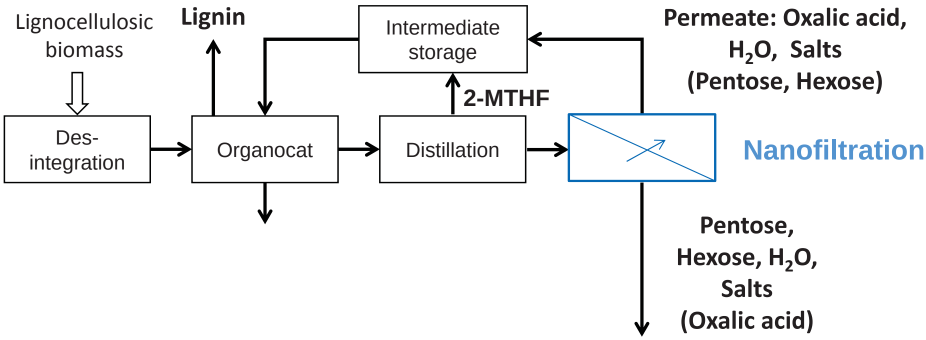
OrganocCat Process: An innocent little box



Reference process for 3-MTHF via Itaconic Acid



Recovery of Oxalic acid by Nanofiltration




Contents lists available at SciVerse ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

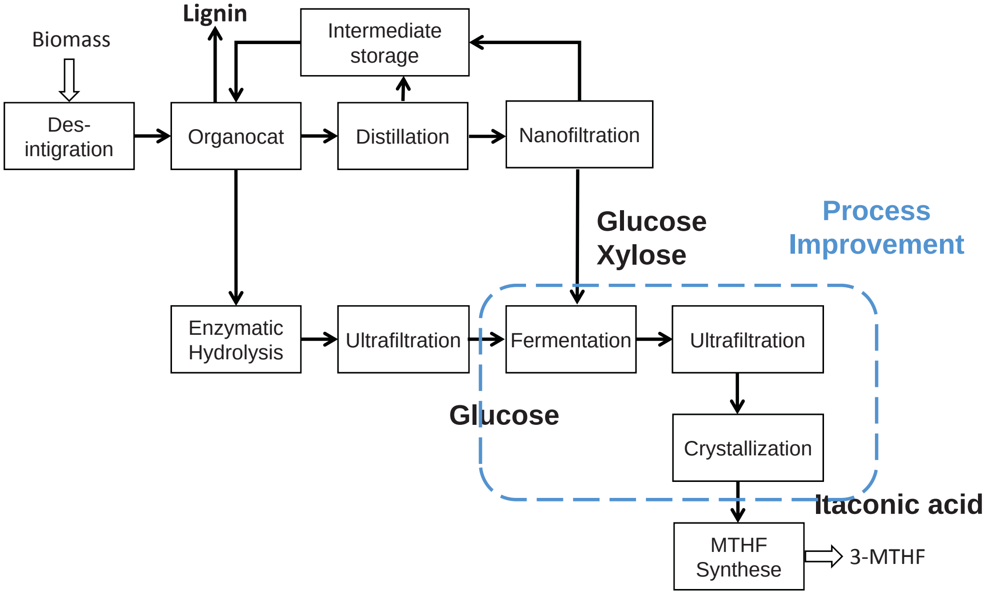
ELSEVIER

Membrane processes in biorefinery applications

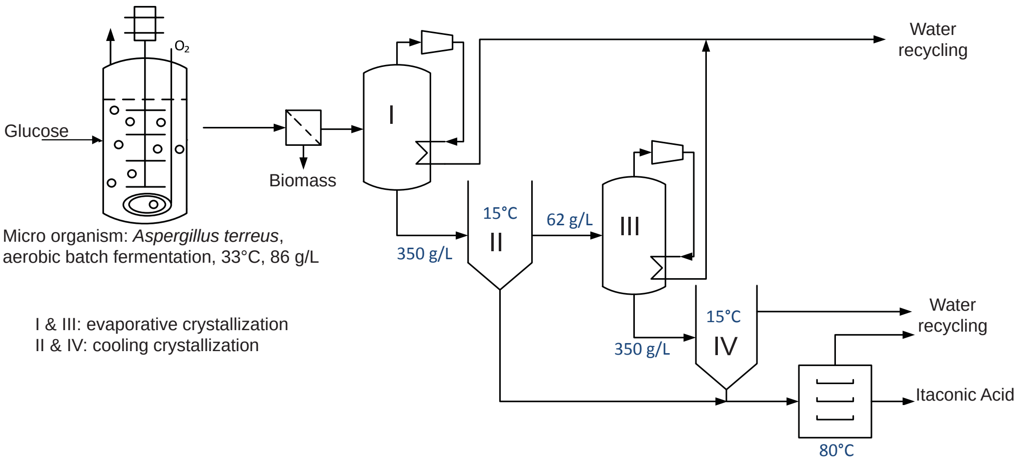
Christian Abels, Frederike Carstensen, Matthias Wessling*

Chemical Process Engineering-AVT.CVT, RWTH Aachen University, 52056 Aachen, Germany

Reference process for 3-MTHF via Itaconic Acid



Itaconic Acid fermentation and purification – proposed concept

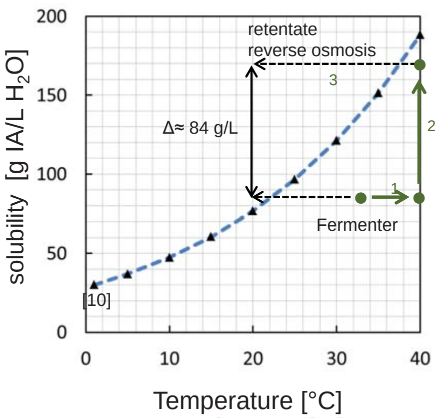


I & III: evaporative crystallization
II & IV: cooling crystallization

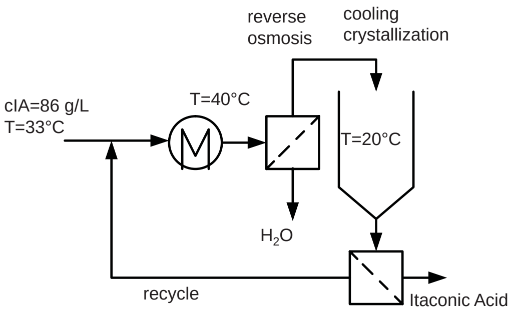
Okabe et al., Appl Microbiol Biotechnol, vol. 84, 2009

Itaconic Acid fermentation and purification – improved concept

- Temperature dependent solubility of Itaconic Acid
- Increased concentration by reverse osmosis

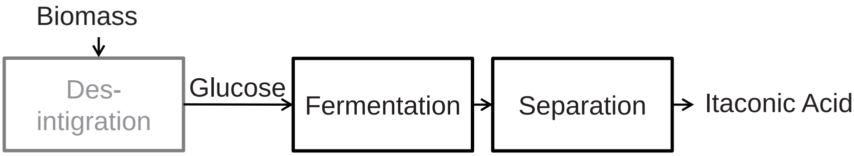


Micro organism: *A. terreus*, 33°C, 86 g/L



Adam et al., US Patent 3.544.455,1970
Stodollick et al. *in preparation*
K. Ulonska, J. Viell, A. Mitsos, W. Marquardt
ProcessNet Jahrestagung, 2014, Aachen

Itaconic Acid fermentation and purification – improved concept



Process concept	Energy [MJ/kg IA]	Cost [$/kg IA]
Proposed process (Okabe)	26	1,0
Reverse osmosis & cooling crystallization	20	0,8

K. Ulonska, J. Viell, A. Mitsos, W. Marquardt
ProcessNet Jahrestagung, 2014, Aachen

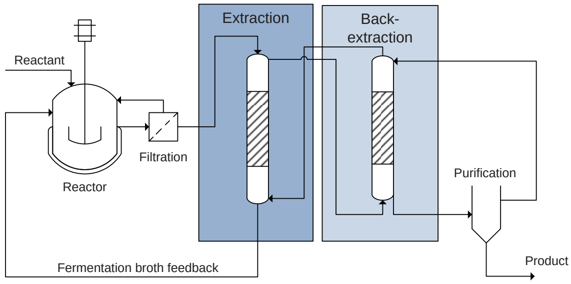
Market price Itaconic Acid: 1,8 $/kg

Weastra, Determination of Market Potential for selected Platform chemicals, 2012

Process intensification – in-situ extraction or in-situ adspoption

Current research projects

- Fermentation: often limitations by product inhibition
  → low product titer
  → long fermentation times
  → low space-time-yield
- In-situ product removal by
  - liquid-liquid extraction
  - adsorption



Next Generation Processes and Products NGP²

Aachener Verfahrenstechnik – Chairs and Professors

Prof. Büchs
Biochemical Engineering
BioVT

Prof. Wessling
Chemical Process Engineering
CVT

Prof. Spieß
Enzyme Process Technology
EPT

Prof. Modigell
(emeritus)
Mechanical Process Engineering
MVT

Prof. Jupke
Fluid Process Engineering
FVT

Prof. Mitsos
Process Systems Engineering
SVT

Next Generation Processes and Products NGP²

- Offices
- Laboratories
- Workshops
- Main analytics
- Library
- CIP-Pool
- Conferences- and seminar rooms
- **Biorefinery**

In total: app. 15.000 m²

The NGP² Biorefinery

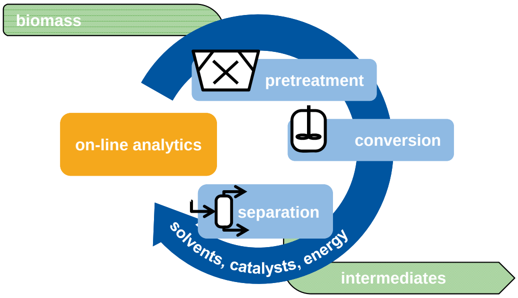
Modular unit operations in technical scale for high flexibility

In situ product separation

Solvent and catalyst recovery to improve economic feasibility

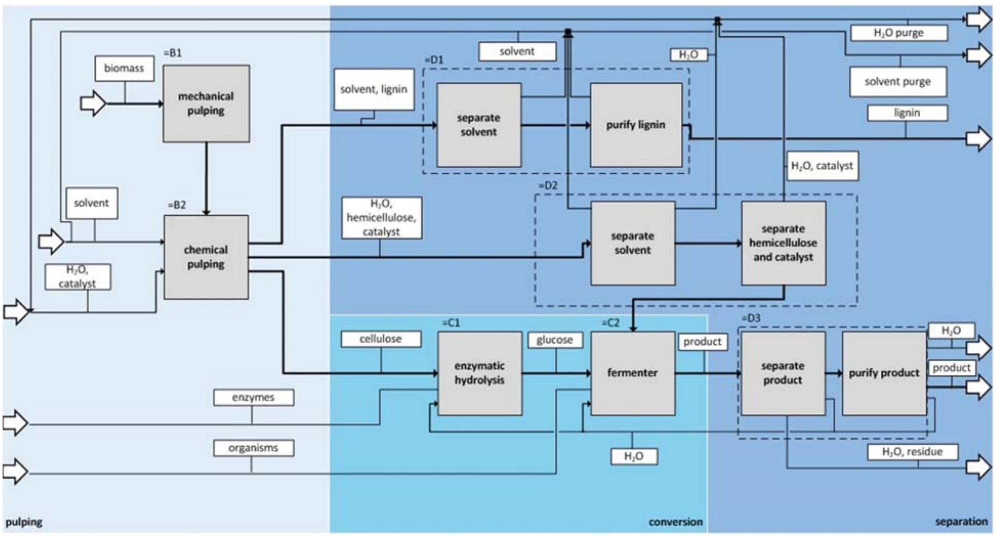
On-line analytics for optimization of process routes

Zero liquid discharge



Source: Heinrich Frings GmbH & Co. KG

The NGP² Biorefinery



Conclusion

Zero Liquid Discharge Biorefineries

- ZLD often increases energy consumption & indirect CO_2 emissions
- ZLD is already applied at first generation bioethanol
- ZLD is possible for lignocellulosic biorefineries
- **Improvements in chemistry, biotechnology and unit operations offer huge potential to reduce / prevent liquid discharges**

A main challenge the process industry is facing today in introducing renewable raw material into their value chains, is the development of cost- and energy-efficient water removal and product-recovery techniques. **In order to unlock the potential of the renewable-based product market for the European process industry, a re-thinking of downstream process development and the development of suitable methodologies for fast-track development of tailored downstream processes as well as the optimization of separation technologies are urgently needed.** (http://spire2030.eu)

Co-authors & Contributors

- Prof. Jochen Buechs
- Prof. Alexander Mitsos
- Prof. Matthias Wessling
- Dr. Jörn Viell
- The NGP² Biorefinery Team

International fuel strategies (or the lack thereof)

Nils-Olof Nylund,
VTT Technical Research Centre of Finland

Today transport is still 93 % dependent on oil based fuels. On the world level, the most important alternatives for the time being are natural gas and biofuels. Electricity in road transport is still marginal, even though relative growth is rapid.

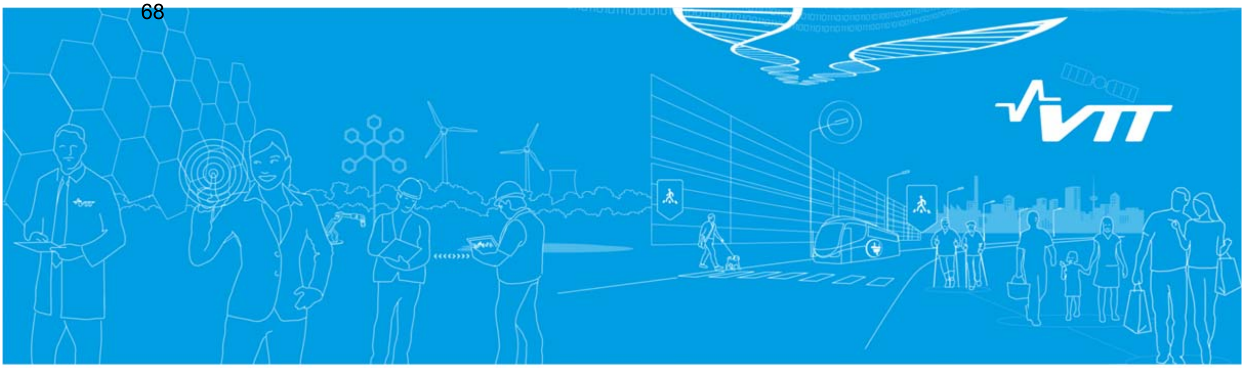
The reasons to move away from oil based fuels to alternative fuels can include oil substitution, making use of locally available fuel, stimulating local economy, reduction of greenhouse gas emissions and reduction of local emissions. There are three main means of reducing CO2 emissions from transport, namely reduction of transport work, improving efficiency on the vehicle as well as the transport system level and finally switching to renewable energy.

The renewable energy alternatives for transport include liquid and gaseous biofuels, renewable electricity, renewable hydrogen, and as a new element, electrofuels (power-to-gas, power-to-liquids). When evaluating alternative energy carriers for transport one has to keep in mind that no single alternative will cater the needs of all modes of transport. Electrification is not suitable for long- haul trucks and commercial aviation, whereas biofuels can replace fossil fuel in all modes of transport. In addition, the various options are at different levels of maturity, e.g., hydrogen and fuel cell vehicles are at the very early stage of development.

There is in fact no common international fuel strategy for transport. However, if transport is to achieve a 60 – 80 % reduction in greenhouse gas emission by 2050, alternatives to fossil fuels are needed. Directive 2009/28/EC on the promotion of renewable energy calls for 10 % renewable in transport by 2020. The EU 2030 climate and energy package no more contains a separate renewable energy target for transport. This, in combination with the discussion of the sustainability of biofuels (iLUC) has slowed down development of biofuels. On the other hand, the new Directive (2014/94/EU) on alternative fuel infrastructure calls for pan-European networks for gaseous (methane) fuels, electric vehicle recharging and hydrogen. In the US, the Renewable Fuel Standard calls for a total of 9.63 % in 2016. The Finnish government has set a very ambitious goal for renewable energy in transport, 40 % by 2030. In 2014, the actual contribution of biofuels in Finland was 12.3 %.

Although the offering of electric vehicles has grown rapidly, the share of EVs in new vehicle registrations in Europe was still below 1 % in 20151. The leading country for EV market share was Norway, 12 % of new registrations. According to IEA, the global EV stock was some 665,000 units at the end of 2014 (of a total world vehicle fleet of some 1 billion units). Japanese and Korean auto manufacturers are bringing fuel cell vehicles to the market in limited numbers.

As a summary, it can be stated that alternative technologies are available (biofuels, gas, electric vehicles, even fuel cell vehicles coming up), but take-up is slow. In fact, there seems to be a lack of energy and vehicle technology policies which could deliver a 30 - 40 % GHG emission reduction by 2030 and a 60 – 80 % reduction by 2050.



International fuel strategies

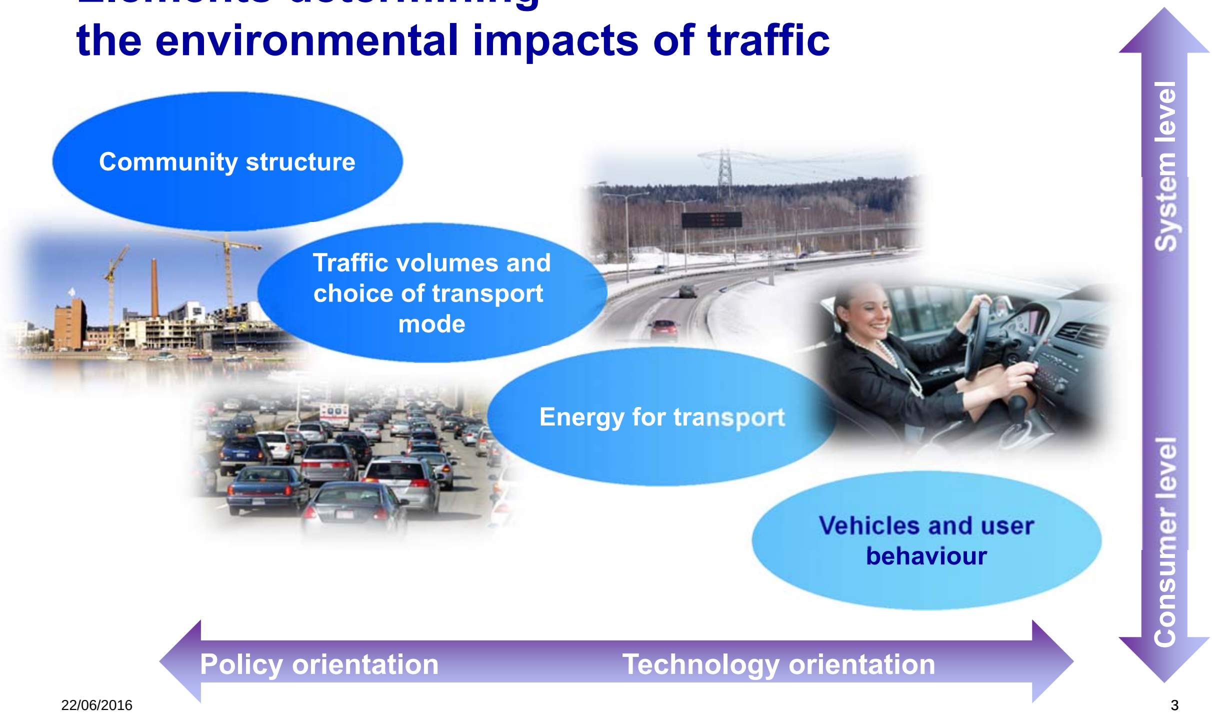
Transition to Renewable Energy Devices & Systems - Transportation Concepts
TRENDS 2015, Aachen 3-4 December, 2015

Nils-Olof Nylund, Research Professor
VTT Technical Research Centre of Finland

Outline

- Setting the stage
- EU policies and guidelines
- Examples of 2030/2050 targets and scenarios
- Comments on and numbers for
  - Transport fuel usage
  - Biofuels
  - Natural gas vehicles
  - Electric vehicles
  - Fuel cell vehicles
- Summary and conclusions

Elements determining the environmental impacts of traffic

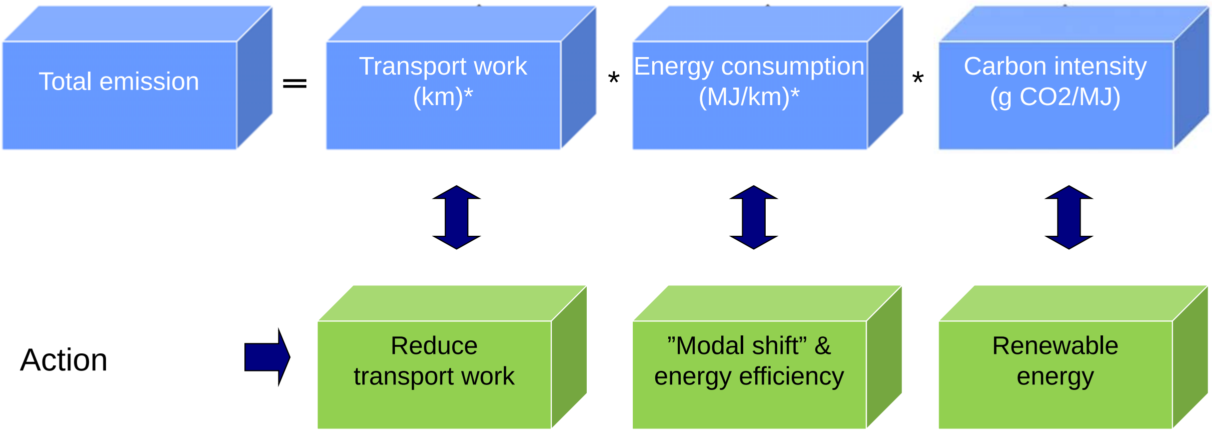


Why use alternative fuels?

- Oil substitution
- Use of locally available fuels
- Stimulating local economy
- Reduction of greenhouse gas emissions
- Reduction of harmful local emissions

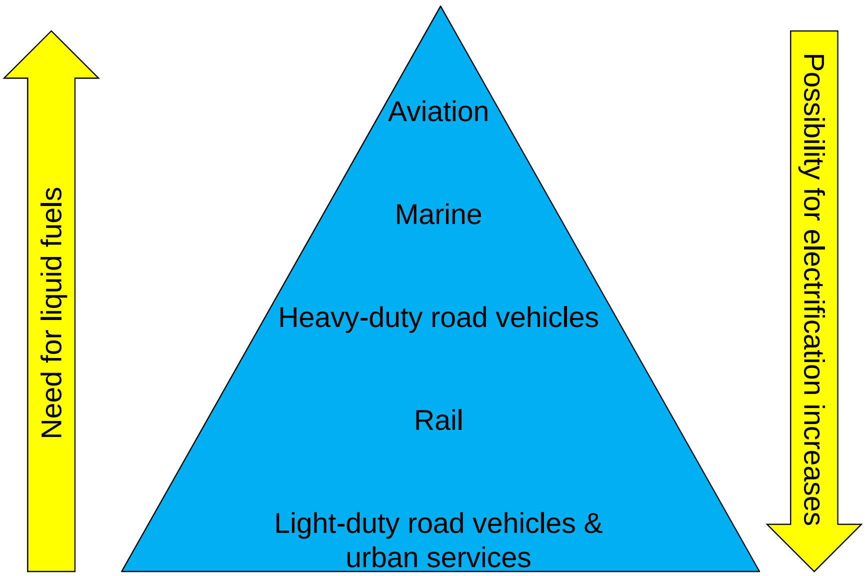
Picture: Stefan Schmerbeck/VW 2014

Reducing CO_2 emissions



*passenger km/ton km

Hierarchy of fuels



Ministry of Transport and Communications

Renewable energy for transport

- The options are:
  - Liquid and gaseous biofuels
  - Renewable electricity
  - Renewable hydrogen
  - Electrofuels
    - Power-to-gas
    - Power-to-liquids

Comparative Assessment of Renewable Transportation Fuels for EcoMobility

JOANNEUM RESEARCH RESOURCES

	"B-Mobility"	"E-Mobility"	"H_2-Mobility"
Primary energy	many options	many options	many options
Fuel production technology	1st generation existing 2nd generation under development	existing	fossil existing renewable under development
Sustainability	food/feed/fibre/fuel	renewable	renewable
Local emission	yes	no	very low
Infrastructure	existing	partly existing	not existing
Vehicle technology	existing	first vehicles on market	under development
Customer needs (Range/Refuel time)	common	uncommon	less common

Gerfrid Jungmeier 2014

"The world cannot support continued business-as-usual growth without some major changes in how we approach transport: either through ICT or mode shifting or some combination of these options. In developing regions in particular, it simply will not be possible to build enough roads to support 3 billion vehicles by 2050, electric, gas or conventional diesel … this is certainly a driver for finding real solutions to sustain long-term travel demand growth beyond vehicle and fuel technologies."

John Dulac/IEA 2013

The 2011 EU White Paper on Transport

- A vision for a competitive and sustainable transport system
- Growing transport and supporting mobility while reaching a 60% GHG emission reduction target

- Ten goals grouped in three main groups:
  - Developing and deploying new and sustainable fuels and propulsion systems
  - Optimising the performance of multimodal logistic chains, including by making greater use of more energy-efficient modes
  - Increasing the efficiency of transport and of infrastructure use with information systems and market-based incentives

http://ec.europa.eu/transport/strategies/2011_white_paper_en.htm

2020 climate and energy package & Directive 2009/28/EC ”RES”

2020 climate & energy package

Policy | Documentation | Studies | FAQ | Links

The 2020 package is a set of binding legislation to ensure the EU meets its climate and energy targets for the year 2020.

The package sets three key targets:

- 20**%** cut in **greenhouse gas** emissions (from 1990 levels)
- 20% of EU energy from **renewables**
- 20% improvement in **energy efficiency**

The targets were set by EU leaders in 2007 and enacted in legislation in 2009. They are also headline targets of the Europe 2020 strategy for smart, sustainable and inclusive growth.

10 % renewable energy in transport by 2020

”ILUC Directive”

Revision to the Fuel Quality Directive and Renewable Energy Directive

On 28 April 2015, the European Parliament voted to approve **new legislaton, the "iLUC Directive",** which limits the way Member States can meet the target of 10% for renewables in transport fuels by 2020, bringing to an end many months of debate. There will be a cap of 7% on the contribution of biofuels produced from 'food' crops, and a greater emphasis on the production of advanced biofuels from waste feedstocks. Member States must then include the law in national legislation by 2017, and show how they are going to meet sub-targets for advanced biofuels.

Key elements of the draft EU Directive

The contribution of biofuels produced from 'food' crops (to the 10 % renewables in transport target) is capped at 7%

The other 3% will come from a variety of multiple counted alternatives:

- Biofuels from Used Cooking Oil and Animal Fats (double counted)
- Renewable electricity in rail (counted 2.5 times)
- Renewable electricity in electric vehicles (counted 5 times)
- Advanced biofuels (double counted and with an indicative 0.5% sub-target)

European Biofuels
TECHNOLOGY PLATFORM
Accelerating deployment of advanced biofuels in Europe

Sitemap | RSS | Links | Legal notice | Cookies | Con

European Commission

CLIMATE ACTION

European Commission > Climate Action > Newsroom > Articles

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Latest news
- All News
- Latest events
- Public consultations
- RSS

EU leaders agree 2030 climate and energy goals

24/10/2014

EU Heads of State and Government have agreed the headline targets and the architecture for the EU framework on climate and energy for 2030. The agreed targets include a cut in greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels, an EU-wide binding target for renewable energy of at least 27% and an indicative energy efficiency target of at least 27%. The decision underlines the European Union's position as a world leader in the fight against climate change. The agreed greenhouse gas target will be the EU's contribution to the global climate change agreement due to be concluded in Paris next year. The renewables and energy efficiency targets will increase the security of the EU's energy supplies and help reduce its dependency on imported fossil fuels.

No 2030 target for renewable energy in transport!

Questions and answers on 2030 framework on climate and energy

European Commission

Why is there no new target as regards transport?

- The future of EU transport development should be based on alternative, sustainable fuels as an integrated part of a more holistic approach to the transport sector.
- The Commission has therefore not proposed new targets for the transport sector after 2020 (current targets: 10% renewable energy for the transport sector. The share of renewables in transport rose to 4.7% in 2010 from 1.2% in 2005).
- Based on the lessons of the existing target and on the assessment of how to minimise indirect land-use change emissions, it is clear that **first generation biofuels** have a **limited role in decarbonising** the transport sector. A **range of alternative renewable fuels** and a mix of targeted policy measures building on the Transport White Paper are thus needed to address the challenges of the transport sector in a 2030 perspective and beyond.

Clean Power for Transport Package

European Commission

Alternative Fuels for Transport

	Road						Air	Rail	Water		
Range	Urban	Medium	Long	Short	Medium	Long			Inland	Short sea	Maritime
Natural gas					LNG	LNG	✗		LNG	LNG	LNG
Electricity		✗	✗		✗	✗	✗			✗	
Biofuels											
Hydrogen						✗	✗			✗	✗

Liquid biofuels and methane are the most versatile alternatives!

Marc Steen/JRC 2014

Directive 2014/94/EU (October 2014) on the deployment of alternative fuels infrastructure

The final Directive, as adopted by the European Parliament and the Council on 29 September 2014 following the inter-institutional negotiations:

- Requires Member States to develop national policy frameworks for the market development of alternative fuels and their infrastructure;
- Foresees the use or common technical specifications for recharging and refuelling stations;
- Paves the way for setting up appropriate consumer information on alternative fuels, including a clear and sound price comparison methodology.

The required coverage and the timings by which this coverage must be put in place is as follows:

	Coverage	Timings
Electricity in urban/suburban and other densely populated areas	Appropriate number of publically accessible points	by end 2020
CNG in urban/suburban and other densely populated areas	Appropriate number of points	by end 2020
CNG along the TEN-T core network	Appropriate number of points	by end 2025
Electricity at shore-side	Ports of the TEN-T core network and other ports	by end 2025
Hydrogen in the Member States who choose to develop it	Appropriate number of points	by end 2025
LNG at maritime ports	Ports of the TEN-T core network	by end 2025
LNG at inland ports	Ports of the TEN-T core network	by end 2030
LNG for heavy-duty vehicles	Appropriate number of points along the TEN-T core network	by end 2025

US renewable fuel standard

Annual Percent Standards

Biofuel Category	Final 2010	Final 2011	Final 2012	Final 2013	Proposed 2014	Proposed 2015	Proposed 2016	Proposed 2017
Cellulosic biofuel	0.004%	0.003%	0.006%	0.004%	0.019%	0.059%	0.114%	
Biomass-based diesel	1.10%	0.69%	0.91%	1.13%	1.42%	1.41%	1.49%	
Advanced biofuel	0.61%	0.78%	1.21%	1.62%	1.52%	1.61%	1.88%	
Total renewable fuel	8.25%	8.01%	9.23%	9.74%	9.02%	9.04%	9.63%	

http://www2.epa.gov/renewable-fuel-standard-program

EPA United States Environmental Protection Agency

Finland, a land of solutions

Strategic Programme of
Prime Minister Juha Sipilä's Government
29 May 2015

Ten-year objective:

- Finland is a pioneer in the bioeconomy, a circular economy and cleantech. By developing, introducing and exporting sustainable solutions we have improved the balance of current accounts, increased our self-sufficiency, created new jobs, and achieved our climate objectives and a good ecological status for the Baltic Sea.

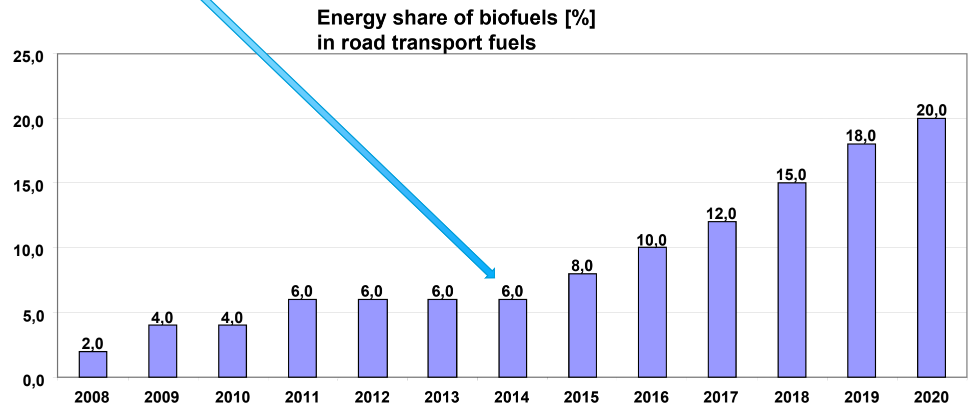
Transport:

- The use of imported oil will be cut in half during the 2020s
- The share of renewable transport fuels will be raised to 40 per cent by 2030

http://valtioneuvosto.fi/en/sipila/government-programme

Biofuel obligation

- Came into force in January 2008 and was revised in 2010
- **Outcome 2014: actual share 12.3 %, calculatory share 23,5 %**



TYÖ- JA ELINKEINOMINISTERIÖ
ARBETS- OCH NÄRINGSMINISTERIET
MINISTRY OF EMPLOYMENT AND THE ECONOMY

Original title:
40% Reduction of Carbon Dioxide Emissions from Transport by 2030: Propulsion Options and Their Impacts on National Economy

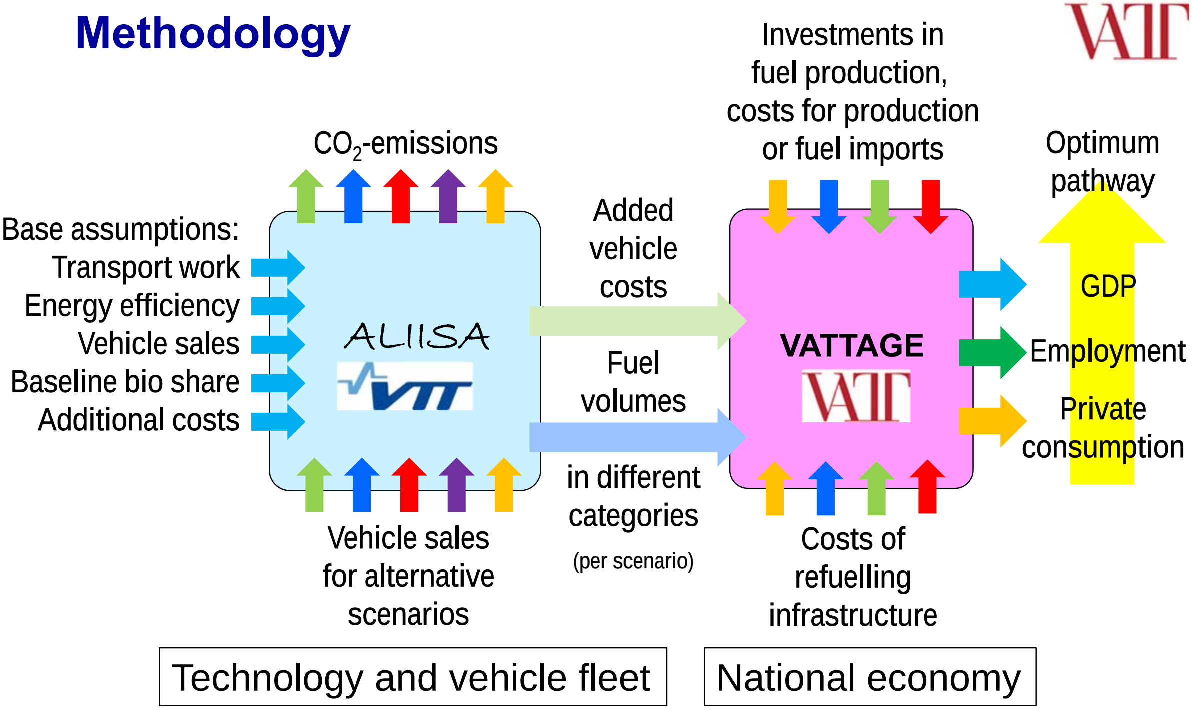
A joint study by VTT and VATT, the Government Institute for Economic Research

VATT
VALTION TALOUDELLINEN TUTKIMUSKESKUS
STATENS EKONOMISKA FORSKNINGSCENTRAL
GOVERNMENT INSTITUTE FOR ECONOMIC RESEARCH

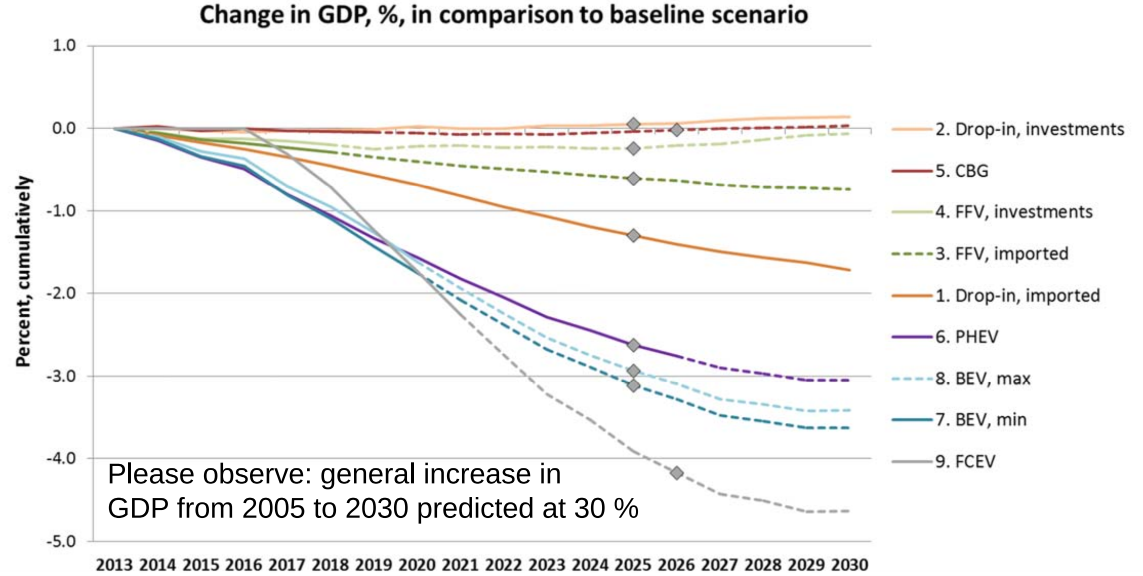
Objective and methodology

- Main financer: Ministry of Employment and the Economy
- Objective: To evaluate which measures could deliver a 30 or 40 % reduction in CO_2 emissions in road transport by 2030 (reference year 2005)
- Execution: Modelling the effects of biofuels and other alternative technologies on emissions and costs, costs also from the viewpoint of the national economy
- Main partners: VTT Technical Research Centre of Finland Ltd and the Government Institute for Economic Research VATT

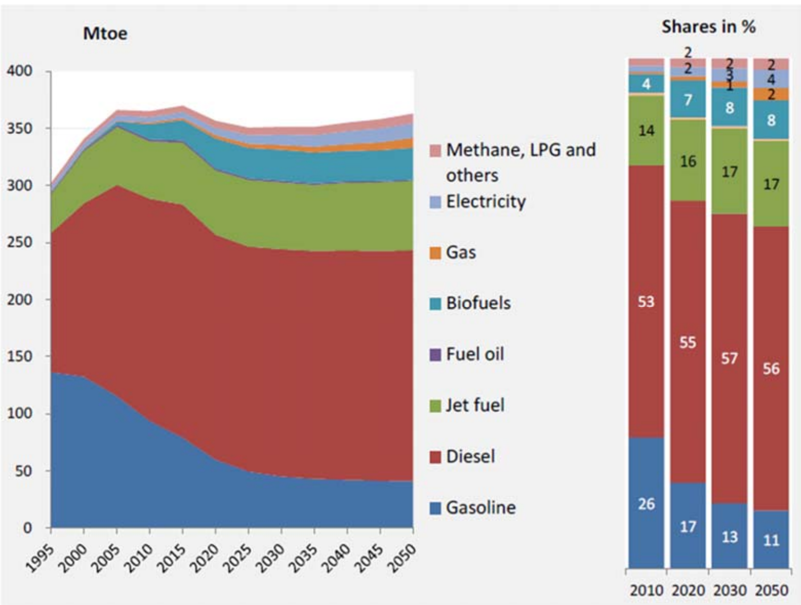
Methodology



Impact on GDP



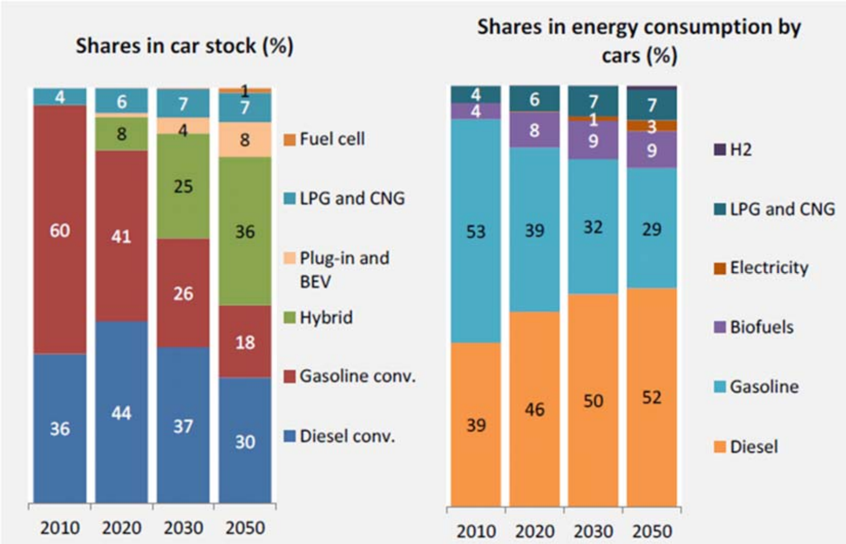
Projections for 2050 – Reference scenario 2013 Transport energy



"Simulating the energy balances and GHG emission trends for future years under current trends and policies as adopted in the Member States by spring 2012"

https://ec.europa.eu/energy/en/statistics/energy-trends-2050

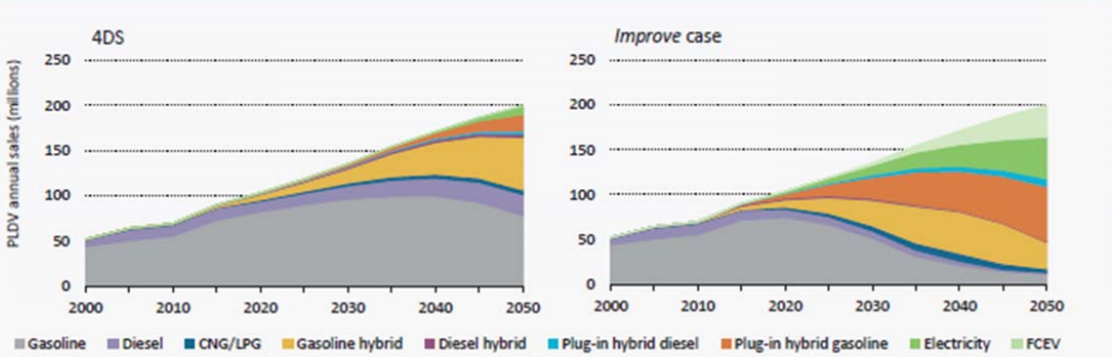
Projections for 2050 – Reference scenario 2013 Passenger cars



https://ec.europa.eu/energy/en/statistics/energy-trends-2050

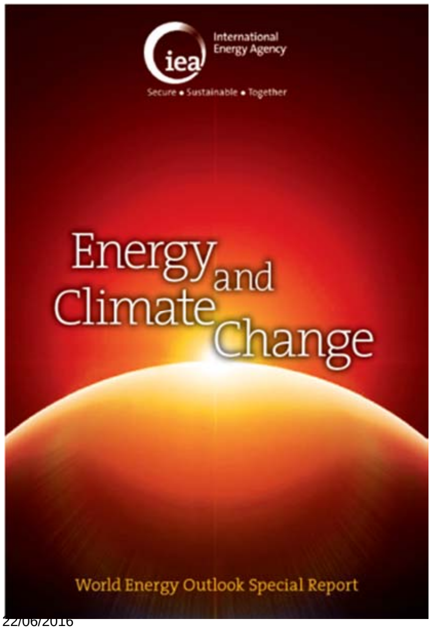
IEA 2050 projection for LDV sales Energy Technology Perspectives 2012

Figure 13.18 Global portfolio of technologies for passenger LDVs



Key point *In the Improve case, electric, PHEV and FCEVs together account for nearly three-quarters of new vehicle sales in 2050.*

IEA World Energy Outlook 2015

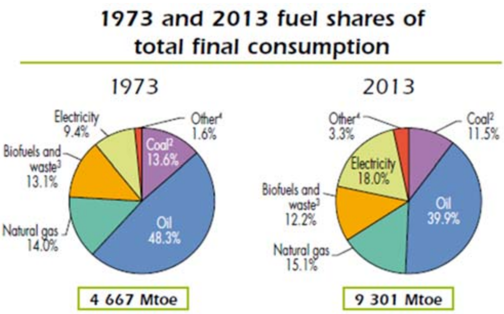


We face a moment of opportunity, but also of great risk. The world is counting on the UN climate talks in Paris later this year to achieve a global agreement that puts us on a more sustainable path. As IEA analysis has repeatedly shown that the cost and difficulty of mitigating greenhouse-gas emissions increases every year, time is of the essence. And it is clear that the energy sector must play a critical role if efforts to reduce emissions are to succeed. While we see growing consensus among countries that it is time to act, we must ensure that the steps taken are adequate and that the commitments made are kept.

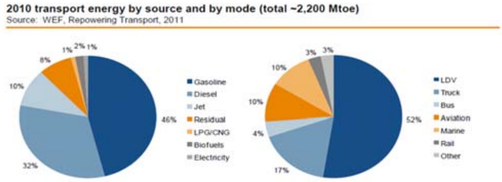
In recent years, progress has been made in developing cleaner, more efficient energy technologies. Indeed, we are seeing signs that economic growth and energy-related emissions – which have historically moved in the same direction – are starting to decouple. The energy intensity of the global economy continued to decline in 2014 despite economic growth of over 3%. But increased effort is still needed if we are to keep open the possibility of limiting the rise in global mean temperature to 2 °C. The pledges – or Intended Nationally Determined Contributions (INDCs) – made by individual countries for the 21st UN Conference of the Parties (COP21) in December 2015 will determine whether this goal will remain attainable.

”Paris will show where we are heading”

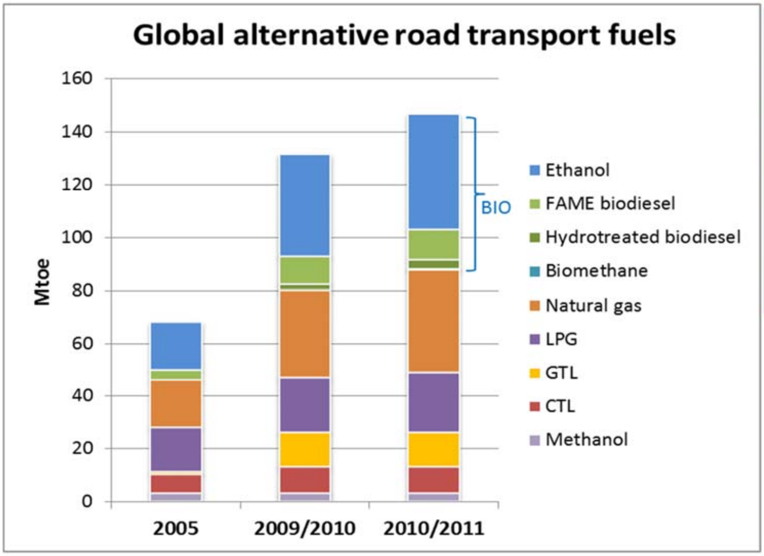
IEA Energy Balances IEA 2015, Figures for 2013



- Total final consumption 9301 Mtoe
- Transport 2564 Mtoe (28 %)
- Total oil 3716 Mtoe
  - Transport 64 %= 2374 Mtoe
  - Transport dependency on oil 93 %
- Total natural gas 1401 Mtoe
  - Transport 6.9 %= 97 Mtoe or some 3,8 % of total transport
- Total electricity 1677 Mtoe
  - Transport 1.5 %= 25 Mtoe or some 1,0 % of total transport
- Total coal 1069 Mtoe
  - Transport 0.3 %= 3,2 Mtoe
- Balance transport 65 Mtoe



Compilation by AMF (2012)



Energy demand of transport sector is appr. 2300 Mtoe. Major part of that, appr. 73% (~ 1700 Mtoe), is consumed in road transport sector.

Alternative fuels are estimated to represent max. 8.8% share of road transport fuels in 2010. Share of biofuels is estimated to be 3.5%, respectively.

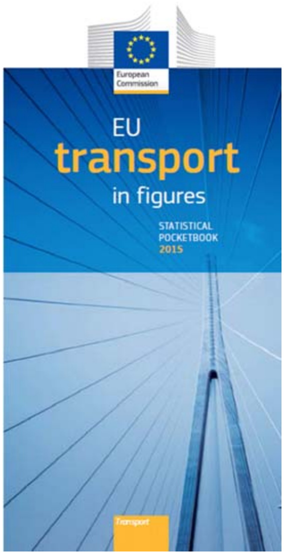
Sources: Ethanol 2010 (REN21, 2011); FAME and hydrotreated biodiesel 2010/2011 (EurObserv'ER, 2011; Press releases); CNG, biomethane 2010/2011 calculated from vehicle population (NGVA Europe and GVR, 2011); GTL and CTL capacities (IEA ETSAP, 2010); Methanol 2010 (Methanol Institute); World transport fuels 2009 (IEA WEO, 2011).

Figure by IEA-AMF (A-S 2012)

Fuel volumes for road transport in EU28 Statistical pocketbook 2015, figures for 2013

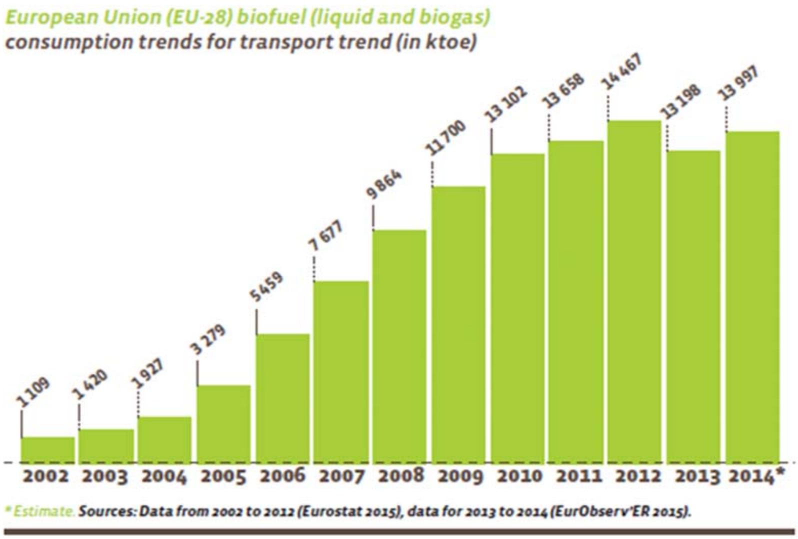
Final Consumption of Motor Gasoline, Diesel and Biofuels for Transport – BY FUEL 2013 (ktoe)

	FINAL CONSUMPTION OF MOTOR GASOLINE AND DIESEL FOR TRANSPORT (*)	Motor Gasoline	Gas / Diesel Oil	BIOFUELS	Biogasoline	Biodiesel	Other liquid biofuels (**)
EU-28	270 965.2	79 337.1	191 628.1	13 014.2	2 716.8	10 292.7	4.6



Bio-share 4.6 %

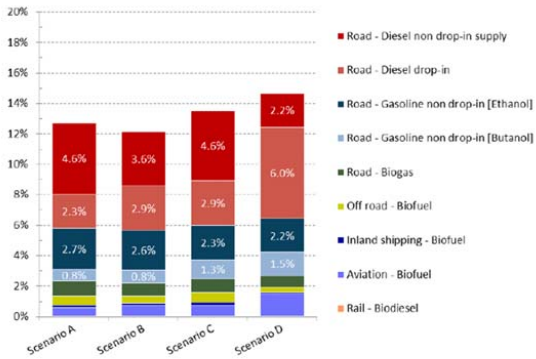
European biofuel trends



Total share of biofuels 14 Mtoe/286 Mtoe= 4.9 %
Source: Biofuels Barometer 2015

Some statements and estimates regarding the potential of biofuels

- World level
  - 27 % by 2050
  - International Energy Agency 2011
- European Union
  - Up to 15 % by 2030
  - E4tech 2013
    (A harmonised Auto-Fuel biofuel roadmap for the EU to 2030)
- Finland
  - Up to 32 % by 2030
  - VTT & VATT 2015

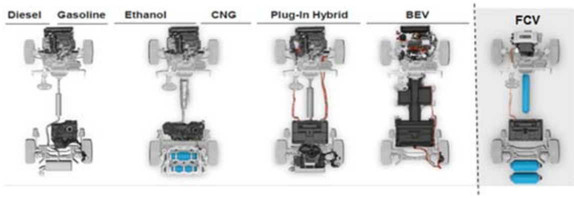


Electric and alternative fuel vehicle registrations in EU in 2015

29/10/2015

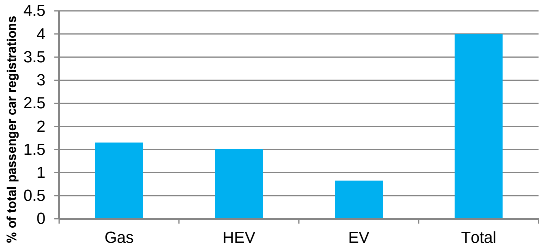
Alternative Fuel Vehicle registrations: +19.8% in the first nine months; +13.4% in Q3

Brussels, 29 October 2015 - In the third quarter of 2015, total alternative fuel vehicle registrations in the EU increased (+13.4%), reaching 127,661 units.



Picture: S. Schmerbeck/VW 2014

Alternative vehicle shares Q1-Q3/2015

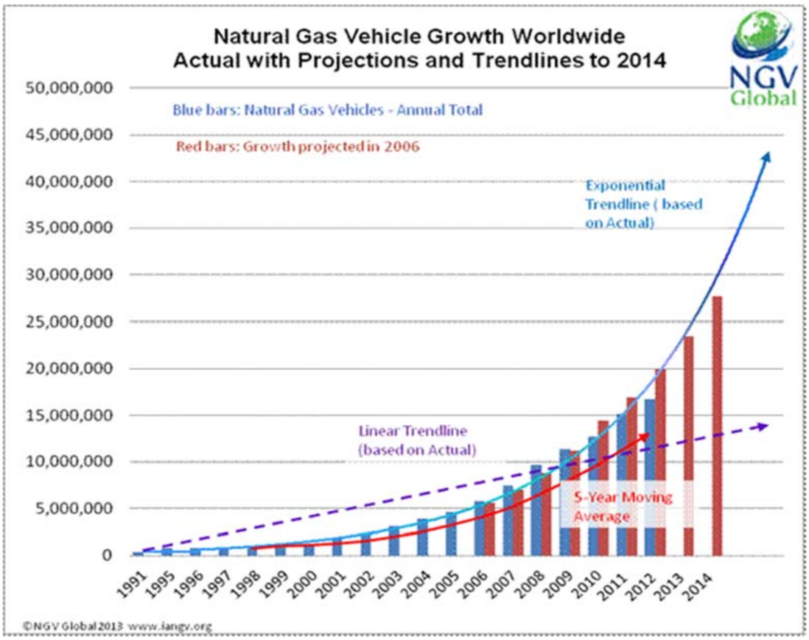


Total registrations10,413,675
Alternatives in total 415,896

- Gas 171,924
- HEV 157,830
- EV 86,142

www.acea.be/statistics

World NGV numbers



Source: IANGV

European NGV numbers

Country	Total NGV population (other than ships, trains and aircraft)							
	Total NGVs	LD+MD +HD Vehicles	LD Vehicles	MD+HD Buses	MD+HD Trucks	Other	% of total LD+MD+HD vehicles in the country	% of total NGVs in the area
EU countries								
Austria	8 323	8 321	8 100	167	54	2	0,16 %	0,72 %
Belgium	1 033	1 033	1 015	3	15	0	0,02 %	0,09 %
Bulgaria	61 320	61 320	61 000	280	40	0	1,83 %	5,34 %
Croatia	329	300	219	78	3	29	0,02 %	0,03 %
Crypus	0	0	0	0	0	0	0,00 %	0,00 %
Czech Republic	7 488	7 243	6 650	512	81	245	0,14 %	0,65 %
Denmark	104	104	61	26	17	0	0,00 %	0,01 %
Estonia	340	340	300	30	10	0	0,05 %	0,03 %
Finland	1 689	1 665	1 600	45	20	24	0,05 %	0,15 %
France	13 550	13 550	10 050	2 400	1 100	0	0,04 %	1,18 %
Germany	98 172	97 619	95 708	1 735	176	553	0,20 %	8,54 %
Greece	1 000	1 000	280	618	102	0	0,02 %	0,09 %
Hungary	5 118	5 118	5 000	86	32	0	0,15 %	0,45 %
Ireland	3	3	3	0	0	0	0,00 %	0,00 %
Italy	885 300	885 300	880 000	2 300	3 000	0	2,16 %	77,04 %
Latvia	29	29	29	0	0	0	0,00 %	0,00 %
Lithuania	380	380	80	300	0	0	0,02 %	0,03 %
Luxembourg	270	270	230	39	1	0	0,07 %	0,02 %
Malta	0	0	0	0	0	0	0,00 %	0,00 %
Netherlands	7 573	7 570	6 498	686	386	3	0,09 %	0,66 %
Poland	3 600	3 500	3 050	400	50	100	0,02 %	0,31 %
Portugal	586	486	46	354	86	100	0,01 %	0,05 %
Romania	0	0	0	0	0	0	0,00 %	0,00 %
Slovakia	1 426	1 426	1 100	261	65	0	0,07 %	0,12 %
Slovenia	58	58	29	24	5	0	0,00 %	0,01 %
Spain	3 990	3 836	905	1 609	1 322	154	0,01 %	0,35 %
Sweden	46 715	46 713	43 795	755	2 163	2	0,92 %	4,07 %
United Kingdom	718	678	20	37	621	40	0,00 %	0,06 %
Total	**1 149 114**	**1 147 862**	**1 125 768**	**12 745**	**9 349**	**1 252**	**0,41 %**	**100,00 %**

for sustainable mobility NGVA europe
Natural & bio Gas Vehicle Association

EV targets to 2020
IEA Electric Vehicle Initiative 2013

Figure 2. EV Sales Targets [select EVI members]

Source: EVI. Note: A 20% compound annual growth rate is assumed for countries without a specific sales target (i.e., only a stock target) or with targets that end before 2020.

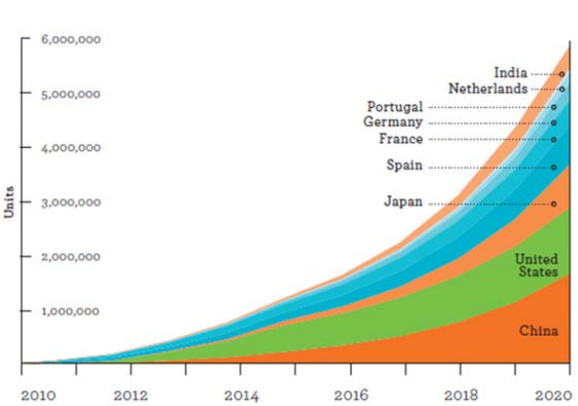
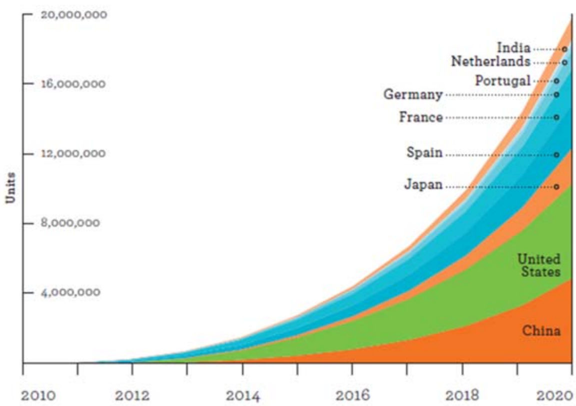
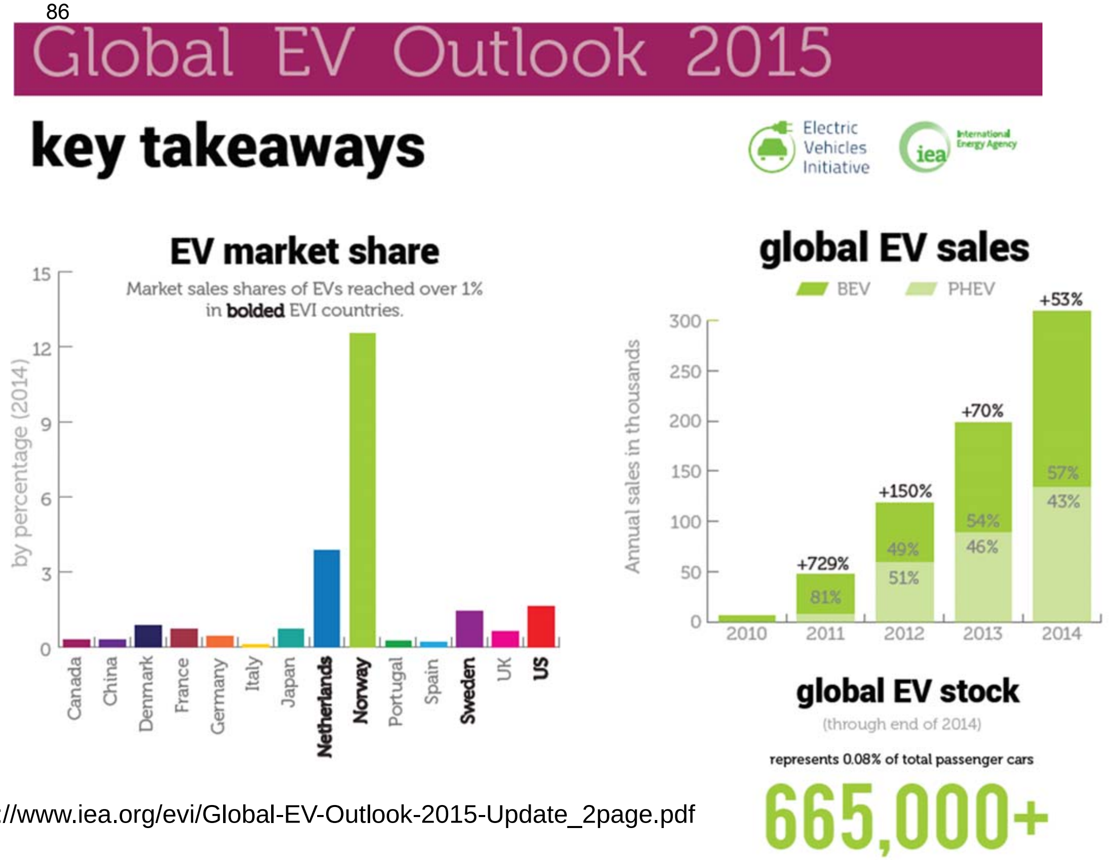


Figure 3. EV Stock Targets [select EVI members]

Source: EVI. Note: A 20% compound annual growth rate is assumed for countries without a specific stock target (i.e., only a sales target) or with targets that end before 2020.



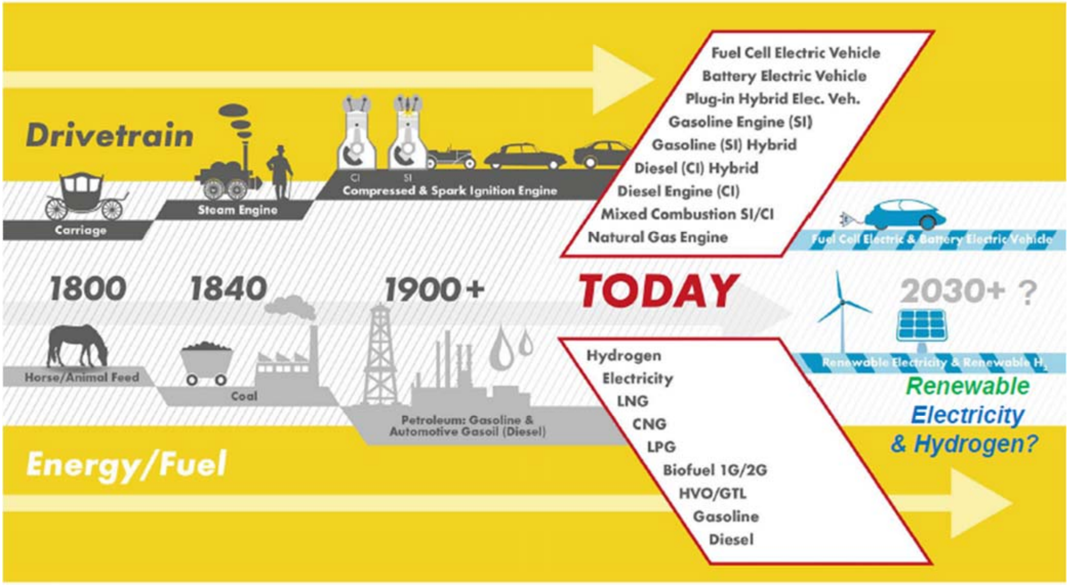


http://www.iea.org/evi/Global-EV-Outlook-2015-Update_2page.pdf

Panel discussion at Eco-Mobility 2014 in Vienna October 2014

- Mr. Hirose of Toyota got the question when will FCVs become mainstream technology?
- Mr. Hirose answered: around 2035!

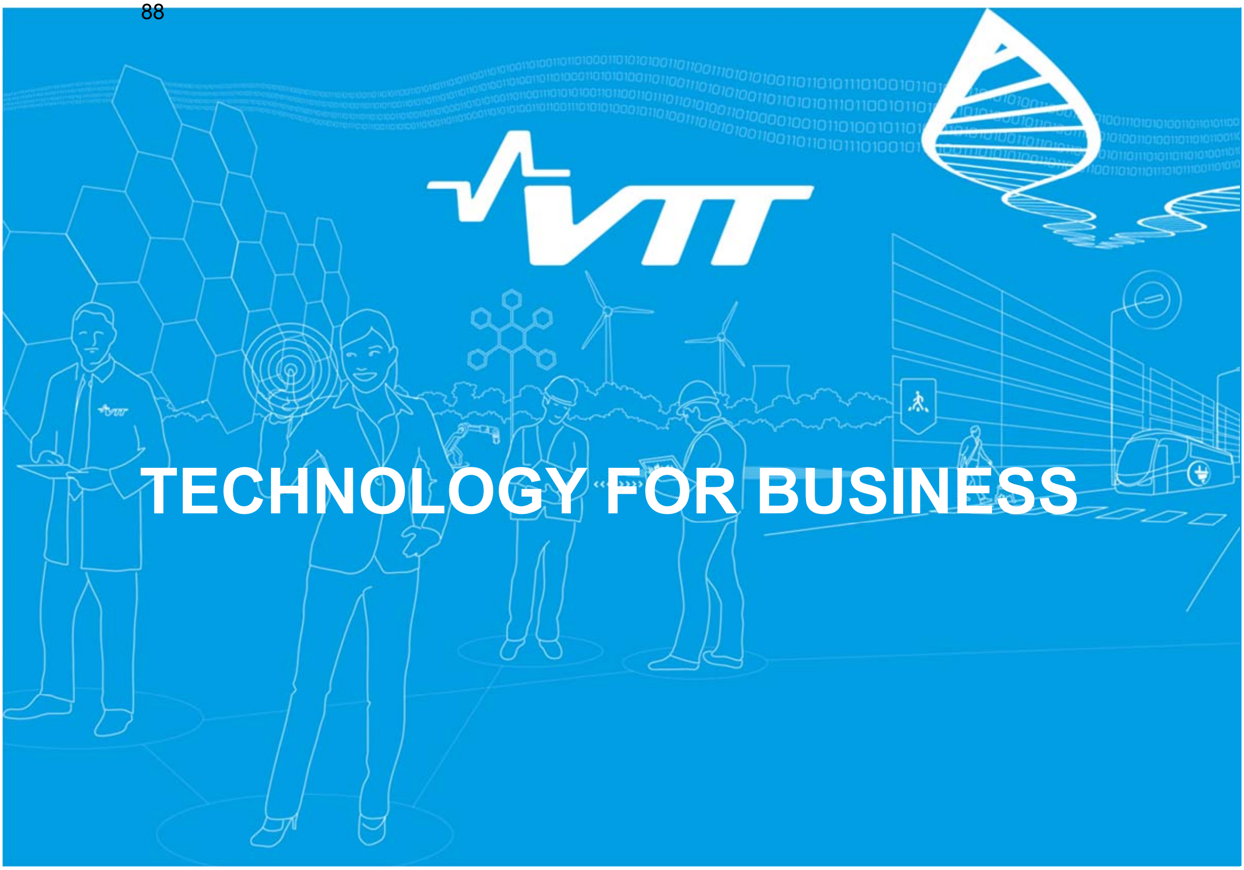
HYDROGEN: THE FUTURE FUEL FOR ZERO EMISSIONS?



Oliver Bishop/ General Manager, Hydrogen Shell Alternative Energies Shell/October 2014

Summary and conclusions

- Transport is currently 93 % dependent on oil
- On the world level, the most important alternatives for the time being are natural gas and biofuels, electricity in transport is still marginal
- In Europe, the use of biofuels has peaked, and the roll-out of EVs is rather slow
- EU has abandoned a mandatory target for renewable energy in transport in the 2030 climate and energy targets
- Alternative technologies are available (biofuels, gas, electric vehicles, even fuel cell vehicles coming up), but take-up is slow
- In fact, there seems to be a lack of energy and vehicle technology policies which could deliver a 30 - 40 % GHG emission reduction by 2030 and a 60 – 80 % reduction by 2050
- Finland and Sweden seem to be forerunners in introducing renewable energy in transport, with a focus on sustainable biofuels


TECHNOLOGY FOR BUSINESS

APUs for Road Vehicles, Ships, Trains and Aircrafts

Ralf Peters,
Forschungszentrum Jülich GmbH, Institute for Energy and Climate Research – Electrochemical Process Engineering (IEK-3)

Electricity generation in mobile applications such as trucks, ships, trains and aircraft is performed by internal combustion engines or turbines. Efficiency of these machines is rather low, i.e. less than 10 % during partial load for trucks and can increase up to 40 % for jet engines during their mission profile. Fuel cell based auxiliary power units (APU) offer advantages like reduced fuel consumption, low emissions and reduced noises. Especially for aircraft APUs their lower maintenance cost, the option of water production by fuel cells and the use of tail gases for tank inerting and fire clearing are interesting prospects to develop multifunctional systems. An important condition for their applicability is the use of the same fuel as for propulsion. An additional fuel leads to an extra tank compartment and a further filling procedure.

The presentation gives an overview about different reforming technologies and the status of APUs for road, maritime and airborne transport applications. The highest technology readiness level has been achieved for truck application. In recent years APUs are just tested as prototypes in real truck application. There is still a huge effort to perform before commercialization of these technologies will start.

The following comments on APUs can be stated:

- Fuel cell based APUs offer a variety of advantages depending on their application in mobile systems;
- Truck applications require more compact systems with reliable fuel processsing of commercial fuels;
- Maritime applications demand 500 kW_e systems at least and use today SOFC for demonstration projects;
- Mass balances for aircraft application prefer liquid hydrogen storage for short-range missions and JET A-1/ BtL reforming for long-range missions;
- Achievements in system development are necessary for the scale-up to the 100 kW_e power class, especially for fuel cell stacks and system cost.

Further information can be taken from [1-8].

Literature

[1] T. Grube, B. Höhlein, and R. Menzer, "Assessment of the application of fuel cell APUs and starter-generators to reduce automobile fuel consumption," *Fuel Cells,* vol. 7, pp. 128-134, 2005.

[2] K. Leites, A. Bauschulte, M. Dragon, S. Krummrich, and P. Nehter, "SchIBZ - Design of different diesel based fuel cell systems for seagoing vessels and their evaluation," *ECS Transactions,* vol. 42, pp. 49-58, 2012.

[3] N. Lutsey, C.-J. Brodrick, and T. Lipman, "Analysis of potential fuel consumption and emissions reductions from fuel cell auxiliary power units (APUs) in long-haul trucks," *Energy Policy,* vol. 32, pp. 2428-2438, 2007.

[4] J. Rechberger, A. Kaupert, C. Graae Greisen, J. Hagerskans, and L. Blum, "Fuel Cell Auxiliary Power Units for Heavy Duty Truck Anti-Idling," *SAE International journal of commercial vehicles,* vol. 6, pp. 555-562, 2013.

[5] R. Peters and R. C. Samsun, "Evaluation of multifunctional fuel cell systems in aviation using a multistep process analysis methodology," *Applied Energy,* vol. 111, pp. 46-63, 2013.

[6] R. Peters and A. Westenberger, "Large auxiliary power units for vessels and airplanes," in *Innovations in Fuel Cell Technologies*, R. Steinberger-Wilckens and W. Lehnert, Eds., ed Cambridge: The Royal Society of Chemistry, 2010, pp. 76-148.

[7] J. W. Pratt, L. E. Klebanoff, K. Munoz-Ramos, A. A. Akhil, D. B. Curgus, and B. L. Schenkman, "Proton exchange membrane fuel cells for electrical power generation on-board commercial airplanes," *Applied Energy,* vol. 101, pp. 776-796, 2013.

[8] R. Peters, "Auxiliary Power Units for Light-Duty Vehicles, Trucks, Ships and Airplanes," in *Hydrogen and Fuel Cells*, D. Stolten, Ed., ed Weinheim: Wiley-VCH Verlag, 2010, pp. 681-714.

APUs for Road Vehicles, Ships, Trains and Aircrafts

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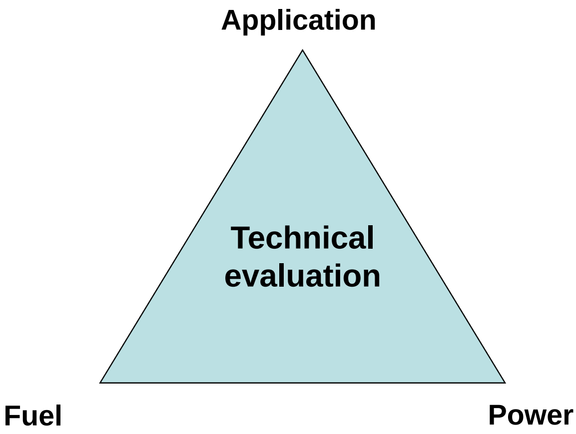
Forschungszentrum Jülich GmbH
Institute for Energy and Climate Research – Electrochemical Process Engineering (IEK-3)

TRENDS 2015
Transition to Renewable Energy Devices & Systems - Transportation Concepts
December 3-4, 2015, Aachen

Contents

- Motivation for fuel cell based APUs
- Reforming technologies
- Road application
- Maritime application
- Aircraft application
- Train application
- Summary

Motivation for fuel cell systems



APU: Auxiliary Power Unit

- Electric on-board power generation
- Fuelled by the same fuel as for propulsion

<u>In general:</u>

- Reduced fuel consumption
- Low emissions
- Reduced noises
- No/ low CO_2 emissions (H_2 as energy carrier for drive systems)

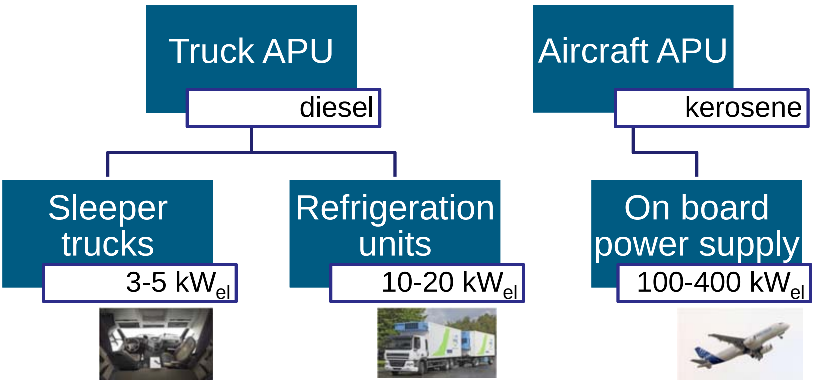
<u>Especially for light-duty vehicle APUs:</u>

- More comfort
- Extended safety measures

<u>Especially for aircraft APUs :</u>

- Lower maintenance cost
- Water production
- Use of tail gases for tank inerting
- Water injection in jet engines to decrease NO_x emissions

Potential applications of diesel or kerosene fueled APU systems



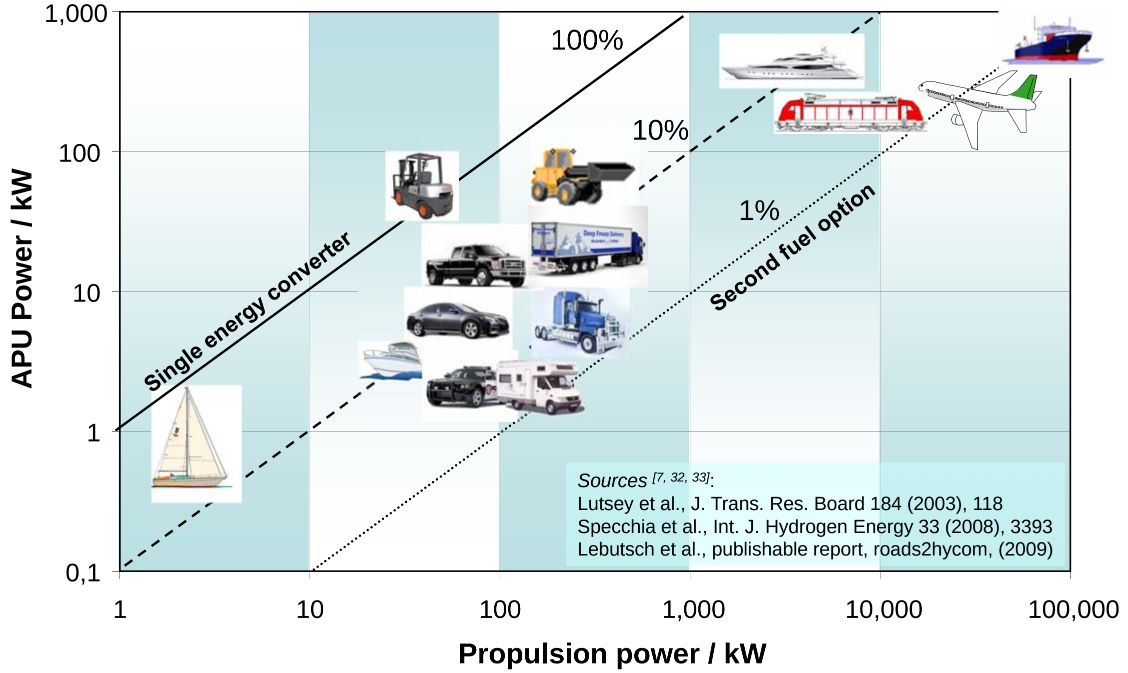
Targets for 1-10 $kW_{el.}$ fuel cell APUs (DOE)[1]	2013	2020
Electrical efficiency	30%	40%
Power density	30 W_{el}/l	40 W_{el}/l
Specific power	35 W_{el}/kg	45 W_{el}/kg

Targets for fuel cell APUs for aircraft [2]	
Electrical efficiency	40%
Power density	750 W_{el}/l
Specific power	500-1000 W_{el}/kg

[1] Revised APU Targets, DOE Program Record, Record #: 11001, 2010

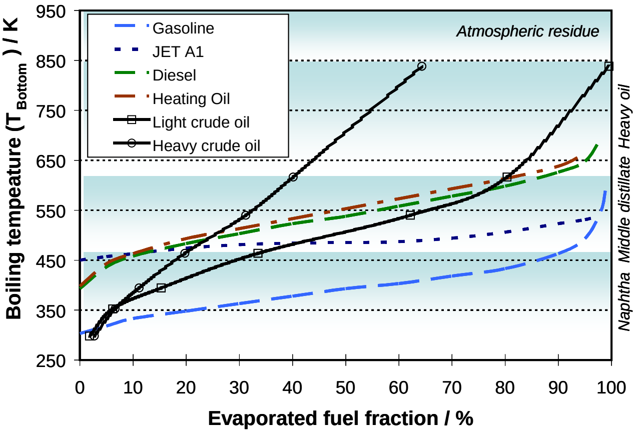
[2] R. Peters and A. Westenberger, in Innovations in Fuel Cell Technologies, Eds. R. Steinberger-Wilckens and W. Lehnert, RSC Energy and Environment Series No. 2, RSC 2010

Installed power class for different mobile applications



Commercial fuels for mobile applications

- Boiling behavior of different fuels

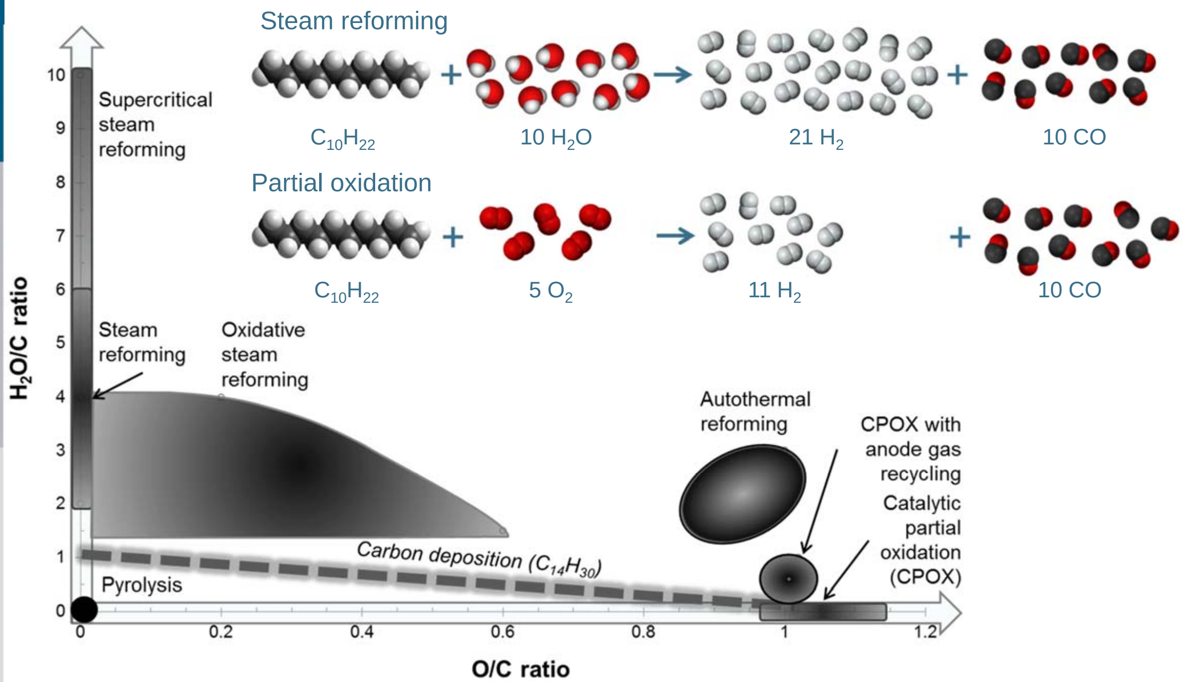


JET A-1: high sulfur content (3000 ppmw)

Diesel: wide boiling range low sulfur content (10 ppm)

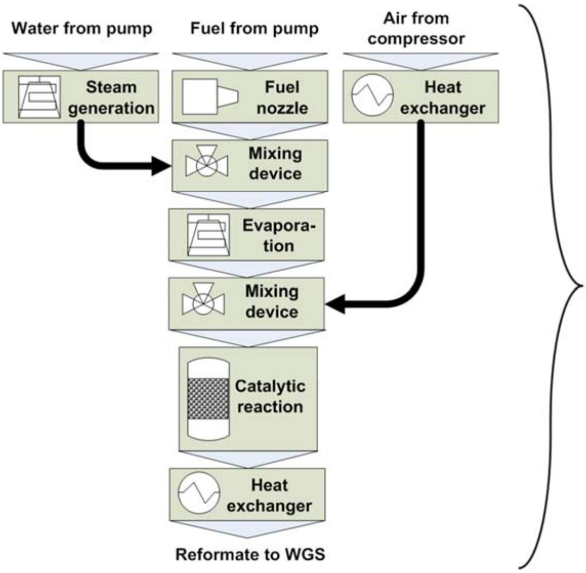
Marine gas oil: high boiling temperatures; high amount of evaporation residues high sulfur content; complexe moleculare structure of thiophenes and of aromatics

Classification of reforming processes



Component development

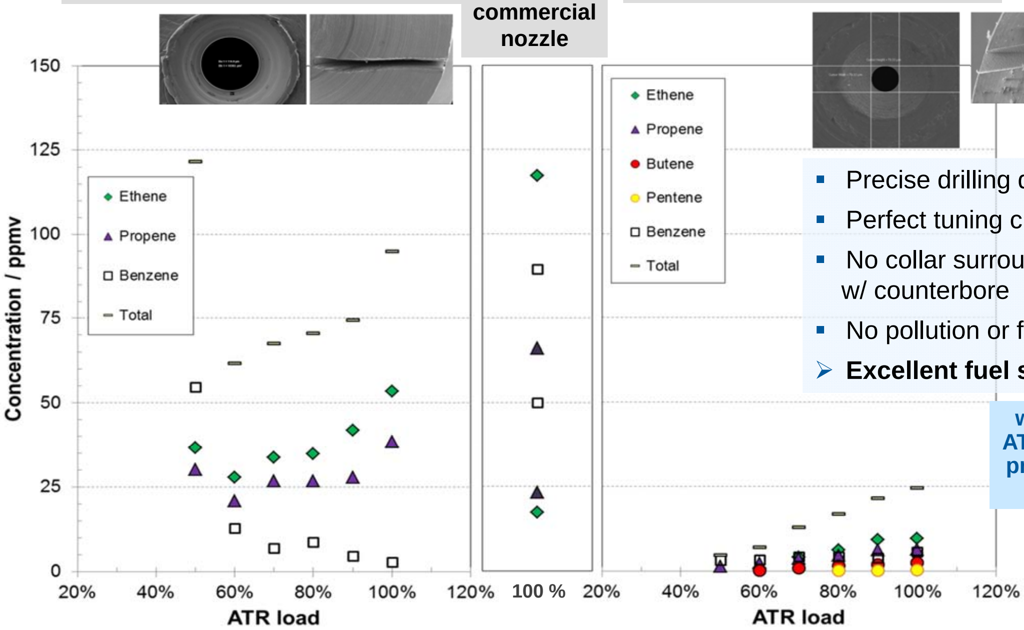
- High level of integration
- CFD-supported design
- Industrial manufacturing processes



zurück

Reforming of standard diesel quality

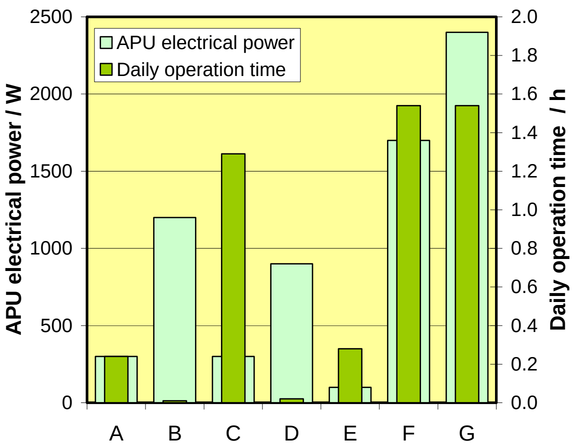
NExBTL diesel w/ commercial nozzle of bad quality | **Standard diesel w/ commercial nozzle** | **Standard diesel w/ own nozzle of high quality, d_{Nozzle} = 80 µm**



- Precise drilling diameter
- Perfect tuning channels
- No collar surround hole w/ counterbore
- No pollution or fats
- **Excellent fuel spray**

w/ improved ATR process: preheated air @ 300 °C

Conditions for APU truck application



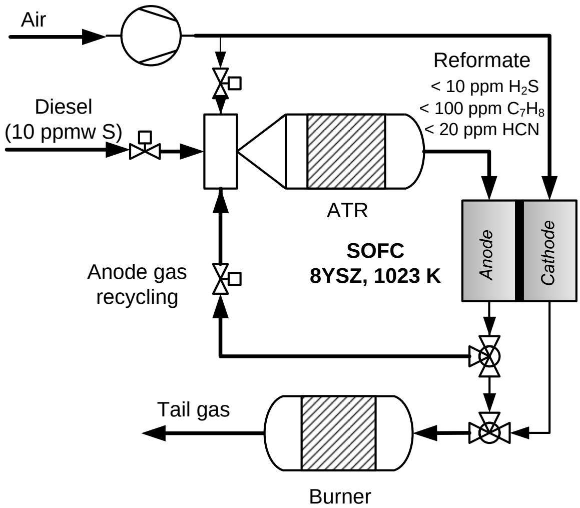
A: TV; B: Microwave;
C: Refrigator; D: Coffee machine
E: Electric blanket; F: Cabin cooling system;
G: Cabin heating system;

Sources [5, 7, 8, 14]: Sriramulu et al. presented at Fuel Cell Seminar (2004), San Antonio, U.S.A.; Lutsey et al. Transportation Research Record 1880 (2004), Jain et al. J. Power Sources 160 (2006) 474; Lim, H. (2002) Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices, EPA420-R-02- 025

- Different studies published with idling times, for example 1700 hr/yr; 6 hr/day at efficiencies between 9-11%
- ICE demands 3.5 ± 1.2 l/h leading to 6000 – 11000 l yr^{-1} $truck^{-1}$; SOFC-APU 0.57 ± 0.3 l/h
- Emissions lead to 0.29 t NO_x & 0.08 t HC & 0.1 t CO yr^{-1} $truck^{-1}$ and finally to in USA 6.8 Mio. t CO_2 and 0.19 Mio t NO_X per year
- Existence of competing systems, mainly ICE-based APUs with 5 – 7 kW_e at an efficiency between 20 - 30%
- Jan. 2007: California Code of Regulation, § 2485 bans truck idling and ICE-based APUs for more than 5 min. (from class 3 up, i.e. 4.5 t truck weight)
- Economic pay-back time should by 2 years depending mainly on diesel prices

System development for truck application

Example: flow sheet of a SOFC APU system



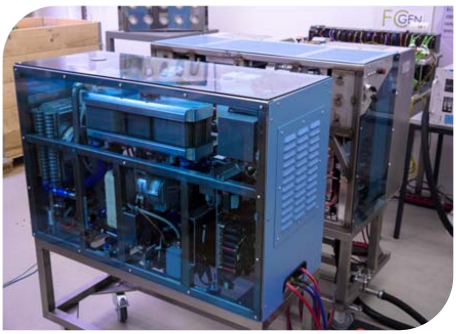
SOFC APU system by Delphi

DPS3000-D
244 l, 150 kg
3 – 3.5 kW$_e$ net
Operated at
-40 - 60°C
Sleeper cabs:
28 hr/ week
1456 hr/yr
Day cabs:
6 hr/ week
312 hr/ yr

Partners: PACCAR,
Volvo Trucks North America, Electricore

Sources [93, 95]:
Blake, G.D., presented at DOE Peer Review 2008, http://www.hydrogen.energy.gov/pdfs/review08/fc_44_blake.pdf (16 November 2009);
Kerr, R. (2009) presented at 2009 SECA Annual Meeting, 14-16 June 2009, Pittsburgh, PA, USA

3 kW$_e$ Auxiliary Power Unit combining PEFC stacks with Jülich's reforming technology



FCGEN – EU funded project:

- 7 partners incl. VOLVO, Powercell, IMM, JSI
- Design, develop, integrate and demonstrate a proof-of-concept diesel-powered PEM fuel cell based 3 kW$_e$ APU in the laboratory

- **Fuel processing demonstration**
- **APU integration**
- **Successfully complete system testing**


Contribution IEK-3:

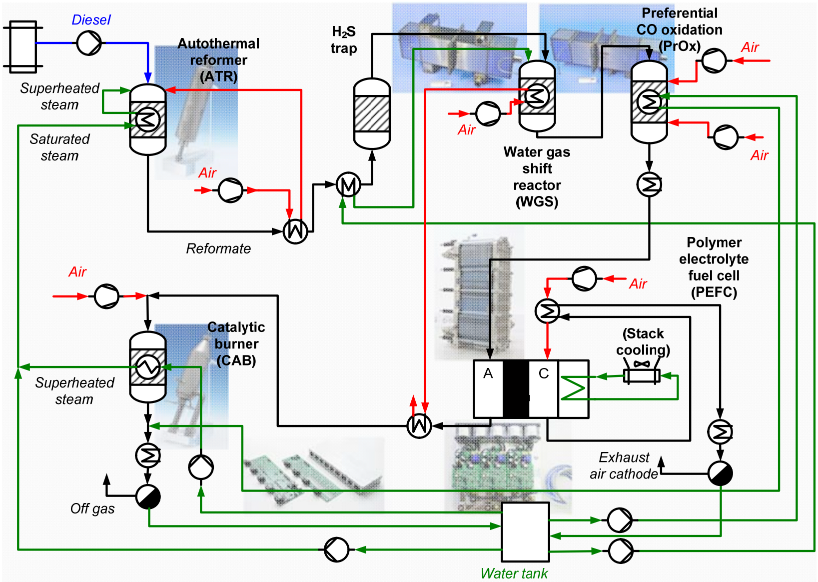
- ATR with improved nozzle technology (with 80 µm injection hole drilled by ZEA-1) produces adequate reformate quality for PEFC using standard truck diesel
- CAB designed and tested for low emission combustion and steam generation during standard operation and for combustion of reformate during by-pass mode

PEFC system architecture

Objective: Develop and demonstrate a proof-of-concept complete fuel cell auxiliary unit in a real application, on-board a truck

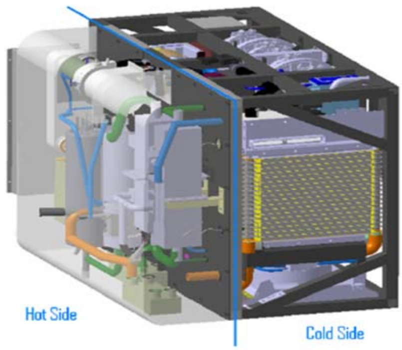
Project partners:

Fraunhofer ICT – IMM
Johnson Matthey
Institut "Jožef Stefan" Ljubljana, Slovenia
JÜLICH FORSCHUNGSZENTRUM
Modelon
POWERCELL
VOLVO



BoP optimization and system integration

- Market screening, purchasing and testing of BoP sub-system (air, coolant, and process water) components.
- Development of a CAD system packaging. The compact APU box consists of a hot side part for FP reactors and a cold side part for FC sub-system and BoP components.



PEFC system: simulation results

Simulation parameters and specifications:

Electrical power output: **4.5 kW**

Fuel: **$C_{13.4}H_{24.7}$**
Fuel flow rate: **1222 g/h**
ATR parameters: $n(O_2)/n(C)$=**0.47**
$n(H_2O)/n(C)$=**1.9**

Average cell voltage at full load: **633 mV**
Hydrogen utilization in the stack: **80%**

Air ratio catalytic burner: **1.05**

Key results from system simulation:

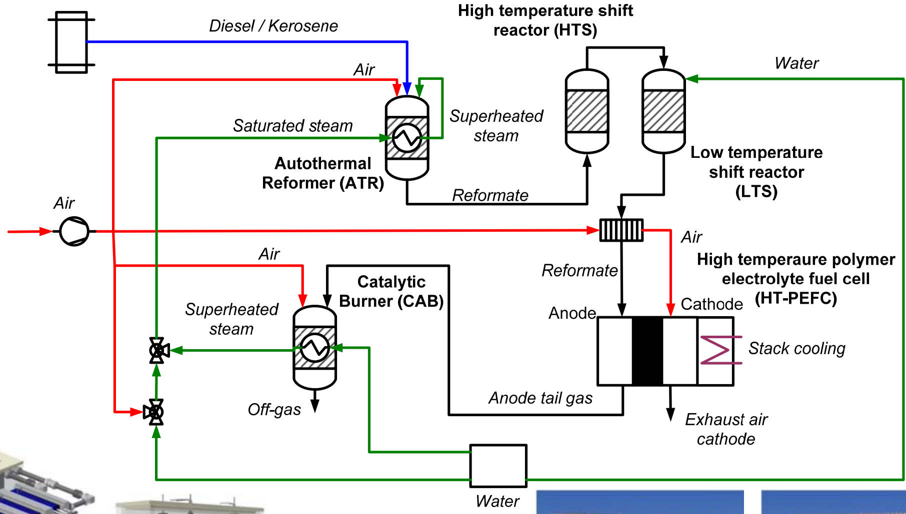
System efficiency for gross power production: **31%**

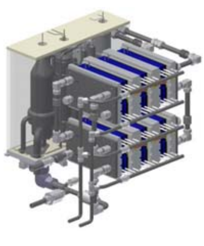
Net system efficiency:

Case 1: 28.4 %
(η_{is}=60% for blowers and compressors,
η=75% for pumps)

Case 2: 25.8 %
(η_{is}=20% for blowers,
η_{is}=50% for compressors,
η=75% for pumps)

HT-PEFC system: Integrated system architecture and design





HT-PEFC system: simulation results

Simulation parameters and specifications:

Electrical power output: **5 kW**

Fuel: $\mathbf{C_{17}H_{36}}$
Fuel flow rate: **1718 g/h**
ATR parameters: $n(O_2)/n(C)$=**0.47**
$n(H_2O)/n(C)$=**1.9**

Average cell voltage at full load: **461 mV**
Hydrogen utilization in the stack: **83%**

Air ratio catalytic burner: **1.05**

Key results from system simulation:

System efficiency for gross power production: **24%**

Net system efficiency:

Case 1: 22.2%
(η_{is}=60% for blowers and compressors,
η=75% for pumps)

Case 2: 21%
(η_{is}=20% for blowers,
η_{is}=50% for compressors,
η=75% for pumps)

Current status of truck APU

PEFC

Powerpack Transportation
250 l, 150 kg
3 kW_e net
Start-up in 10 min.
10,000 h
> 1000 start/ stop
Operated at
-25 - 45°C

SOFC

System development for refrigeration trucks

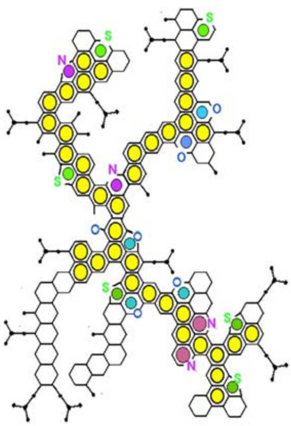
Specification	10-15 kW Diesel APU
Operation time (h)	20000-40000
Efficiency	> 35% (40%)
Mass (kg)	300 (80)*
Volume (l)	400 (90)*
Noise (7 m)	45 db(A)
Start-up (cold)	< 15min
Start-up energy	Max. 1 kW_{el}
Start-up (Stand-by)	< 30 sec.
Temperature range	-40 – 80°C
Load range	20-120%

Target	midterm	longterm
Power density per volume	33 W_{el}/l	190 W_{el}/l
per mass	25 W_{el}/kg	170 W_{el}/kg

⇒ More challenging related to DOE-targets

Fuels for maritime applications

No.1 is similar to kerosene
No.2 road diesel- the same fuel as heating oil.
No.4 is usually a blend of distillate fuel oils and residual fuel oils, No.2 & No.6; marine diesel fuel up to 15 % residual process streams up to 5 % PAHC
No.5/ No.6 residual fuel oils or heavy fuel oils. No.6 is fed by heavy fuel oils and residues from distillation steps after cracking and from vacuum distillation. It contains about 15 % paraffins, 45 % naphthenes, 25 % aromatics, and 15 % non-hydrocarbon species HCs with 30 and more carbon atoms.



Asphaltenes consist primarly of C, H_2, N_2, O_2 and S as well as trace amounts of metals such as V and Ni.

DIN 51595: insoluble in 30-fold amount of heptane at 18 – 25 °C; remaining liquid: maltene

Asphaltenes cause high viscosity and high density of heavy oils

Alternative fuels for shipping

Low sulfur diesel
- \+ commercial fuel
- \+ no system change
- \- higher costs
- \- not covered by regulations

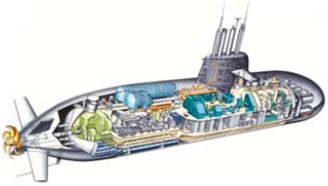
HVO/ BTL etc.
- \+ simplified exhaust gas cleaning
- \- higher costs
- \- not covered by regulations

Methane
- \+ no exhaust gas cleaning
- \+ reduced maintance
- o lower costs
- \- complex safety issues
- \- high investment

Alcohols
- \+ emission reduction
- \+ fair supply structure
- o lower costs
- \- toxic

Fuels cells for maritime applications

Propulsion systems with PEFC for:



Submarines;
H_2/ O_2 stacks
HDW

Tourist sight seeing boats;
H_2/ air stacks; 2 x 48 kW_e
Proton Motors

Ferry to Spiekeroog;
H_2/ air stacks ; 240 kW_e
Proton Motors

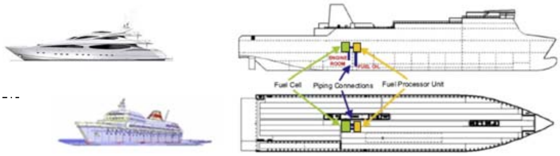
Small APU systems for sail and leisure boats:

DMFC stack; 50 W_e
Smart Fuel Cells

PEFC stack with LPG
reforming; 300 W_e, ZBT

Large APU systems for mega yachts and cruising vessels:

MCFC from MTU onsite energy & Ansaldo Fuel Cells



Source [31]: Bensaid et al., Int. J. Hydrogen Energy 34 (2009), 2026

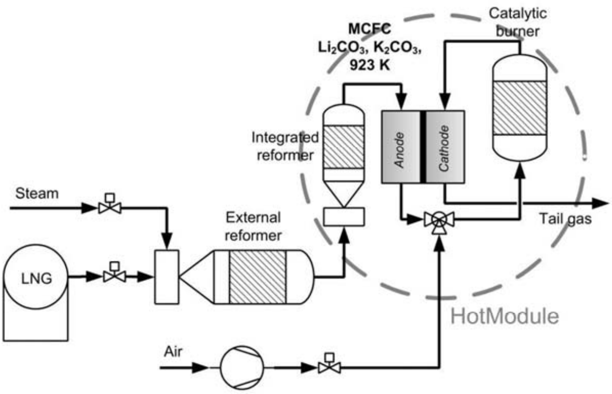
Competing diesel generators:
- **Sufficient efficiency ~37%**
- **High emissions**
- **High noise level**

} Restrictions for APU operation

Benefits for FC-APU:
- **Low emissions**
- **Low noises**
- **Less restrictions**

System development for maritime applications with MCFC

Simplified process flow sheet for a MCFC system with LNG reforming by mtu onsite energy



MCFC APU system by MTU onsite energy

320 kW_e

Reduction of
4755 t CO_2 / yr
180 t NO_x / yr
33 t SO_2 / yr

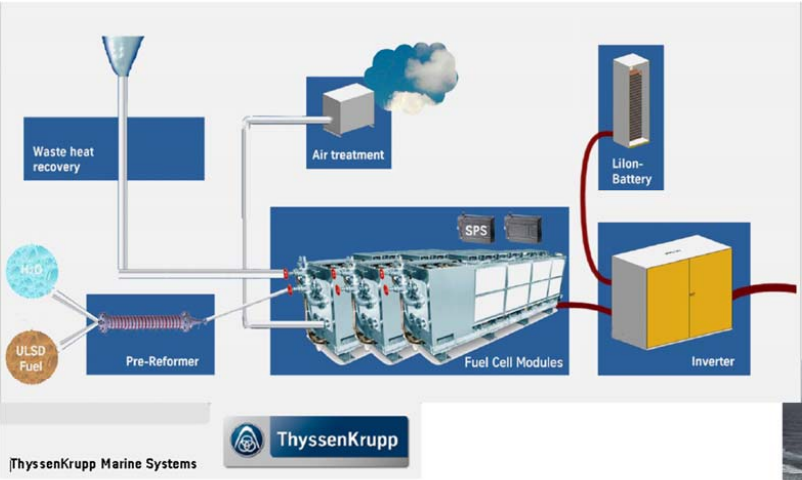
Projects:
- Fellowship: Off-shore testing on the supply ship “Viking Lady“, since September 2009
- e4ships: MCFC on a passenger vessel (“PaXell“) & on a mega yacht (“SchIBZ“)

Sources: Hotstrøm, MTU-Report 03/09, p.23-27, http://www.mtu-online.com/fileadmin/fm-dam/mtu-global/pdf/mtureport/0903/0903_MTU-Report_Hotstrom.pdf , (18 January 2010); Bordstromversorgung für Schiffe – das HotModule lernt schwimmen, BWK (2009), 61, 11, 20-21.

System development for maritime applications with SOFC

Project:

- SchIBZ Fuel cells and fuel strategy for seagoing vessels
- Steam reforming combined with SOFC



Source: Keno Leites, ZTF, presented at HVO Expierence Day, 16.10.2015

Objectives:

- 500 kW_e output
- High efficiency: > 50 %
- Road diesel (15 ppmw S) or XtL, optional LNG
- Operation time > 20,000 h MTBO
- Thermal integration
- Approvable design

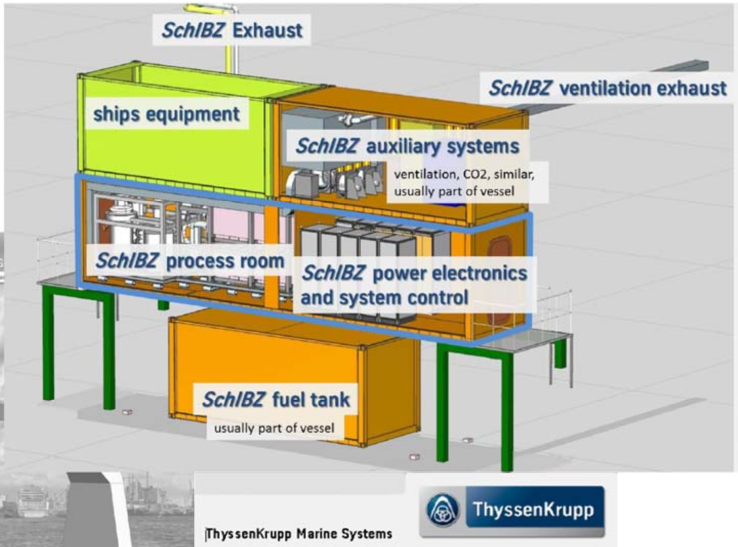
Conditions:

- Verified components
- Marinization

Current status of ship APU

SchIBZ **:**

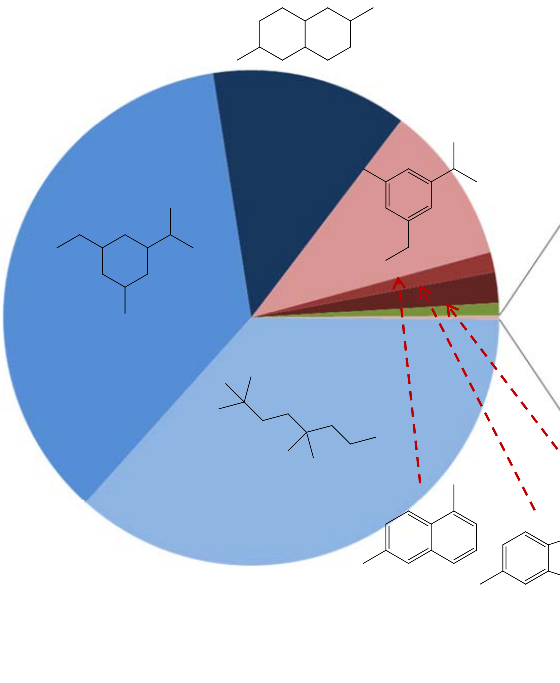
- Demonstration of a 50 – 100 kW_e system

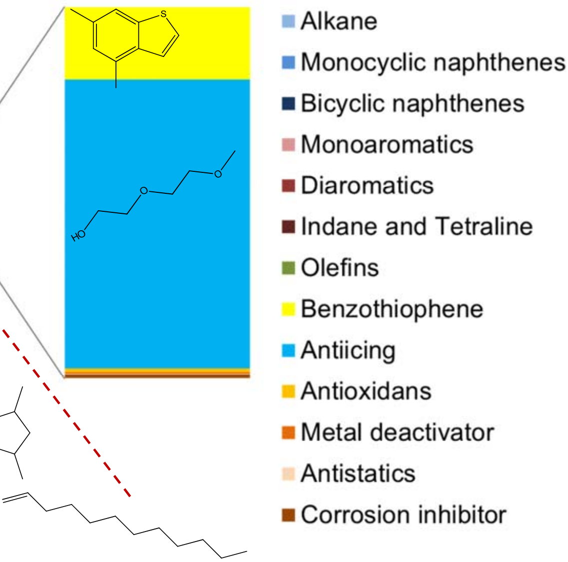


Source: Keno Leites, ZTF, presented at HVO Expierence Day, 16.10.2015

Chemical composition of Jet fuels

Synthetic fuel:	Alkanes/ isoalkanes min. 8% aromatics **minimum oxgyen content** sulphur << 10 ppmw





Auxiliary Power Unit for aircraft

Electrical, Hydraulic and Bleed Air Power (kW)	Main Engines	APU	RAT	Battery
	~ 1000	~ 550 (ground)	~ 25	~ 3

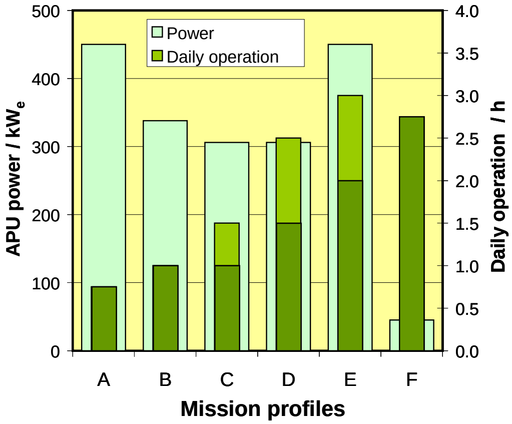
Source: V. Hiebel at 2nd Annual Event of H_2&FC Technological Platform, Brussels 17th to 18th March 2005

Conditions for APU aircraft application

3 - 5 short range missions / day of 926 - 1852 km

450 kW_e APU ⇒ **1500 – 3400 kWh / day at η_{APU} = 20%** ⇐ **Conventional use of APU**

Multifunctional use of APU



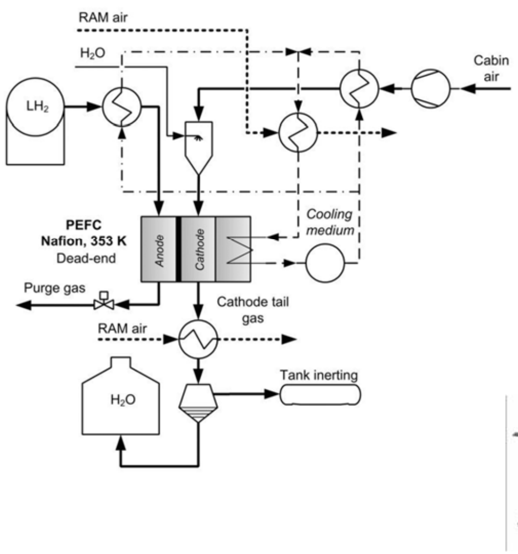
A: Cabin pull down; B: Sustain cool cabin;
C: Passenger unload; D: Service
E: Passanger load; F: Flight overnight maintance;
without MES main engine start: 200 – 400 kW_e

Sources [39, 40]: Gummalla, M. et al., NASA/CR- 2006- 214457/VOL1; Srinivasan, H. et al., NASA/CR- 2006- 214458/VOL1

- Water production: 0.26 l/(kW_e h), i.e. 105 l/h for 400 kW_e
- Tank inerting depends on mission profile & aircraft tank size, for example max. 7.7 m³ / min for 182 m³ with oxygen content less than 12 % (vol.) during the decent phase (30 – 40 min.)
- Anti-ice measures demands about 400 – 500 kW for 5 min. during climbing and 20 min. during descent

Fuel cell concept for aircraft APU based on liquid H_2

PEFC with liquid hydrogen as energy carrier (switch to HT-PEFC)



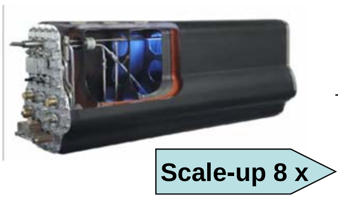
<u>Advantages for H_2 operation:</u>

- Higher efficiencies 38 - 55 % (dead-end)
- Less complex system architecture, especially for HT-PEFC (without humidification as for PEFC)

<u>Multifunctional use:</u>

- Water production of 0.3 - 0.5 l/ (kW_e h)
- Oxygen content of 11 % at λ = 2 in the cathode off-gas
- N_2 rich gas of about 4.3 m^3_N/ min/ 100 kW_e
- Residual heat is limited (Pinch-Point): 50 kW_{th} at 260 kW_e (HT-PEFC: 1 kW_{th}/kW_e)

<u>Challenge:</u> Hydrogen storage



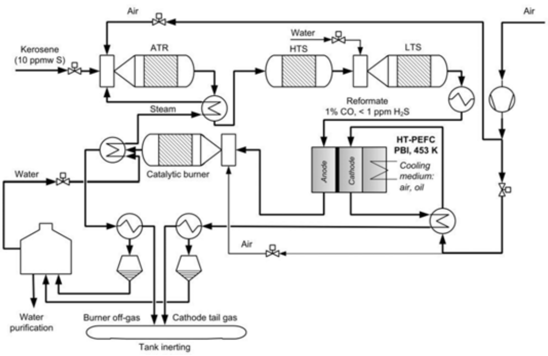
Scale-up 8 x

Mass specific density:
5.6 kg_{System}/ kg_{LH2}
Power density:
1.6 l_{System}/ l_{LH2}
3 h mission à 1130 kW_eh
1.27 m³; 440 kg LH2-Tank

Sources: Hydrogen storage systems for automotive applications, Publishable final activity report, (2008), European Commission, Project No. 502667

Fuel cell concepts for aircraft APU based on JET A-1 and BtL

HT- PEFC system with low sulfur JET A-1 as energy carrier (switch to BtL)

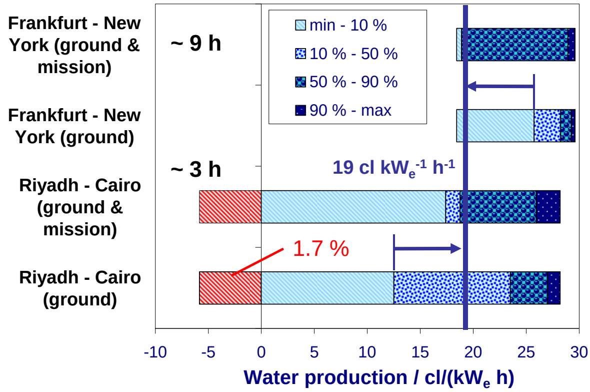


Advantages for JET A-1 operation:

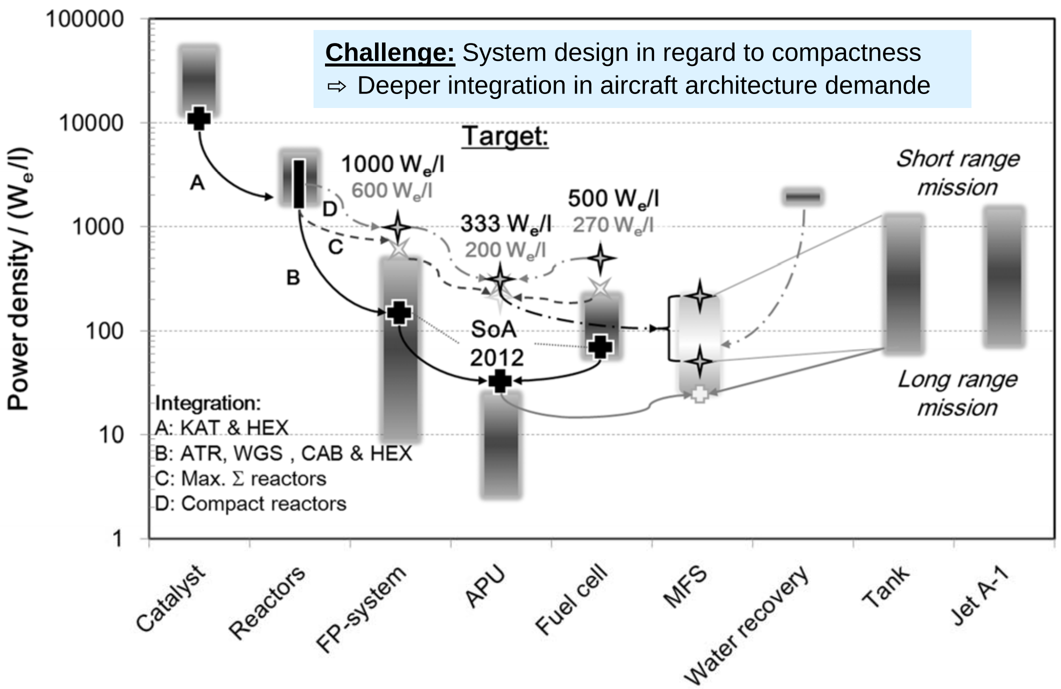
- Simple storage system
- All items of a multifunctional use are fulfilled

Multifunctional use:

- Higher efficiencies 28 - 38.5%
- Oxygen content of 11 % at λ = 2 in the cathode and 1.5 % in the anode off-gas
- N_2 rich gas of about 7 m^3_N/ min/ 100 kW_e
- Residual heat (Pinch-Point): 1.25 kW_{th}/kW_e
  $\Rightarrow$ 425 kW_{th} (340 kW_e) for anti-icing
  $\Rightarrow$ 7.7 m^3_N/h (110 kW_e) for tank inerting
- Water production of 0.2 - 0.27 l/ (kW_e h):



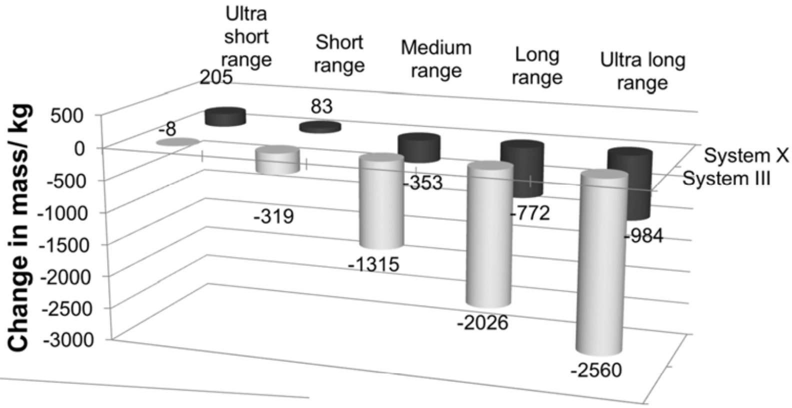
Further development of fuel cell concepts for aircraft APU

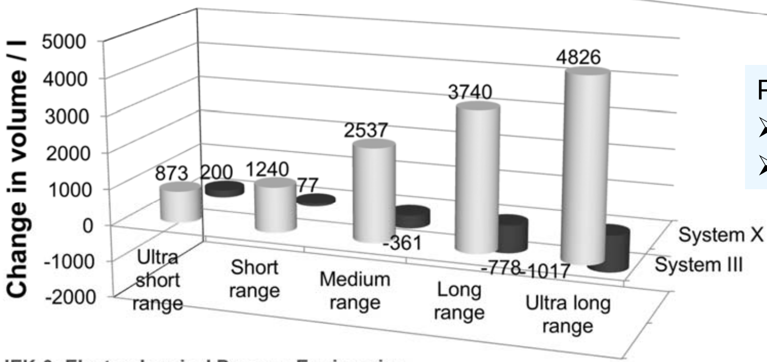


Choice of fuel for aircraft APU

System III:
PEFC system w/ **1 kg_{System}/ kW_e**
with LH2 tank w/ **5.6 kg_{System}/ kg_{LH2}**

System X:
HT-PEFC system
w/ **1 kg_{System}/ kW_e**
Fuel processing
w/ **1.3 kg_{System}/ kW_e**
with Jet A1 tank
w/ **1.4 kg_{System}/ kg_{LH2}**

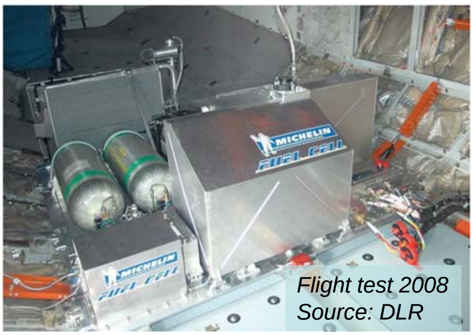




Final system design:
- ➢ Long range prefers JET A1
- ➢ Short range prefers LH2

Current status of aircraft APU

Hydrogen based PEFC systems



Flight test 2008
Source: DLR

Focus on multifunctionality
- ➢ Replacement of RAM Turbine
- ➢ Water recovery and grey water treatment
- ➢ Flight test with A 320 (DLR)
- ➢ PEFC test at low pressures (0.2 – 1 bar)
- ➢ Use for tank inerting system
- ➢ Nose-wheel drive (DLR)

Kerosene based HT-PEFC systems

ATR 50 kW_e

WGS 50 kW_e

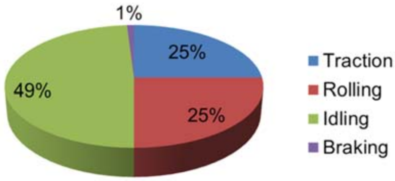
Focus on R & D (2003-2012)
- ➢ CFD supported fuel processor design
- ➢ Long-term test for 5000 hours w/ GTL-kero.
- ➢ Up-scale of ATR/ WGS on 50 kW_e
- ➢ HT-PEFC stack development for 5 kW_e
- ➢ Integrated HT-PEFC system for 5 kW_e
- ➢ Verified desulfurization process for jet fuels

Auxiliary Power Unit for trains

25-100 kW_{el}

Technical data

- ➢ Total weight: 80 t
- ➢ Engine power: 1500 kW
- ➢ Maximum speed: 100 km/h
- ➢ Operation profile



- ◆ Growing interests (project initiative Horizon 2020)
- ◆ Competing ICE technology

Evaluation of different system technologies

	SOFC / CPOX	SOFC/ ATR	HT-PEFC / ATR	PEFC / ATR
Efficiency	+	+(+)	-	O
Power density (volume/ mass)	-	-	O	-
Load change	-	-	O	+
Start-up	-	-	+	-
Degradation/ tolerance impurities	-	-	+	-
Operation time	O	O	O	O
System complexity	+	+	O	-
Challenges	C-deposition Thermomechanics	Thermomechanics	Electrochemistry Power density	Poisoning Operation time Membrane
Competition	high	medium	low	1 EU-Projekt

Summary

- Fuel cell based APUs offer a variety of advantages depending on their application in mobile systems
- Truck applications require more compact systems with reliable fuel processsing of commercial fuels
- Maritime applications demand 500 kW_e systems at least and use today SOFC for demonstration projects
- Mass balances for aircraft application prefer liquid hydrogen storage for short-range missions and JET A-1/ BtL reforming for long-range missions
- Achievements in system development are necessary for the scale-up to the 100 kW_e power class, especially for fuel cell stacks and system cost

Transition to Renewable Energy Devices & Systems – Transportation Concepts

Andreas Pastowski,
Wuppertal Institute

Dercarbonizing transport systems is somewhat tricky because -opposed to stationary energy use- vehicles typically reqire energy at different locations during operation. On high frequency routes it might make sense to invest in electricity grids and current collectors. However with road vehicles, ships or aircraft this may be cumbersome and costly if at all possible.

Thus decarbonizing transport energy use is not mainly about the primary production of renewable energy for transport purposes but about how renewable elecriticity or hydrogen may be delivered to and stored on board of vehicles. Moreover, it needs to deal with how the transition from ubiquitous transport modes that traditionally depend on fossil fuels can be started and stremalined. While there is no single switch that allows to make this happen, numerous game changing innovations are required.

Such innovations often need to start like islands of change at a limited spatial scale. They do not only require innovative strength in terms of technologies involved but also regarding smart applications and business models. This presentation does not pretend to be complete in term of the innovation required but is intended to provide some food for thought beyond traditional thinking.

Wuppertal Institute
for Climate, Environment and Energy

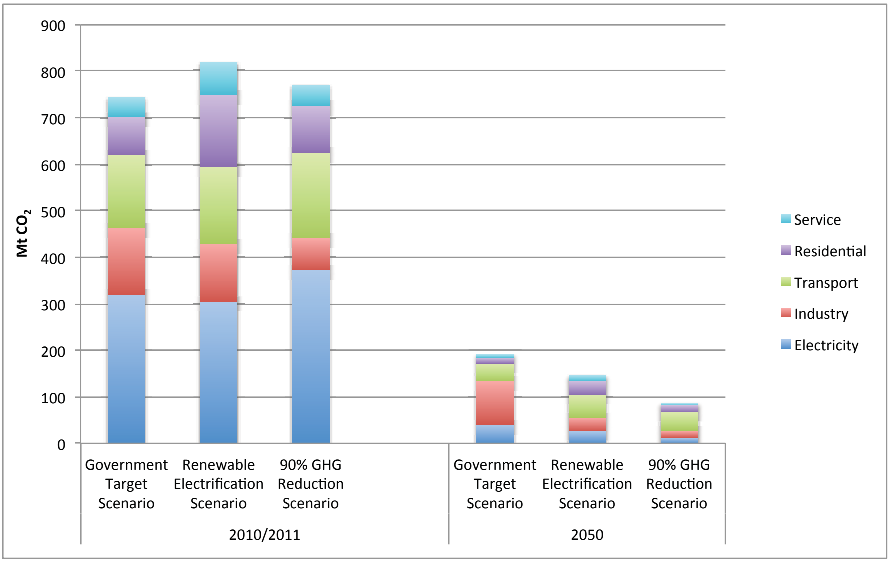
Research Group 1

Future Energy and Mobility Structures

Transportation Concepts
Andreas Pastowski

Trends 2015 Transition to Renewable Energy Devices & Systems – Transportation Concepts
Aachen December 3-4 2015

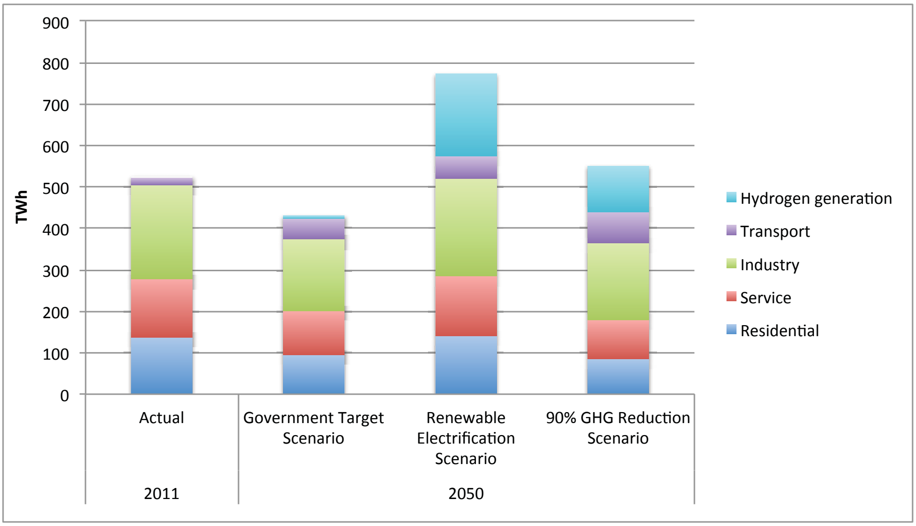
Transportation Concepts GHG from Transport in 2050?



Energy-related CO2 emissions by sector in 2010/2011 and 2050 for Germany
Hillebrandt, K. et al. (2015). Pathways to deep decarbonization in Germany, SDSN - IDDRI

Transportation Concepts

Transport Electricity in 2050?



Electricity use by sector in major scenarios for Germany (including electricity for hydrogen)
Hillebrandt, K. et al. (2015). Pathways to deep decarbonization in Germany, SDSN - IDDRI

Transportation Concepts

What Kind of Transition?

- 1 The reduction of GHG emissions necessary is massive and revolutionary
- 2 This amount of change requires disruptive technologies
- 3 If technology pull is insufficient, regulation and incentives will need to push technology
- 4 It is not all about technology
- 5 A conducive set-up is required for the various applications and actors involved

Transportation Concepts — How Many Transitions?

- 1 There is not one transport system but multiple systems
- 2 Passenger and freight transport serve different purposes and require tailor-made solutions for each mode
- 3 The various modes of transport have different properties and solutions will need to be a good match for those
- 4 The low-hanging fruits are modes with electric traction under a power line
- 5 Various game changers will be required to deal with the multitude of transitions

Transportation Concepts — What is a Game Changer?

- 1 The rules of a game may require to be changed (climate change)
- 2 The technology involved in a game may change and offer new solutions
- 3 The strategy of a team may change and create new opportunities
- 4 The cooperation within a team may change and provide more options

Benefits of the >Energiewende<

- **Challenges**
  GHG emissions associated with transport-related electricity use of electric modes
- **(Potential) Game Changer**
  Phasing in of higher shares of renewable electricity
- **Key Factors**
  GHG-balance of electrified modes gradually improves, photovoltaics on buildings and certified renewable electricity may further increase production capacity
- **Main Actors**
  Operators of public and private vehicles with an overhead line or similar systems

Low Cost Fuel Cell Production

- **Challenges**
  Fuel cells are still way too costly components for competitive vehicles
- **(Potential) Game Changer**
  Lower mass of platinum per unit, mass production versus laboratory design
- **Key Factors**
  Reduced material and production cost per unit
- **Main Actors**
  Research and fuel cell producers

Hydrogen-powered Trams from China

- **Challenges**
  Urban air pollution, 1,200 miles of new tram tracks in China within 5 years
- **(Potential) Game Changer**
  Tram with FC and onboard H_2 versus traditional systems
- **Key Factors**
  TCO of trams with overhead line versus onboard FC and H_2
- **Main Actors**
  Qingdao Sifang Co., Ballard Power Systems, Chinese Government

Highways with Overhead Lines?

- **Challenges**
  Decarbonising road freight versus energy density of H_2
- **(Potential) Game Changer**
  Direct connection to the grid for hybrid trucks on motorways
- **Key Factors**
  Cost of overhead lines versus those of onboard systems, payload and energy density with onboard energy
- **Main Actors**
  Grid operators, vehicle manufacturers, vehicle users

Vehicles to Grid

- **Challenges**
  Increasing volatility of electricity production results from growing shares of photovoltaics and wind power
- **(Potential) Game Changer**
  H_2 and fuel cells in vehicles as buffers for stabilising the grid
- **Key Factors**
  Diurnal variation of renewable electricity production, timing of vehicle use and grid connection
- **Main Actors**
  Grid operators, employers, vehicle users

Combined Business Models

- **Challenges**
  Limited turnover of early H_2 filling stations
- **(Potential) Game Changer**
  Dispensing and on-site H_2 production combined with an increased buffer and a fuel cell for grid services
- **Key Factors**
  Increased turnover from complementary business models
- **Main Actors**
  Industrial gas companies (Air Liquide, Linde Gas etc.)

Fleet Operation as an Incubator

- **Challenges**
  Average vehicle range scales up costly fuel cells, H_2 tanks or batteries
- **(Potential) Game Changer**
  Focus of early implementation on urban fleets with limited daily mileage
- **Key Factors**
  Downsizing of costly components, lower unit cost of fuel supply and maintenance
- **Main Actors**
  Fleet operators with relatively low daily mileage per vehicle

Second Life for Vehicle Batteries

- **Challenges**
  Relatively short-lived batteries for vehicles may still be good for stationary use which allows to reduce cost and material intensity of deployment
- **(Potential) Game Changer**
  Using former vehicle batteries as stationary buffers for electricity
- **Key Factors**
  Cost and resource use for mobile and stationary buffers can be reduced
- **Main Actors**
  Grid operators, vehicle manufacturers, vehicle users (Getec, Remondis)

Transportation Concepts

What is the Bottom Line?

- 1 Game changers may primarily be technology driven, provided the technologies are disruptive
- 2 However technologies and their development stages may need fruitful niches of application as well as conducive frameworks and business models
- 3 Climate change requires regulations to make traditional systems look dated, inconvenient and costly
- 4 Market prices don’t tell the environmental truth and there is way to much cheap carbon
- 5 The transition of transport systems towards low carbon designs requires mode-specific pathways as far as those don’t operate under a power line

Wuppertal Institute
for Climate, Environment
and Energy

Thank you for your attention!

Power Electronics in View of Transportation Concepts

Rik W. De Doncker,
Institut für Stromrichtertechnik und Elektrische Antriebe (ISEA), RWTH Aachen
Institute for Power Generation and Storage Systems E.ON ERC|PGS, RWTH Aachen

The cost of power electronic converters (currently based on silicon devices) has fallen rapidly over the past ten years. It is expected that inverters for motor drive in electric vehicles will drop from current prices in the order of 20 €/kVA down to 5 €/kVA. Key to cost reduction is the strong integration of control electronics, power semiconductors and passive components. Furthermore, wide bandgap materials (GaN, SiC) are becoming available that allow a tenfold increase of switching frequency is promising. Higher switching frequencies reduce size of passive components (inductors, transformers, capacitors, filters). To fully utilize the potential of these wide bandgap materials high temperature packages are needed. This would allow designs with higher power densities, i.e. less weight and volume, which is advantageous in mobile applications.

Another aspect that deserves attention is the interoperability between electric vehicles and the distribution grid. Highly efficient chargers (dc-to-dc converters) are needed. The industry is investigating the use of conductive, as well as inductive chargers. Trends are to develop inductive chargers at 85 kHz with air gaps as large as 15 cm. The use of dc technology will find its place in homes an buildings as they become prosumers (using PV systems). In such an environment a (fast) dc charging system can be deployed.

Modular designs of electric vehicle propulsion systems and modular low-voltage batteries are drawing the attention of OEMs (for example, the AUDI Q6 will implement the e-tron concept, developed at RWTH within the e-performance project). These power electronic concepts, that are integrated in the battery to form a so-called “smart battery”, are directly compatible with low-voltage dc bus systems that are proposed in homes and buildings. Consequently, these concepts provide higher efficiency, enable flexible demand side management and extend the life of Li-Ion batteries.

Fast charging could be offered by the electric grid of many public transportation systems (trams, trolley buses, etc), which operate at 750 Vdc. These grids offer high power capacities that are typically used only up to 12 %.

Summarizing, one can state that the electrification of the transportation sector, in all areas, is progressing at a higher pace due to innovation and cost reduction of power electronic systems.

Power Electronics in View of Transportation Concepts

TRENDS 2015

04.12.2015

Univ.-Prof. Dr. ir. Dr. h. c. Rik W. De Doncker

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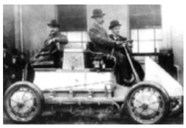
Development of Electrical Transportation Systems

- **1881: First electric car with rechargeable battery**
  - Gustave Trouvé builds three wheeled electric car
  - Ayrton and Perry build first roadworthy electric car
- **1899: "La Jamais Contente" ("The never satisfied")**
  - Designed by Camille Jenatzy
  - First car to go faster than 100 km/h
- **1900: Lohner-Porsche**
  - Range: 50 km
  - Top speed: 50 km/h
- …



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Quelle:
Scribner's Magazin, 1910

Development of Electrical Transportation Systems

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- **1900: Lohner-Porsche**
  - Range: 50 km
  - Top speed: 50 km/h
- …
- **Today:**
  - More than one billion cars worldwide
  - More than 20 % of worldwide CO_2 emissions are attributed to the transport sector

Outline

- Current development trend in Germany
- Drive-train concepts
- New semiconductor devices - Enriching possibilities
- Low-voltage concepts
- DC-grids and Electromobility – supporting the *Energiewende*
- Conclusion

State of the Art in Germany
BMW Group

2009: Mini E (Pilot Project)

- 150 kW, 220 Nm
- 152 km/h, 250 km

2011: BMW Active E (Pilot Project)

- 125 kW, 250 Nm
- 145 km/h, 160 km

2013: BMW i3

- 75 kW, 250 Nm
- 150 km/h, 190 km

2014: BMW i8 (Plug in Hybrid)

- Electric: 96 kW, 120km/h, 37 km
- Combined: 266 kW, 250 km/h, 600 km

- Mini E and BMW Active E as key learning projects for the BMW i3
- More than 230 BMW i3 are registered in Germany in March 2014 alone
- Currently six month delivery time for BMW i3

State of the Art in Germany
BMW Group: i Concept

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- **New materials and production concepts**
  - Carbon fiber chassis
  - „LifeDrive“ architecture
    - No tunnel trough the middle of the car
    - Lower center of gravity

© BMW/bmw.com

© BMW/bmw.com

Passenger cell:
- Carbon-fiber-reinforced plastic

Drive module:
- 100 % Aluminum
- Suspension, crash and drive components
- High-voltage battery

State of the Art in Germany
StreetScooter GmbH

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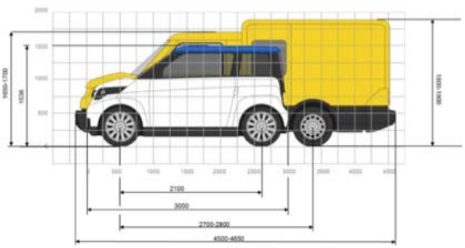
- Cooperation of more than 80 companies
- Cost-efficient, short distance electric vehicles
  - Inner-city traffic
  - Fleet solutions
- Highly modular concepts
  - Range and power scalability
- **Compact model**
  - Available by 2015
- **Work model**
  - Launched in 2014
  - Currently 50 vehicles are operated by DHL/German Post

STREETSCOOTER



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Drive-train concepts
Basic Drive-train concept : Inverter + Machine

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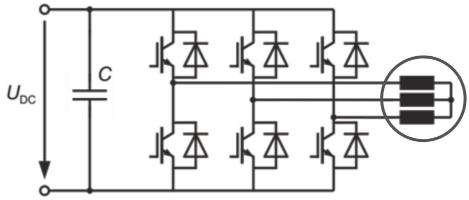
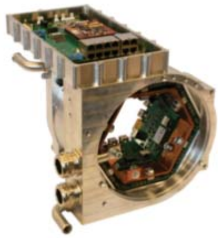
- Basic Drive-train concept :
  - Modularization of sets of individual components : Inverter + Motor
  - Combination of both



Level of integration

[ISEA, *e performance*, 2012]

[ISEA, *e performance*, 2012]



[ISEA, *eMoSys*, 2014]

Drive-train concepts
Scalability of power and driving range (1)

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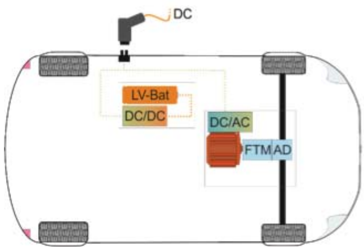
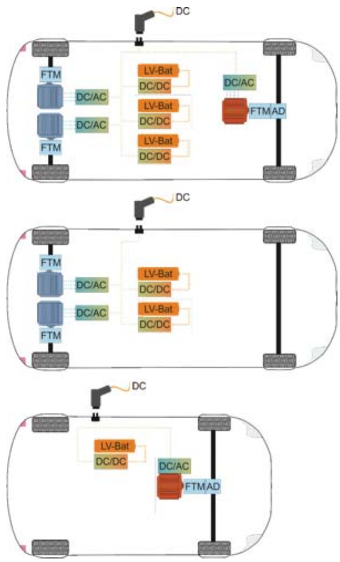
- Modular components
  - Low-voltage battery
  - Dc-to-dc converter
  - Inverter
  - Electrical motor
  - Gearbox
- Standardized voltage level
  - Adjustable by dc-to-dc converter
- Scalability
  - Modular building blocks
  - Battery voltage independent drive-train topology
  - Range and power adjustable by amount of building blocks



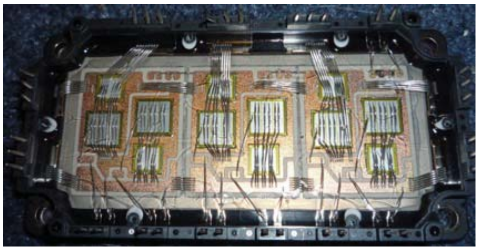
Drive-train concepts
Scalability of power and driving range (2)

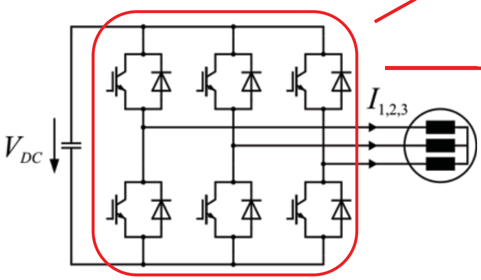
- Vehicle platforms
  - Medium-sized/luxury vehicle
  - Compact vehicle
  - Urban vehicle
- Battery
  - Smaller packs
  - Replacement of single packs possible
  - Coupling packs with different state of health or battery technology
- New possibilities for driving dynamics and comfort
- Redundancy
  - Component failure decreases only limited power or range

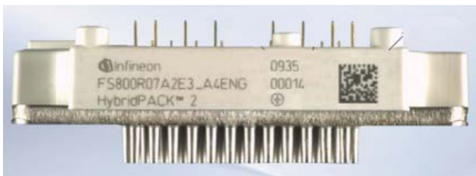


Semiconductor Devices
Integrated power module

- Inverter power module
  - Integration of the power devices in one case
  - Reproducible thermal behavior
  - Mechanical stability
  - Improved heat transfer to the cooling agent







Semiconductor Devices
Comparison of materials

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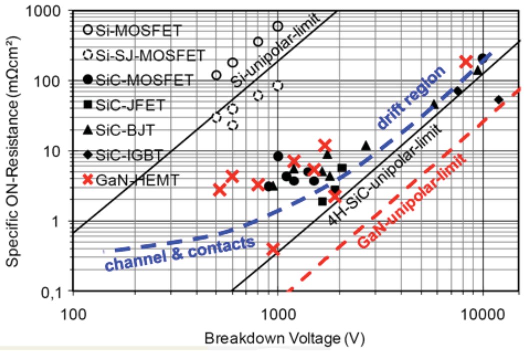
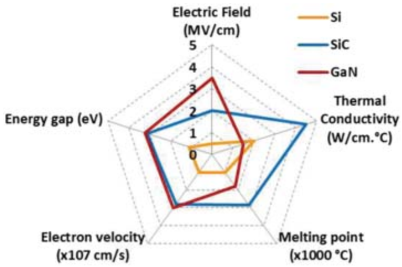
- Diamond best choice by far
- GaN offers the best high-voltage and high-frequency performance
  - Limited by the lack of good quality substrates
- SiC offer excellent thermal performance





Semiconductor Devices
Impact of high switching frequencies

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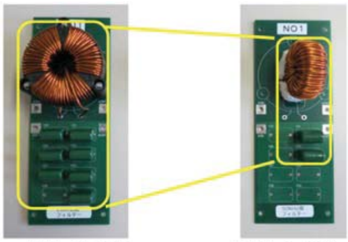
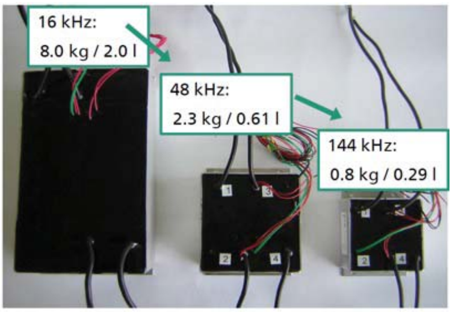
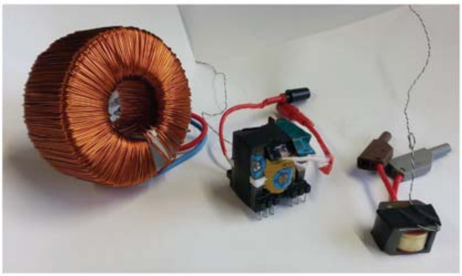
- Reduction of size reduction vs. frequency



LC filter for 20kHz LC filter for 50kHz



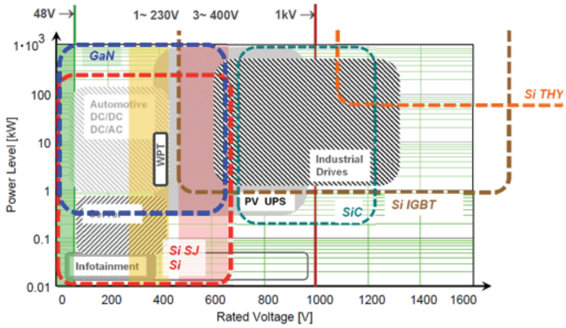
Drosseln für einen einphasigen 5 kW PV-Wechselrichter bei unterschiedlichen Schaltfrequenzen

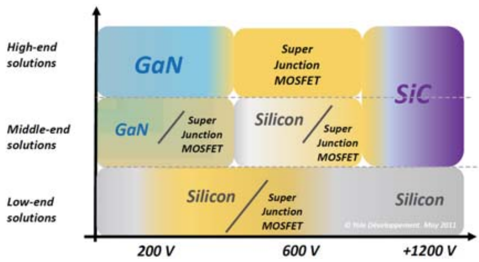


Optimierte Drosseldesigns für 16kHz; 100kHz und 200kHz (Umax=600V und (2..3)kW)

Semiconductor Devices
Applications

- Each technology has its own application area
- Still not in direct competition. Intersection around 600-900 V
- Application areas and roadmap change a lot depending on manufacturer





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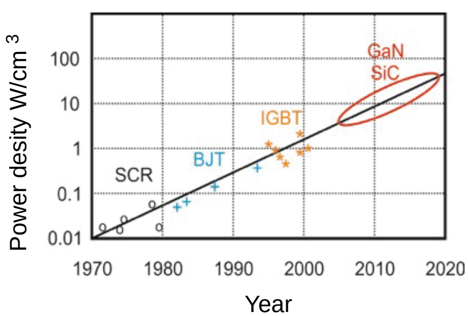
Semiconductor Devices
New semiconductor materials - Trends



Cost per SiC-Wafer.
(Source: Yole Development, 2013)

Power density.
(Source: Transphorm, 2013))

Semiconductor Devices
New semiconductor materials - Applications

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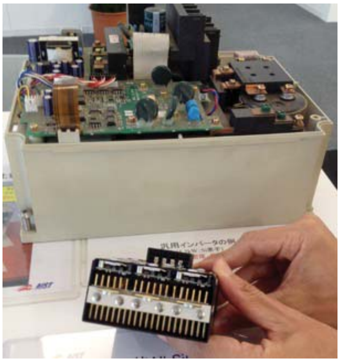
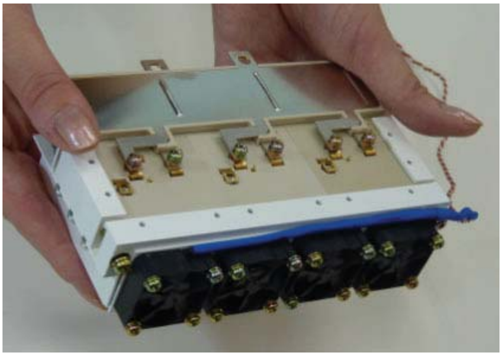


SiC-Inverter (Front)
and
Si-Inverter (Rear)
Both forced – air cooled



SiC-Inverter 30 kW/Liter
Forced – air cooled

Semiconductor Devices
Projekt VISA und PROJECT HI-LEVEL

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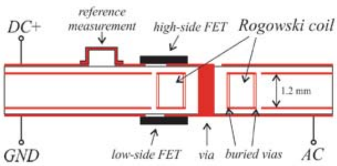
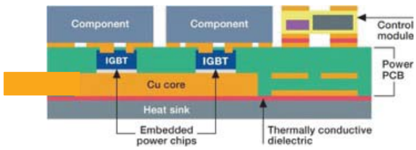
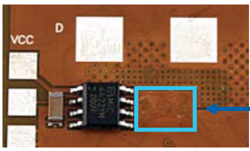
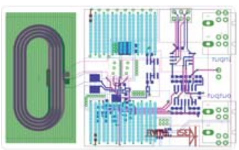
- Integration of passive and active devices
- High current PCB for traction applications
- PCB-integrated control and monitoring

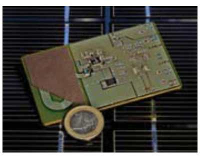


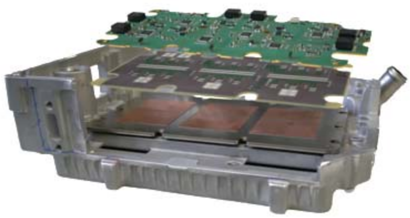




Integrated MOSFETs



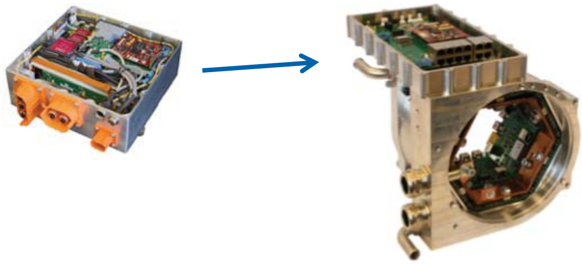




Semiconductor Devices
Integration of inverter and motor

- Compact Drive
  - Reduced EMC
  - Less bulky wiring – Less failure
  - One compact Component
- Design Aspects
  - Higher thermal expansion (CTE)
  - Vibration

Quelle: Hitachi



[ISEA, *eMoSys*, 2014]

Semiconductor Devices
Cost aspects

- Standardized interfaces
  - Electrical connectors
  - Communication
  - Cooling
- Increase amount of identical components
  - Decreasing certification and development costs
  - Short term: Moving threshold for higher production numbers
  - Long term: Higher numbers in mass production of components

	Power	Energy	Inverter[1]	Li-Ion cells[2]
Urban vehicle	30 kW	20 kWh	112 €	3,500 €
Compact vehicle	50 kW	30 kWh	186 €	5,250 €
Medium-sized vehicle	80 kW	40 kWh	297 €	7,000 €

1: Targets for the year 2015. [VDE, 2010], 2: Assuming 175 €/kWh

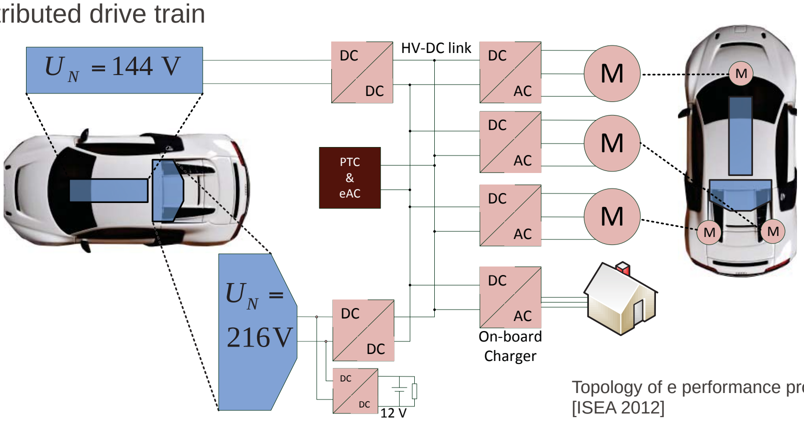
Battery Aspects
Project Example *e performance*

- Features
  - Distributed battery packs
  - Distributed drive train

Drive train of the prototype.
[*e performance*, 2012]

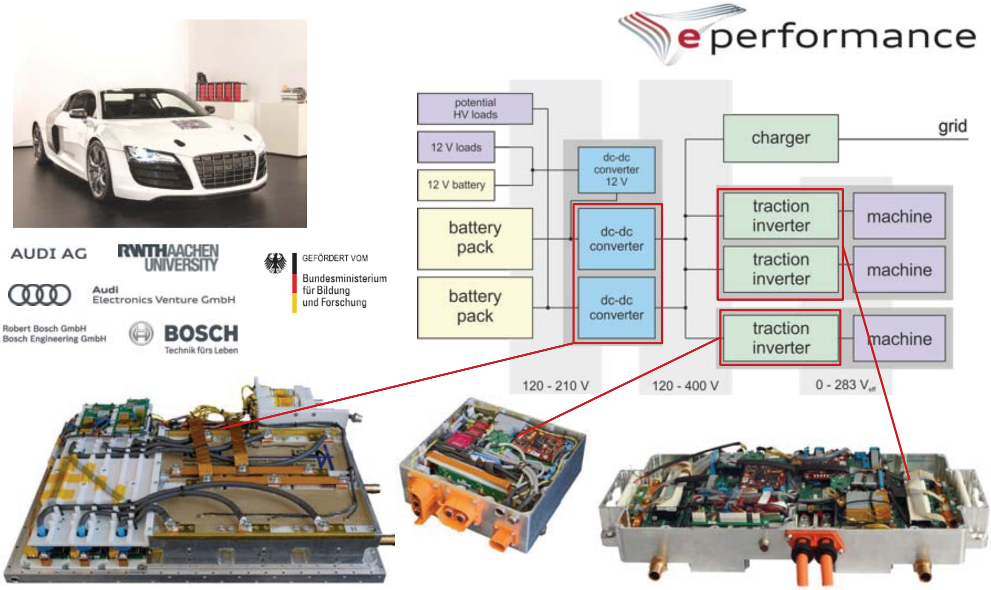
Battery Aspects
Modular high voltage battery concept

- Example: e performance Forschungsprojekt
- Multi-modular drive-train topology
  - Distributed battery packs
  - Distributed drive train

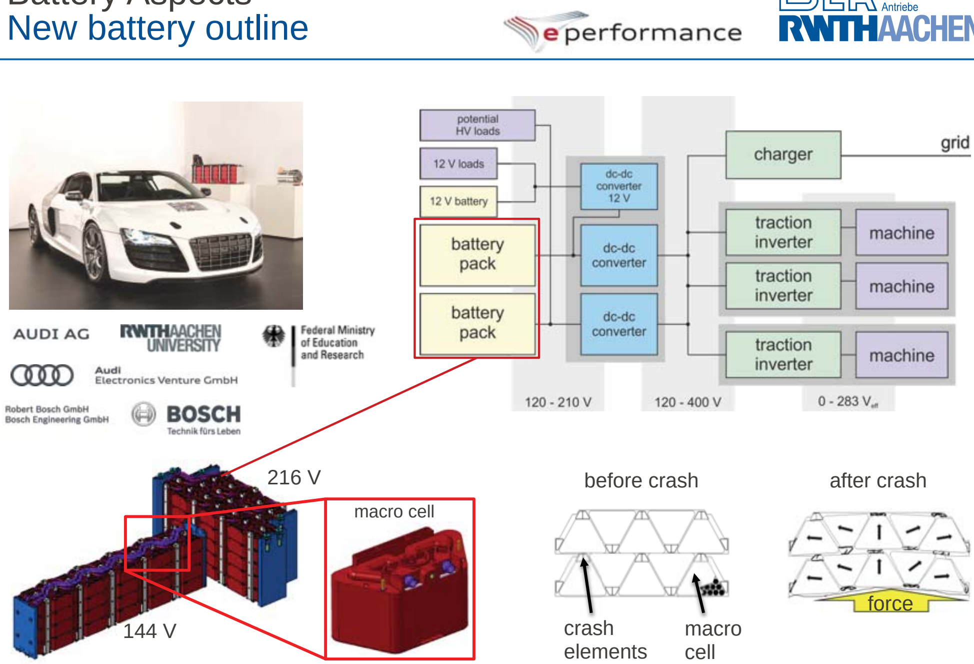


Topology of e performance project.
[ISEA 2012]

Battery Aspects
Example of power train topology



Battery Aspects
New battery outline



Battery Aspects
Characteristics of a Flexible System

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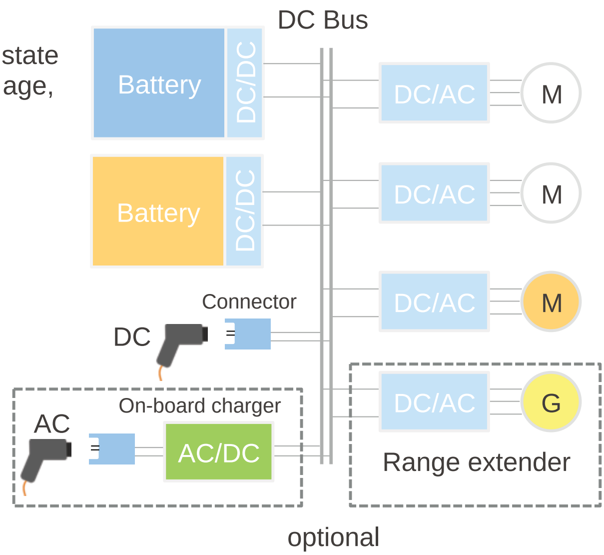
- Different batteries
  - Regarding voltage levels, state of charge, state of health, age, technology
- Control of power flow
- Redundancy
- Flexible interconnection
  - Replace/add/remove components
  - Use components temporarily
- Components can be used for BEV and HEV systems



Battery Aspects
Low-voltage battery concept

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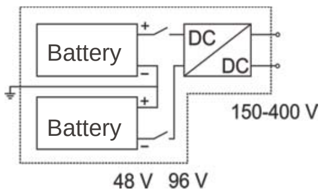
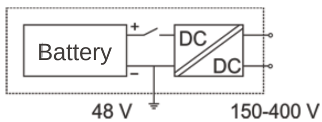
- Increased safety and reliability
  - Battery with SELV nominal voltage
  - System voltage < 60 V after shutdown
  - Lowered risk during production process
  - Lowered risk after accidents
  - Easier maintenance



- Integrated dc-to-dc Converter
  - Decreased dc-link current
  - Controlled pre-charging
  - Dc-link is independent of the inner battery structure and technology
  - Intelligent power and energy management enabled



Battery Aspects
Low-voltage battery concept - Benchmark

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- Smaller building blocks overcome the issues of:
  - Placing the blocks in certain space
  - Connection length of batteries
  - Different aging of batteries
- Cost comparable to HV battery
  - Periphery costs are increased
  - Costs without pre-charge unit of HV battery pack

Costs		
	HV	LV
Cells	15350 €	15350 €
Periphery	1572 €	1947 €
Over all	16922 €	17297 €

→ improved safety provided, when low voltage batteries applied, not rated in the cost analysis !

Battery Aspects
Fast high-power dc charging

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- Standard ac charging with
  - 3.7 kW @ 230 V single phase
  - 43.5 kW @ 400 V three phases
- Fast charging desired
  - Chemical process within battery limits recharging power
- Dc charging enabled by dc-to-dc converter
  - No additional component needed
  - Charging power up to traction power
  - External charging station determines charging power
  - Inherently bidirectional power transfer enables smart grid application

DC-grids and transportation
Prosumers Connected in “Smart Homes”

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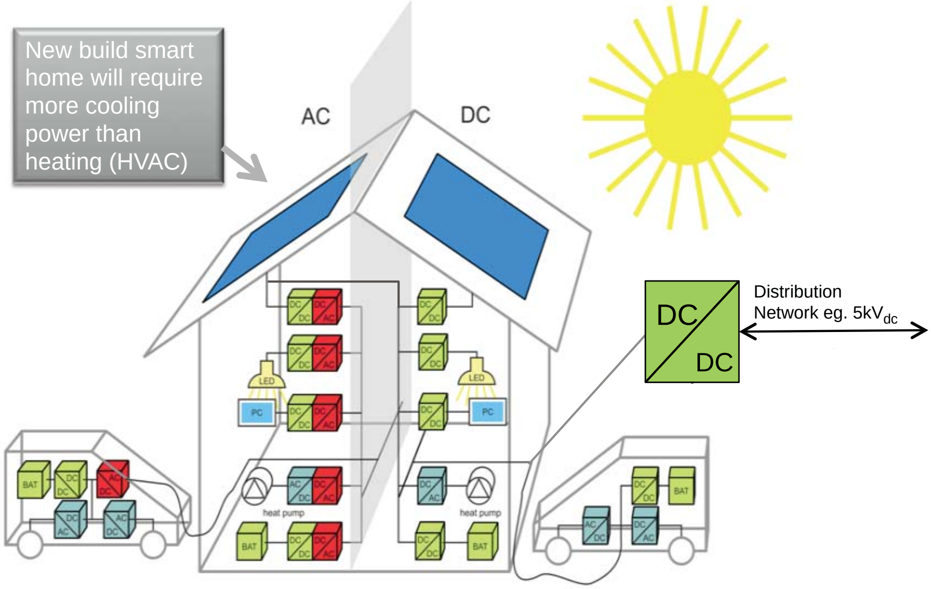

DC-grids and transportation
Multiport-DAB - the DC-local grid transformer

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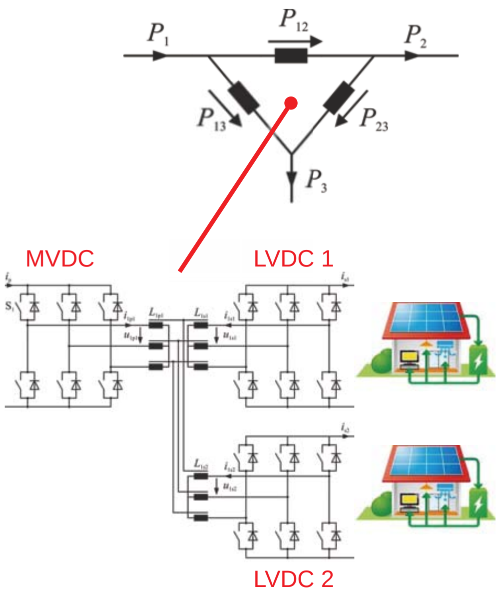
- MVDC
  - 5 kV nom. (±10 %)
  - Split DC-Link: ±2.5 kV; 0 V
  - Insulation: ±5 kV
- LVDC 1 and 2
  - 380 V / 760 V (±10%)
  - Split dc link: ±380 V; 0 V
- Powerr rating
  - MVDC: 150 kVA
  - LCDC je: 75 kVA
- Switching frequency ≥ 10 kHz



DC-grids and transportation
Smart Communities

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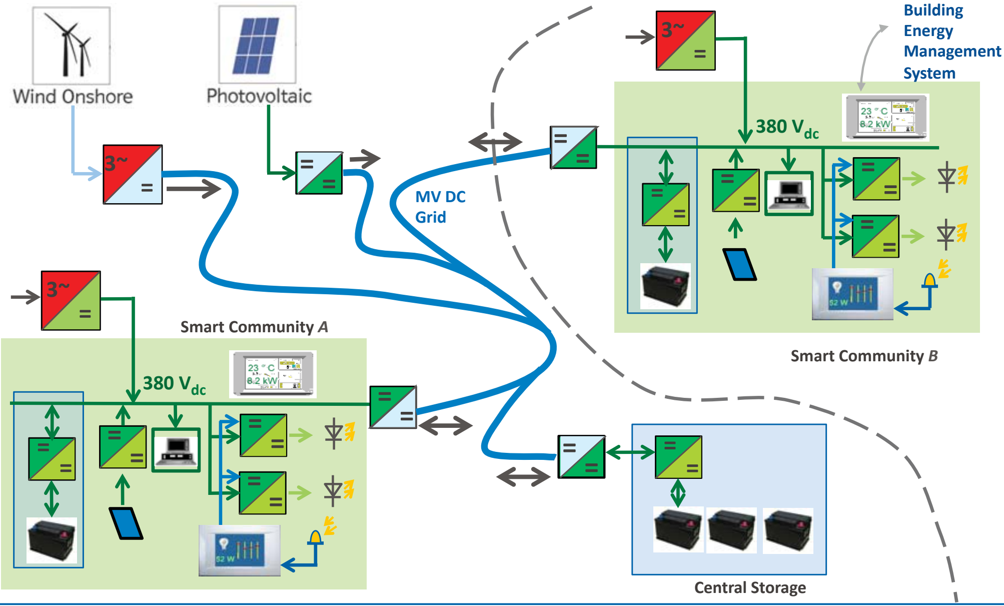
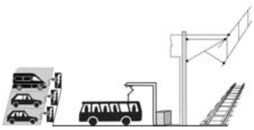


DC-grids and Transportation
Development / Innovation activities infrastructure

Institut für Stromrichtertechnik und Elektrische Antriebe
RWTH AACHEN

- **DB Energie** (business unit of DB, the German railroad company)
  - Builds fast charging stations for Tesla
  - Grid: 110 kV/16,7 Hz
- **Light-rail grid**
  - 750 V DC



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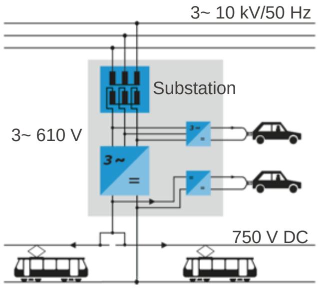

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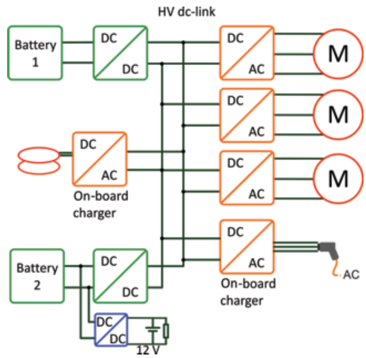
- **Ubitricity:** Mobile metering system inside the cable
  - Low cost charging spots
  - High flexibility
  - Customer can choose the energy provider

Conclusion

- **To accelerate transportation electrification…**
  - …associations of industry and research are needed to pool know-how.
  - …the infrastructure has to be improved.
  - …users must become fans of driving electric vehicles.
  - …the whole concept of the car has to be rebuilt.

- **Vision and future research**
  - Alternative drives
  - Integration of Power Electronics and drive
  - Highly modular drive train concepts
  - Higher machine speeds
  - New materials
    - High temperature semiconductors
    - Alternatives to permanent magnets
    - High voltage batteries (> 5 V)



Power Electronics in View of Transportation Concepts

TRENDS 2015

04.12.2015

Univ.-Prof. Dr. ir. Dr. h. c. Rik W. De Doncker

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Genialer Trick: Mann lädt sein Elektroauto einfach über den Zigarettenanzünder auf

Elektro-Autos sind unpraktisch und müssen bei längeren Strecken immer wieder zum Aufladen pausieren – das galt bislang unter Autofahrern als bewiesen....

Renewable DME and OME for Diesel Power-Trains

Ralf Peters, Alexander Otto,
Forschungszentrum Jülich GmbH, Institute for Energy and Climate Research – Electrochemical Process Engineering (IEK-3)

Diesel engine emissions possess always a contrary trend between particle number and NO_x emission. Finally, a trade-off must be found to fulfill both limited emission thresholds. This behavior is allocated to C-C bonding in fossil fuels. Ethers such as dimethyl ether (DME) and oxymethylenether (OME) have only a C-O bonding, which shows a decoupled emission behavior. In general, blending diesel fuels with ether reduce overall emission, whereby a contrary trend between particle number and NO_x emission still exist. Both chemicals/fuels could be produced via a power-to-fuel process using hydrogen from electrolysis. Excess wind and solar power would be primary energy sources. This concept contributes to the compensation of fluctuating renewable energy. It connects electricity generation with fuel production for transport applications.

The presentation gives an overview about the potential of DME as diesel fuel, reaction pathways, conventional and CO_2 based, the design and simulation of the processes in Aspen Plus, the determination of the energy and feedstock demand as well as investment and it considers different production routes. The most important results are following:

- The conventional production of DME with methanol as feedstock leads to CO_2 emissions of 34 g/MJ_{DME} and manufacturing costs of 2.3 €-cent/MJ_{DME}. These values are higher than for Diesel (14.8 g_{CO2}/MJ_{Diesel}, ≈ 0.7 €-cent/MJ_{Diesel} (Oct. 2015))
- Process design and simulation show that an industrial scale production of DME with CO_2 and H_2 as feedstock is theoretically possible.
- The CO_2 based process offers the opportunity to reduce CO_2 emissions, but only if renewable hydrogen is used. For the case that wind power is used in combination with CO_2 capture from air, the net CO_2 emissions are -22 g/MJ_{DME} and the manufacturing costs are 7.6 €-cent/MJ_{DME}. For the case that the CO_2 is separated at a fossil power plant the costs and net CO_2 emissions are lower (-45 g_{CO2}/$MJ_{DME,}$ 4.8 €-cent/MJ_{DME})

Presently, a mixture of OME-3/4/5 is in discussion as diesel fuel or diesel blend. The synthesis of OME is under development. Current process routes require five main chemical reaction units to produce OME from CO_2 and H_2. Hereby, methanol is formed during a first reaction, followed by formaldehyde, methylal and trioxane synthesis. In a final step, methylal and trioxane forms a mixture of OME with different chain length. It would be desirable to shorten OME synthesis to a direct process from CO_2 and H_2. A thermodynamic analysis offers the following results:

- OME-1 can be formed potentially on a direct synthesis route at 250 bar and up to 200 °C, OME-2 below 100 °C. At low pressure, i.e. 25 bar OME-1 direct synthesis can occur at temperatures below 100 °C in the liquid phase. Higher OME, especially OME-3-5 cannot be formed on a direct synthesis route

- Side reactions such as methanol and DME formation will play a role for OME synthesis
- Oxygen must be removed from CO_2 leading to water production and unfavorably Gibbs energy for the product mixtures. Therefore, water must be removed before the next reaction steps can be performed
- Formaldehyde as intermediate of the indirect synthesis route must be formed from methanol with hydrogen as byproduct, not with partial oxidation forming water. This increases efficiency to a value about 47 %

The following comments on renewable DME and OME fuels for diesel power-trains can be stated:

- DME via P2F path leads to 7 to 10-times higher costs, but offers -48 to -75 % CO_2 emissions compared to diesel after combustion of the fuels.
- Fuel synthesis & CO_2 source must fit to each other
- Monte-Carlo simulations with evaluated CO_2 emission form industry lead to 2.5 Mio. t. fuel / a for a conservative scenario

Further information can be taken from [1-2].

Literature

[1] Maus et al., 35. Wiener Motorensymposium, Fortschrittsberichte VDI Reihe 12, Nr. 777, Nr. 1, 325-347 (2014)

[2] A. Otto, Chemische, verfahrenstechnische und ökonomische Bewertung von Kohlendioxid als Rohstoff in der chemischen Industrie, Forschungszentrum Jülich GmbH, Energie & Umwelt 268, 2015

Renewable DME and OME for Diesel Power-Trains

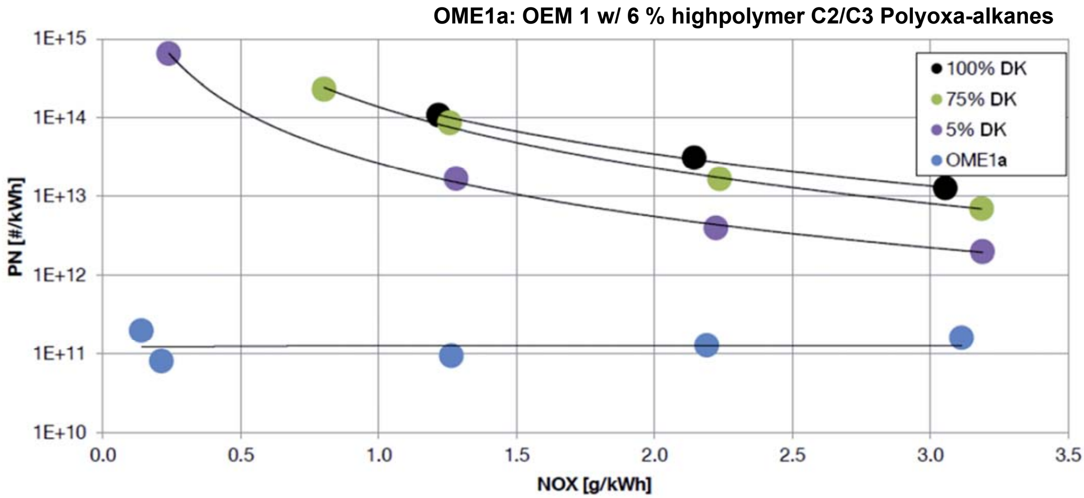
Ralf Peters, Alexander Otto
Forschungszentrum Jülich GmbH
Institute for Energy and Climate Research – Electrochemical Process Engineering (IEK-3)

TRENDS 2015
Transition to Renewable Energy Devices & Systems - Transportation Concepts
December 3-4, 2015, Aachen

Contents

- Potential of DME as diesel fuel
- Reaction pathways, conventional and CO_2 based
- Design and simulation of the processes in Aspen Plus
- Determination of the energy and feedstock demand as well as investment
- Consideration of different production routs

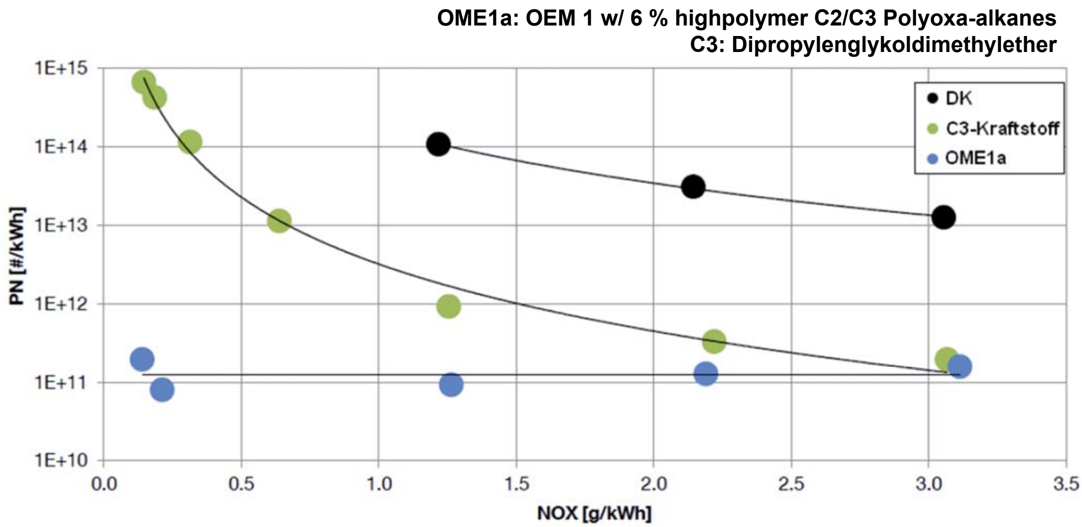
Trade-off between particle number and NO_x emission for diesel OME-1 mixtures



- No trade-off for pure OME 1a
- Stronge emission effect by blending with 5% diesel fuel

Source: Maus et al., 35. Wiener Motorensymposium, Fortschrittsberichte VDI Reihe 12, Nr. 777, Nr. 1, 325-347 (2014)

Trade-off between particle number and NO_x emission for different fuel structures



- Trade-off for C3-fuel indicating effect of two C-C bonding in series
- No particle emissions at high air ratios

Source: Maus et al., 35. Wiener Motorensymposium, Fortschrittsberichte VDI Reihe 12, Nr. 777, Nr. 1, 325-347 (2014)

Usage of DME from syngas for truck application

- DME from regenerative sources
- Co-product from methanol synthesis
- Diesel substitute for truck application
- Highest range by pyrolysis route

Source: P. Klintbom, Volvo AB, Bio-to-liquids, 16.10.2006, München

Syngas reactions

Co-product of methanol synthesis
High pressure synthesis: 150 - 300 bar

$$CO_2 + 3\,H_2 \rightleftharpoons CH_3OH + H_2O$$
$$CO + 2\,H_2 \rightleftharpoons CH_3OH$$
$$CO_2 + H_2 \rightleftharpoons CO + H_2O$$
$$4\,H_2 + 2\,CO \rightleftharpoons CH_3OCH_3 + H_2O$$

Dehydration of methanol
MeOH synthesis at 50 - 60 bar

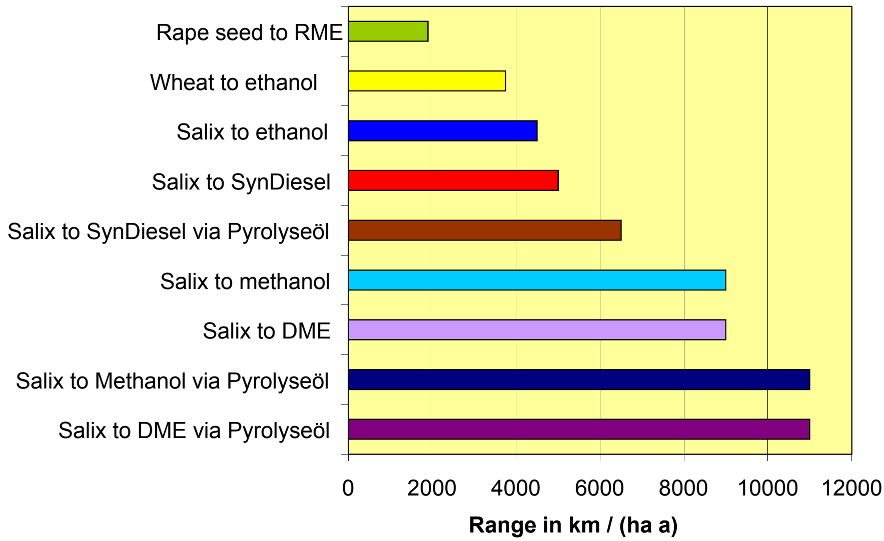
$$2\,CH_3OH \rightleftharpoons CH_3OCH_3 + H_2O$$

Single stage DME synthesis

$$3\,CO + 3\,H_2 \rightleftharpoons CH_3OCH_3 + CO_2$$

DME on a renewable base

SALIX: willow



Source: P. Klintbom, Volvo AB, Bio-to-liquids, 16.10.2006, Munich

Usage of bio fuels of 2nd generation

Substitution of diesel by DME in heavy-duty traffic

Diesel

- Consumption by heavy-duty traffic in Germany 2011[1]: 19.2 Mt or **816 PJ**
- Heat value: **42.5 MJ/kg**
- Density: 0.820 to 0.845 kg/L @ 25°C, 1 bar

Dimethyl ether

- Global production 2010[2]: 1.8 Mt
- Heat value: **28.4 MJ/kg**
- Density: 0.00185 kg/L @ 25°C, 1 bar
  0.654 kg/L @ 25 °C, 6 bar

19.2 Mt diesel → 816 PJ DME or 28.7 Mt DME

Feedstock demand for DME production and actual German production volumes

Methanol route[3] (commercial)	CO_2 based route[4]
$2MeOH \rightarrow DME + H_2O$	$2CO_2 + 6H_2 \rightarrow DME + 3H_2O$
Necessary amount of raw materials to produce 28.7 Mt DME	
MeOH: 40 Mt	CO_2: 55 Mt H_2: 7.6 Mt
Current German production volumes	
MeOH: 0.96 Mio. Mt[6]	H_2: 1.7 Mt[5]

[1] Mineralölwirtschaftsverband e. V., MWV-Prognose 2025 für die Bundesrepublik Deutschland , 2011, www.mwv.de
[2] Bearns, M., *Technische Chemie: Ausgabe 2*, 2014: Wiley, S. 591. [3] Müller, M. and U. Hübsch, *Dimethyl Ether*, in *Ullmann's Encyclopedia of Industrial Chemistry*, 2000, Wiley-VCH .
[4] Sun, K., et al., *Low-temperature synthesis of DME from CO_2/H_2 over Pd- modified CuO–ZnO–Al_2O_3–ZrO_2/HZSM-5 catalysts.* Catalysis Communications, 2004. 5: p. 367-370.
[5] Hydrogeit: *Herstellung von Wasserstoff*. http://www.hydrogeit.de/wasserstoff.htm. [6] Eurostat - Produktionsstatistiken (Prodcom)Prodcom – Produktionsstatistiken, 2014

Examples of laboratory investigations of CO_2 based DME synthesis

	Sun et al. [1]	Wang et al. [2]	Zha et al. [3]	Naik et al. [4]	Zhang et al. [5]
Temperature, °C	200	250	266	260	250
Pressure, bar	30	30	30	50	50
Catalyst	Pd/Cu-ZnO-Al_2O_3-ZrO_2/HZSM-5	CuO-TiO_2-ZrO_2/HZSM-5	CuO-ZnO/Al_2O_3	6CuO-3ZnO-Al_2O_3/HZSM-5	CuZr-Pd/HZSM-5
H_2:CO_2 ratio, mol/mol	1:3.3	1:3	1:3	1:3	1:3
CO_2 conversion, mol-%	18.67	15.60	47.1	≈ 30	18.9
Selectivity, mol-%					
DME	73.56	47.5	32.4	≈ 75	51.8
CO	13.05	39.2	33.58	≈ 20	33.9
CH_4	0.1	-	-		0.2
MeOH	13.29	13.0	33.98	≈ 5	14.1

[1] Sun, K., et al. Catalysis Communications, 2004. 5: p. 367-370.
[2] Wang, S., et al., Catalysis Communications, 2009. 10(10): p. 1367-1370.
[3] Zha, F., et al., Industrial & Engineering Chemistry Research, 2011. 51(1): p. 345-352.
[4] Naik, S., et al., Chemical engineering journal, 2011. 167(1): p. 362-368.
[5] Zhang, M.-H., et al., Applied Catalysis A: General, 2013. 451(0): p. 28-35.

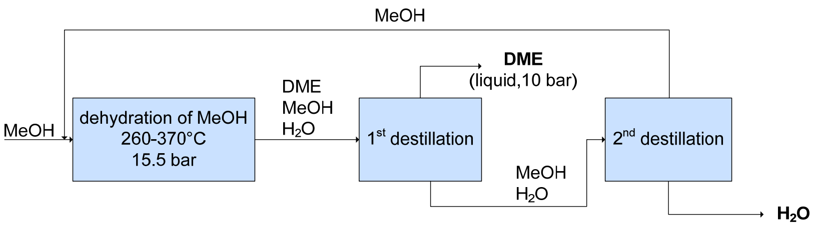
Comparison of conventional and CO_2 based DME synthesis

	Methanol route (commercial)[1,2]	CO_2 based route[3-5]
Reaction	$2MeOH \rightarrow DME + H_2O$	$2CO_2 + 6H_2 \rightarrow DME + 3H_2O$
ΔH_R^0, kJ/mol	7.39	-254.57
ΔG_R^0, kJ/mol	-17.39	-35.47
T, °C	250 - 370	200 - 270
p, bar	15.5 - 16.5	30 - 50
Ratio	pure	H_2:CO_2 = 3 : 1
Conversion	MeOH > 80 %	CO_2 up to 47%
Selectivity	≈ 100 %	up to 75 % main byproduct MeOH
Feedstock	liquid	gaseous

[1] Pontzen, F., et al.,. Catal. Today, 2011, p. 242-250.
[2] CHEMSYSTEM: *PERP Program - Dimethyl Ether Technology And Markets*.
http://www.chemsystems.com/about/cs/news/items/PERP%200708S3_DME.cfm%20%20
[3] Sun, K., et al. Catalysis Communications, 2004. 5: p. 367-370.
[2] Wang, S., et al., Catalysis Communications, 2009. 10(10): p. 1367-1370.
[3] Zha, F., et al., Industrial & Engineering Chemistry Research, 2011. 51(1): p. 345-352.
[4] Naik, S., et al., Chemical engineering journal, 2011. 167(1): p. 362-368.
[5] Zhang, M.-H., et al., Applied Catalysis A: General, 2013. 451(0): p. 28-35.

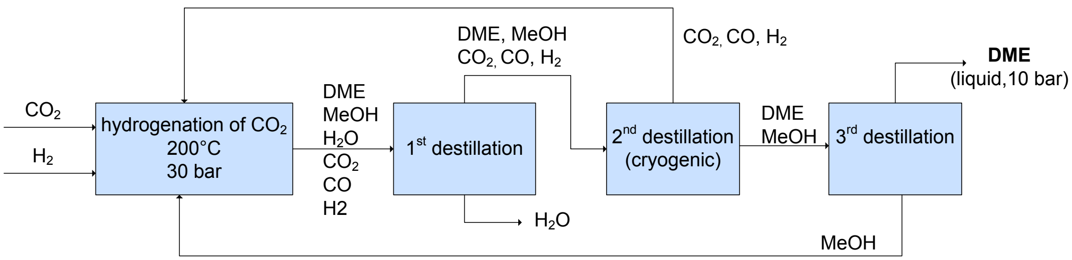
Design and process simulation in Aspen Plus

Conventional process[1]: Process simulation with Aspen Plus



simplified representations

CO_2 based process: Own industrial process design and simulation with Aspen Plus

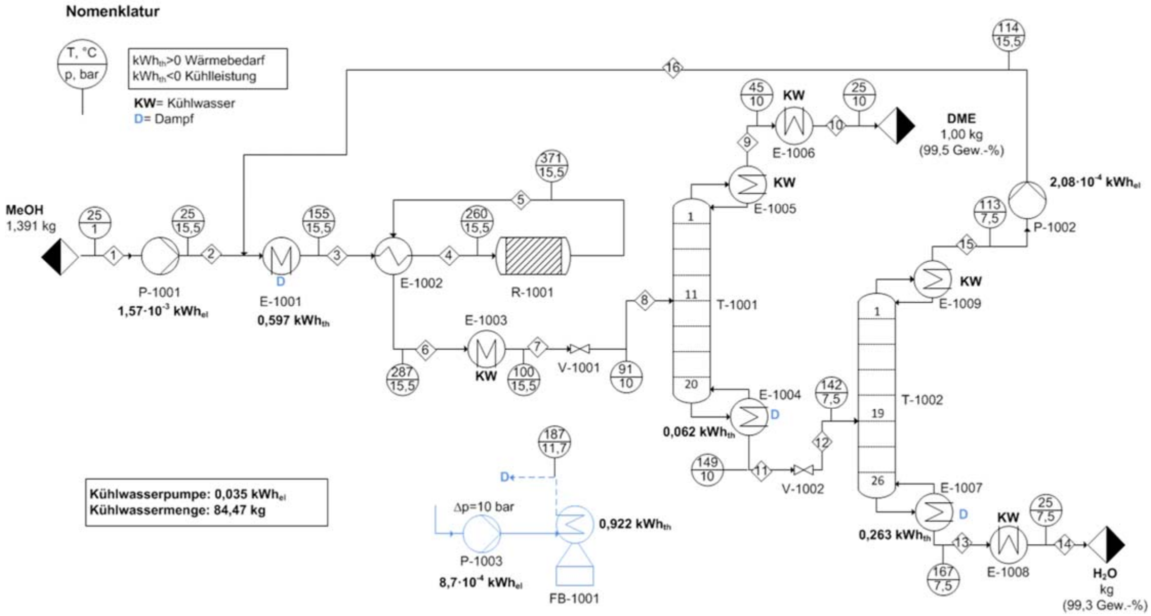


➡ Determination of the energy and feedstock demand as well as of the investment

[1] Turton, R, *Analysis, Synthesis, and Design of Chemical Processes*, 2012, USA: Pearson Education, Inc., ISBN: 978-0-13-261812-0.

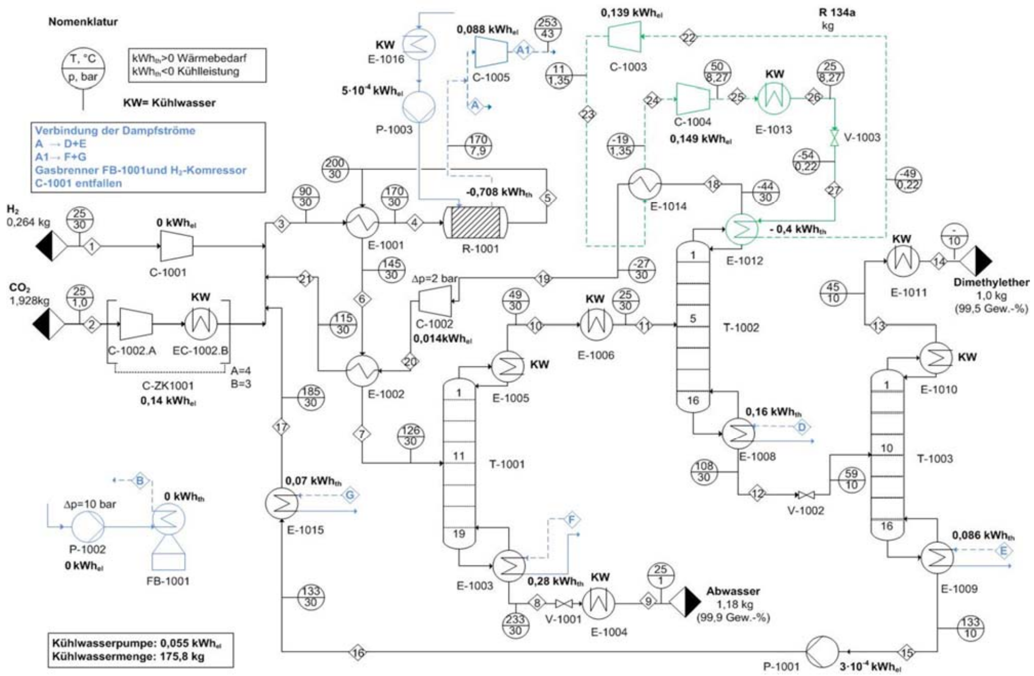
Simulation of the conventional DME synthesis in Aspen Plus

Dehydration of MeOH



Design and simulation of the CO_2 based DME synthesis in Aspen Plus

Hydrogenation of CO_2



Simulation results

	Dimethyl ether	
	Conventional	CO_2-based
Typical plant capacity	143 tons per day[1]	
Investment, million €	**6.8**	**22**
	Energy and feedstock demand	
MeOH, kg/kg_{DME}	1.391	
CO_2, kg/kg_{DME}		1.928
H_2, kg/kg_{DME}		0.264
heat, kWh_t/kg_{DME}	0.922	
power, kWh_e/kg_{DME}	0.0376	0.5928

Method: Simulation results and "Equipment Module Approach"[1] (Typical plant capacity, Investment)

Method: Simulation results from Aspen Plus (Energy and feedstock demand)

→ **Required for the calculation of the manufacturing costs**

[1] Turton, R, *Analysis, Synthesis, and Design of Chemical Processes*, 2012, USA: Pearson Education, Inc., ISBN: 978-0-13-261812-0.

Calculation of manufacturing costs

	Cost components	Symbol/correlation, €/year	
Material costs	**Feedstocks**	C_R	∑ = Manufacturing costs COM
	Operating resources	C_B	
	Overheads; transport, storage,...	0,708 C_P + 0,036 **FCI**	
Production costs	**Production staff**	C_P	
	Monitoring and office personnel	0,18 C_P	
	Maintenance	0,06 FCI	
	Auxiliary materials	0,009 FCI	
	Lab expenses	0,15 C_P	
	Patent and license fee	0,03 COM	
	Tax and insurances	0,032 FCI	
	Annuity	$FCI \cdot \frac{i \cdot (1+i)^T}{(1+i)^T - 1}$	

Calculation of the investment **FCI** with the **"Equipment Module Approach"**→
Investment = Sum of the purchase cost of the individual operation units

Manufacturing Costs: $$COM = 0{,}141\,FCI + 2{,}10\,C_P + 1{,}03\left(C_R + C_B\right) + \underbrace{FCI \cdot \frac{i \cdot (1+i)^T}{(1+i)^T - 1}}_{\text{Annuität}}$$

Personnel costs : $$C_P = 5{,}29 \cdot \sqrt{6{,}29 + 31{,}7P^2 + 0{,}23N_{np}} \cdot 61.737€$$

N_{np} = Number of operation units
P = Number of operation units processing steps with solid materials

Turton, R, *Analysis, Synthesis, and Design of Chemical Processes*, 2012, USA: Pearson Education, Inc., ISBN: 978-0-13-261812-0.

Comparison of the routes with diesel

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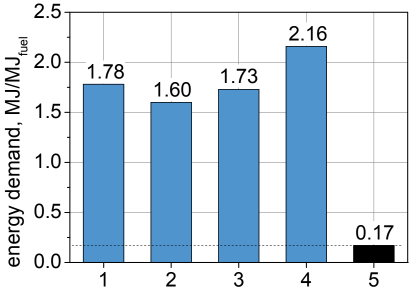
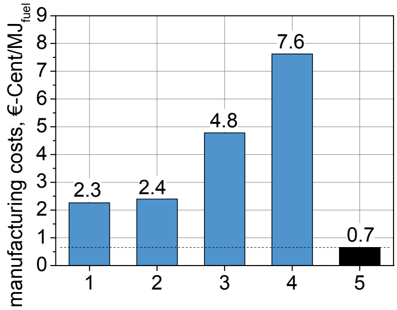
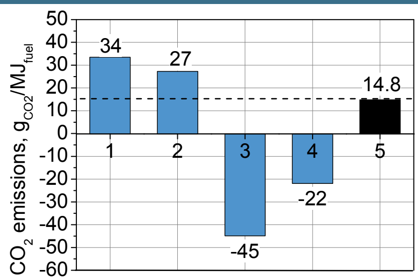
Energy demand for manufacturing



Manufacturing costs



CO_2 emissions



1	Conventional with MeOH
2	H_2 and CO_2 from steam reformer
3	H_2 from electrolyzer & CO_2 from power plant
4	H_2 from electrolyzer & CO_2 from air
5	Diesel: Transport, extraction & processing, refining[1] price: notation Rotterdam, Oct. 2015[2]

[1] Joint Research Centre-Institute for Energy and Transport: *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context"*
[2] Mineralölwirtschaftsverband, http://www.mwv.de/index.php/daten/statistikenpreise/?loc=2&jahr=2015

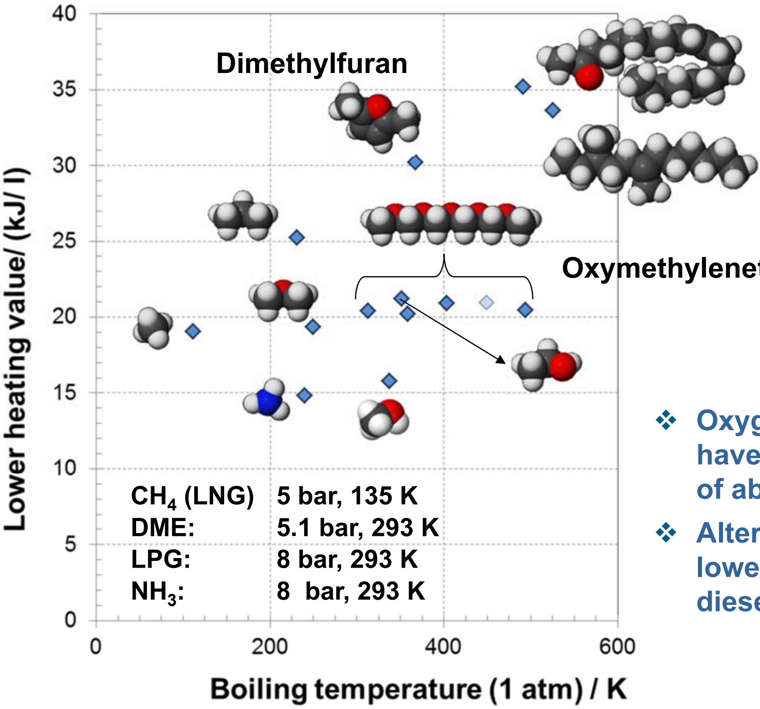
Physical properties of OME 1-8

JÜLICH FORSCHUNGSZENTRUM

Parameter	$M\ [\frac{g}{mol}]$	$\rho[\frac{kg}{m^3}]$	$O_2[wt\%]$	Cetannumber	Lower Heating Value $[\frac{MJ}{kg}]$
OME1	76.10	860	42.1	29	20.00 – 23.00
OME2	106.12	960	45.3	63	20.20 – 21.30
OME3	136.15	1035	47.1	70	19.77 – 20.47
OME4	166.17	1078	48.2	90	18.97 – 20.46
OME5	196.20	1079	48.9	N/A	18.42 – 19.87
OME6	226.23	N/A	49.5	N/A	N/A
OME7	256.25	N/A	50.0	N/A	N/A
OME8	286.28	N/A	50.3	N/A	N/A
OME 3/4/5	160.08	1073	48.8	72	19.11 – 20.21

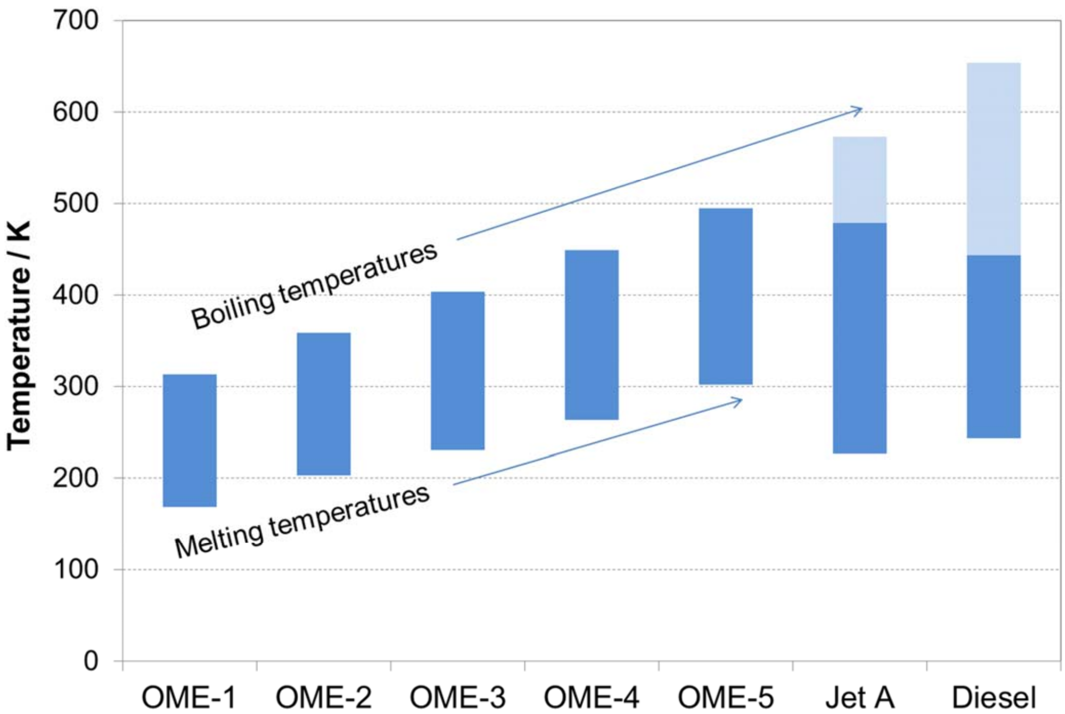
Sources: Burger; KIT; Maus et al.; [FVV-Kraftstoffstudie; ASPEN

Lower heating value and boiling point of P2F- and bio fuels

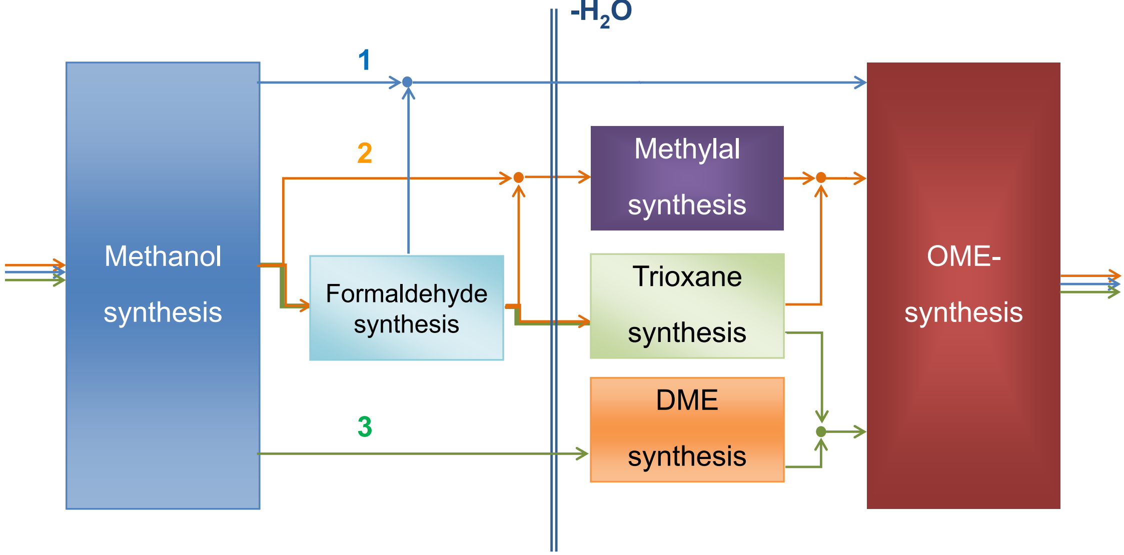


- Oxygenates such as OME have a lower heating value of about 20 MJ/l
- Alternative fuels offer a lower boiling point related to diesel, FT-diesel and FAME

Boiling- and melting point of OMEs related to Jet A1 and diesel

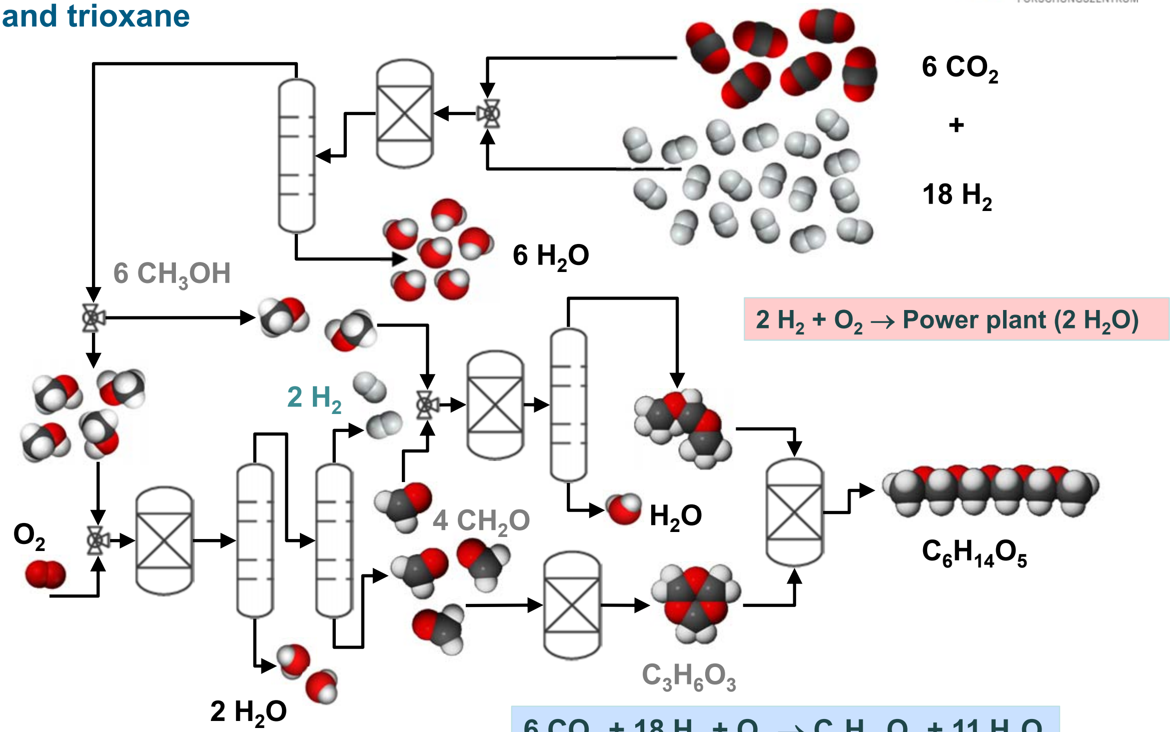


Different reaction paths for OME production



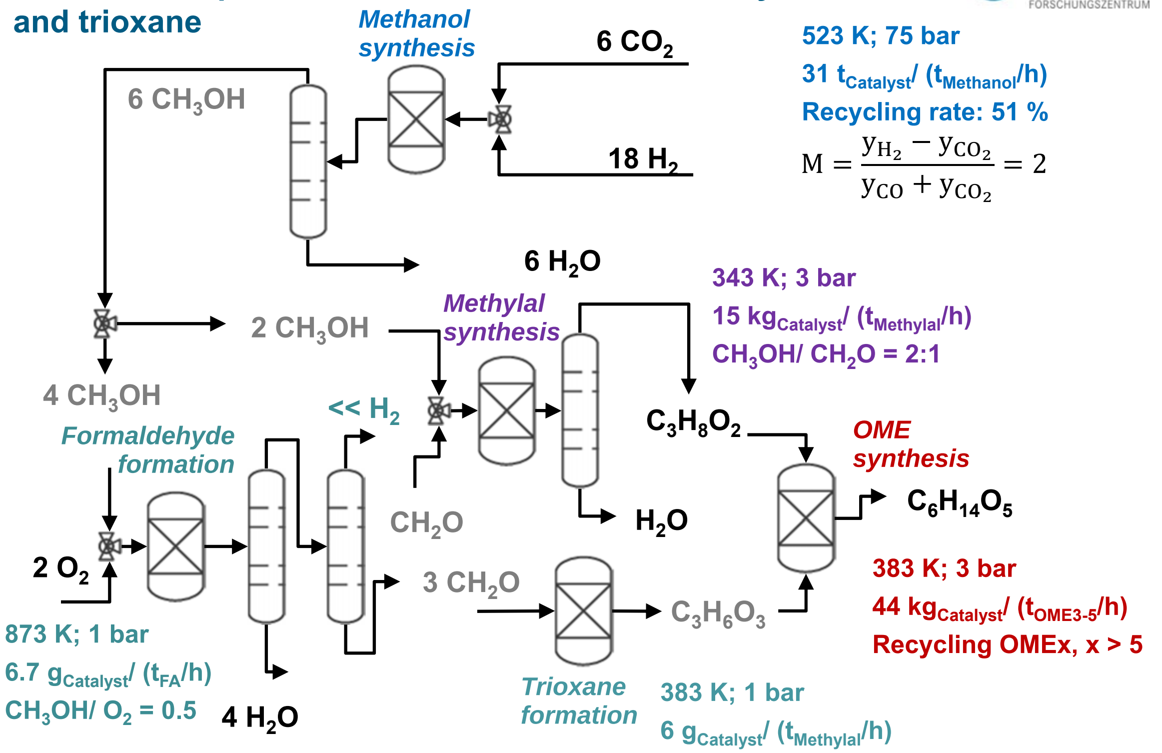
- **Path 1: by-product water during OME formation from methanol and formaldehyde lead to a side reaction between formaldehyde and water forming polyoxymethylenglycole and reduces OME yield**
- **Path 3 was not investigated so far. Catalyst development required.**

Indirect OME production via methanol, formaldehyde and trioxane



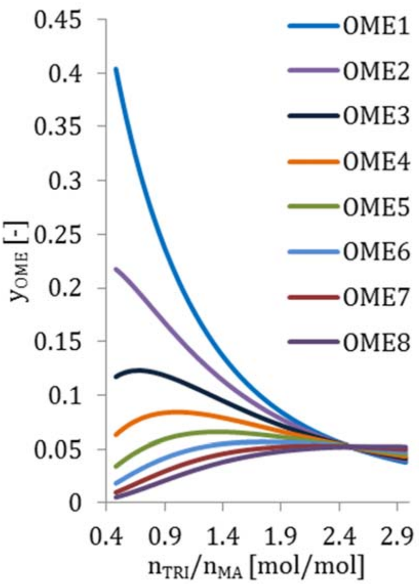
$6\ CO_2 + 18\ H_2 + O_2 \rightarrow C_6H_{14}O_5 + 11\ H_2O$

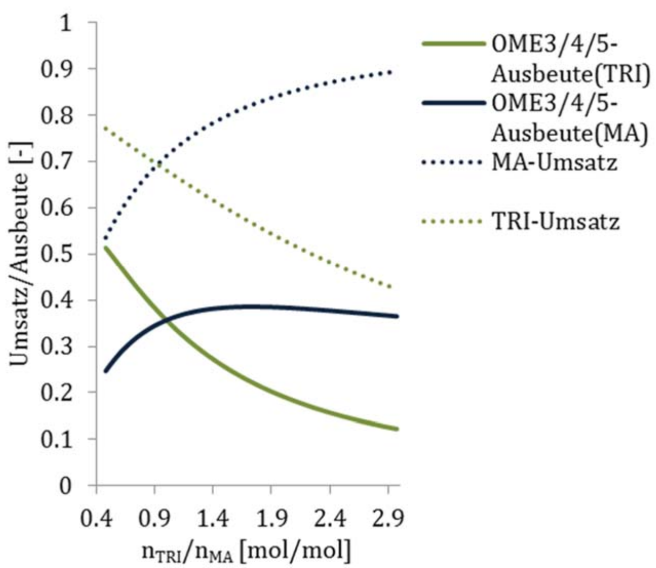
Indirect OME production via methanol, formaldehyde and trioxane



Optimized OME yield

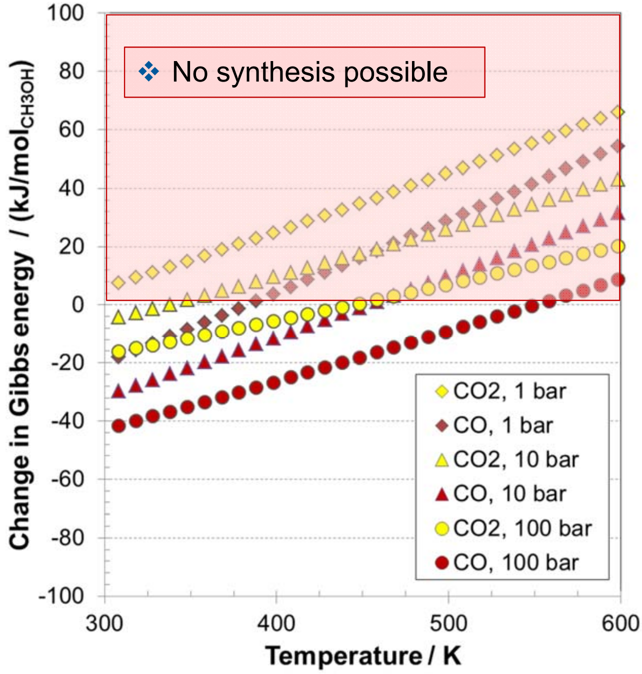
- Results from Aspen calculation @ T = 383 K; p = 3 bar





Nevertheless, efficiency is low with 30 %!

Gibbs Energy analysis as evaluation tool

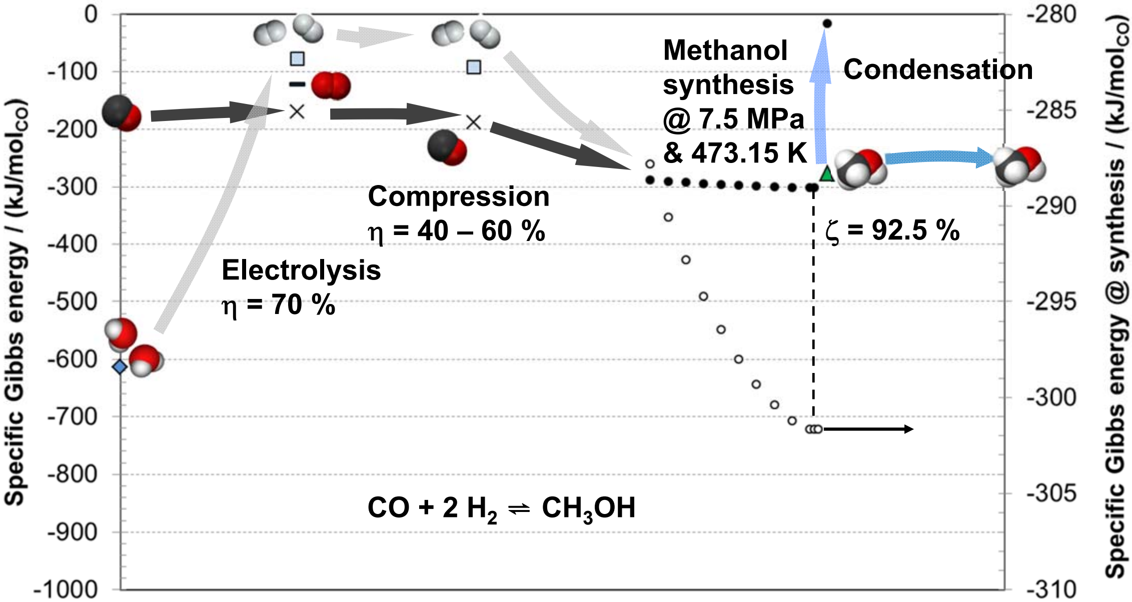


- Ideal gas state
- Stoichiometric educt mix
- **Complete conversion!**
- No CO_2 and H_2 in product
- **Condition for chemical reaction $\Delta G < 0$!**

Results:

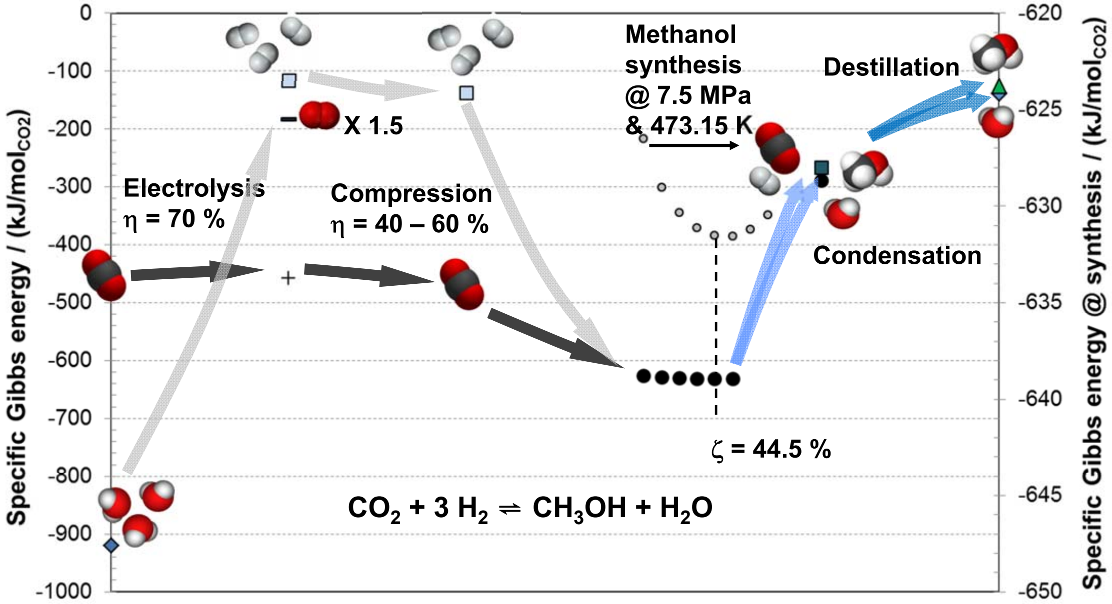
- High temperature limits reactivity
- **High pressure increases reactivity**
- Synthesis from CO_2 is worst related to synthesis from CO

Gibbs Energy analysis for CH_3OH synthesis from CO



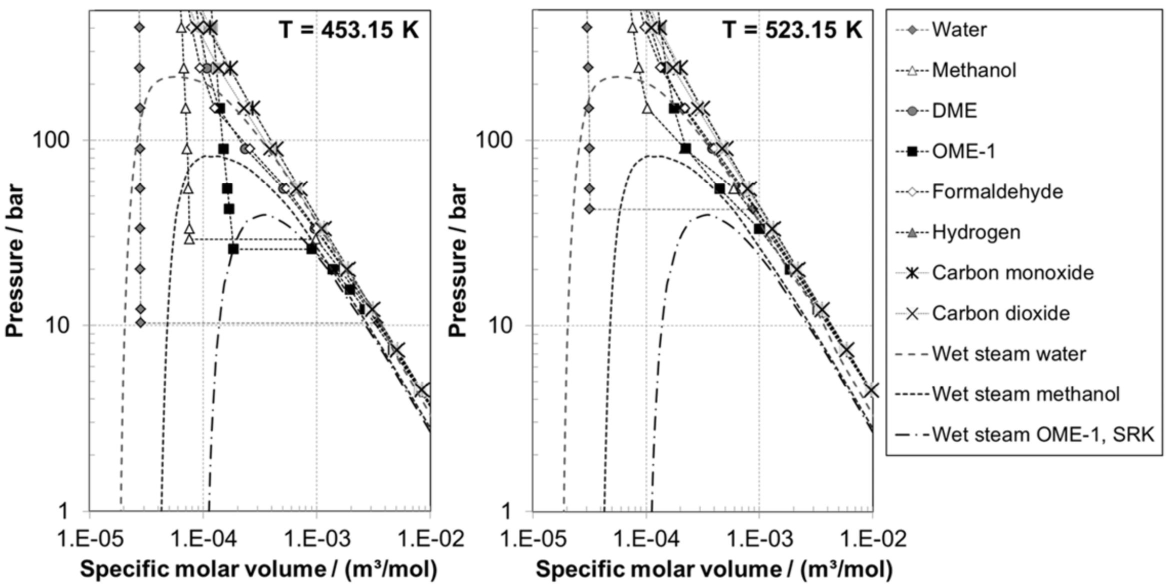
- **Methanol synthesis from CO delivers pure methanol at high conversion**
- **Option for CO_2: upstream water-gas-shift-reactor**

Gibbs Energy analysis for CH_3OH synthesis from CO_2



- Methanol synthesis from CO_2 suffers from low Gibbs Energy of CO_2
- Additional separation effort for product mixture CH_3OH / H_2O

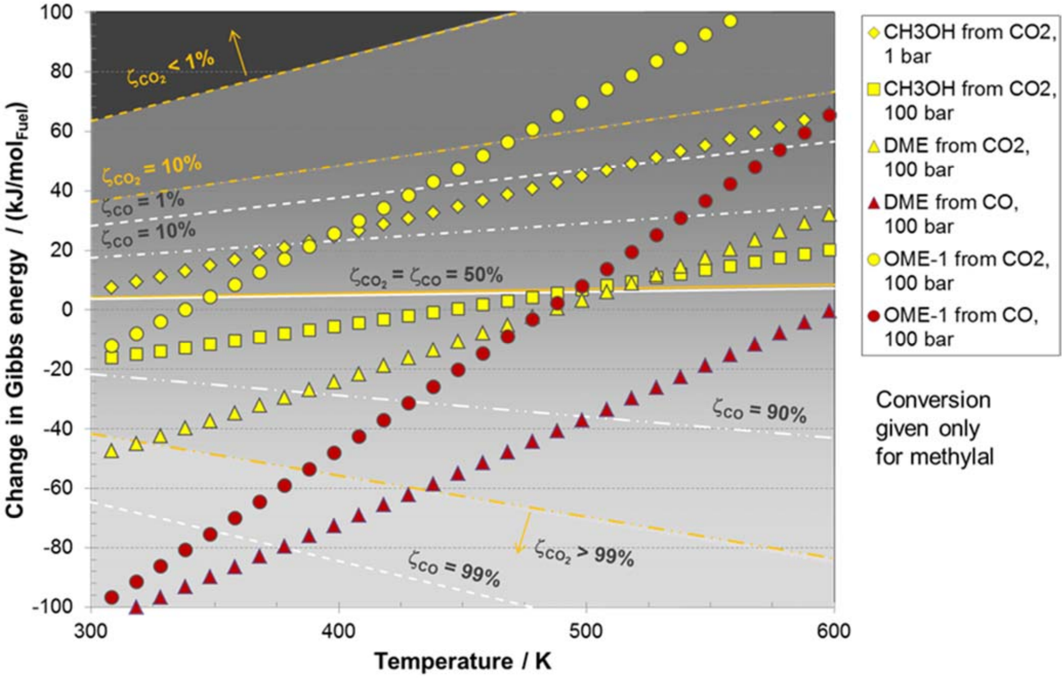
Phase diagrams for water, methanol, DME and OME



- Low temperatures: liquid OME production below 40 bar ⇒ gas/liquid/ solid contact
- Moderate temperature: gas phase reaction, heterogeneously catalyzed

Gibbs Energy evaluation for OME, DME & methanol synthesis from CO_2 on base ideal gas behaviour

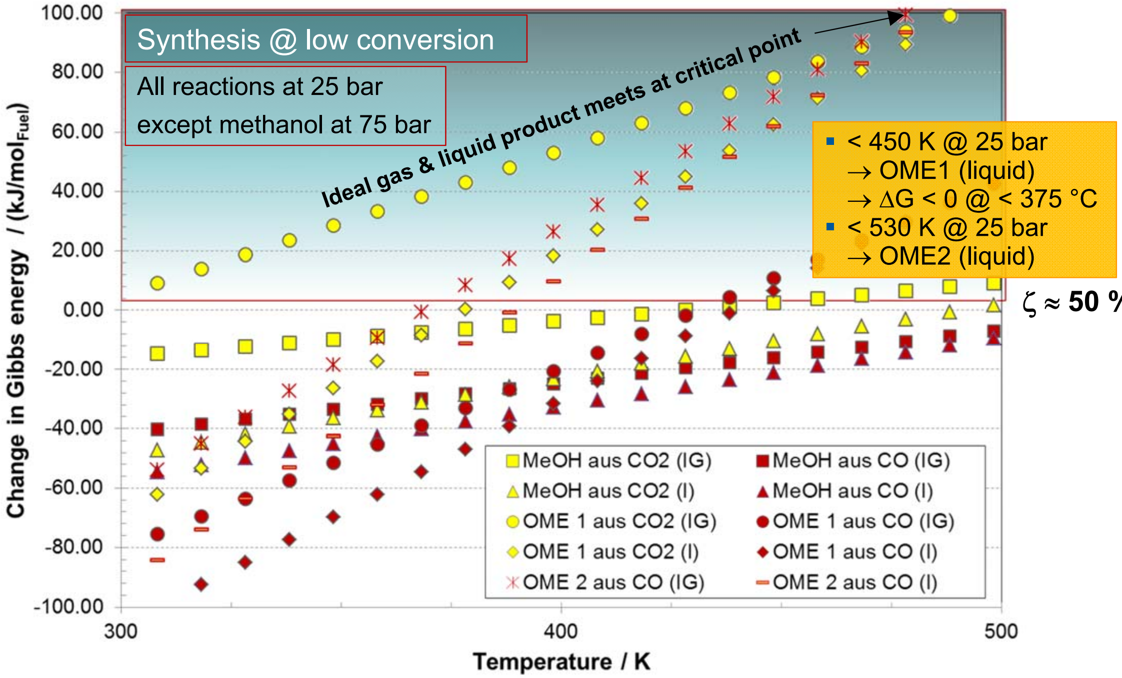
JÜLICH FORSCHUNGSZENTRUM



Conversion given only for methylal

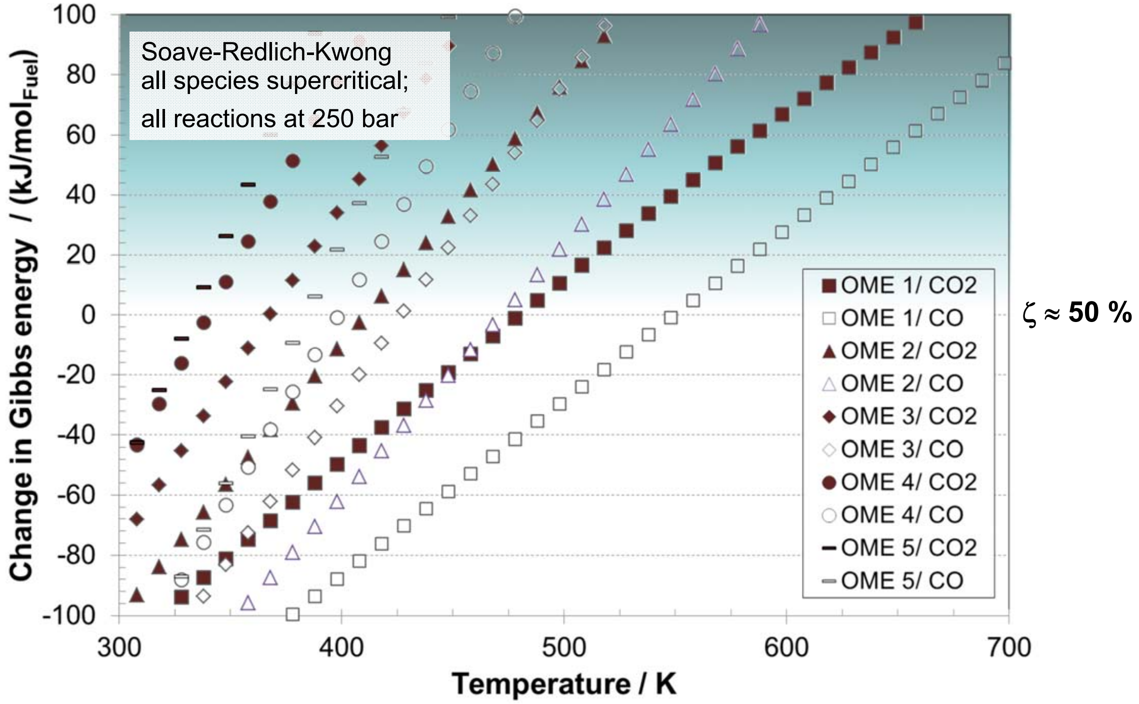
Gibbs Energy evaluation for OME, DME & methanol synthesis from CO_2 on base ideal liquid product mixtures

JÜLICH FORSCHUNGSZENTRUM



$\zeta \approx$ **50 %**

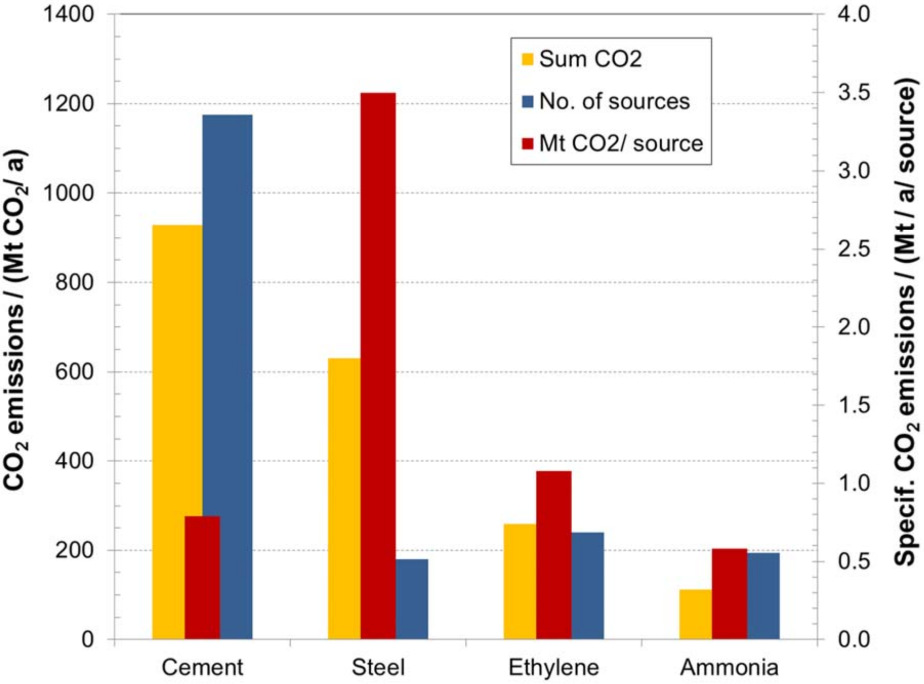
Gibbs Energy evaluation for OME synthesis from CO/ CO_2 - evaluation under supercritical conditions



Evaluation for OME synthesis from CO_2

- OME-1 can be formed potentially on a direct synthesis route at 250 bar and up to 200 °C, OME-2 below 100 °C
- At low pressure, i.e. 25 bar OME-1 direct synthesis can occur at temperatures below 100 °C in the liquid phase. Hereby a water-OME-1 separation is necessary.
- Higher OME, especially OME-3-5 cannot be formed on a direct synthesis route
- Side reactions such as methanol and DME formation will play a role for OME synthesis
- VLE calculations and G^E-models must be applied to evaluate the option of a direct OME-1 synthesis
- Oxygen must be removed from CO_2 leading to water production and unfavorably Gibbs energy for the product mixtures. Therefore, water must be removed before the next reaction steps can be performed
- Formaldehyde as intermediate of the indirect synthesis route must be formed from methanol with hydrogen as byproduct, not with partial oxidation forming water. This increases efficiency to a value about 47 %

Sources for CO_2 from industry

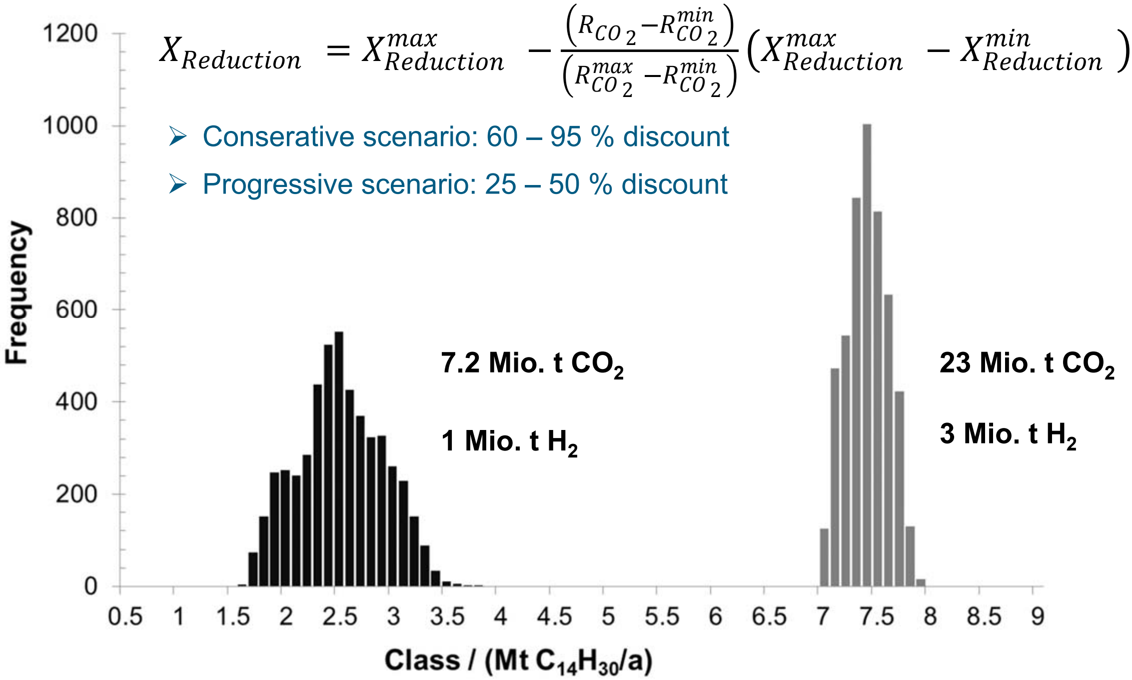


Fuel synthesis & CO_2 source must fit to eachother

Mass balances for P2F

$$X_{Reduction} = X_{Reduction}^{max} - \frac{\left(R_{CO_2} - R_{CO_2}^{min}\right)}{\left(R_{CO_2}^{max} - R_{CO_2}^{min}\right)}\left(X_{Reduction}^{max} - X_{Reduction}^{min}\right)$$

- Conservative scenario: 60 – 95 % discount
- Progressive scenario: 25 – 50 % discount



Summary

- DME via P2F path leads to doubled costs, but offers -45 % CO_2 emissions
- OME-1 can be formed potentially on a direct synthesis route at 250 bar and up to 200 °C, OME-2 below 100 °C
- At low pressure, i.e. 25 bar OME-1 direct synthesis can occur at temperatures below 100 °C in the liquid phase. Hereby a water-OME-1 separation is necessary.
- Formaldehyde as intermediate of the indirect synthesis route must be formed from methanol with hydrogen as byproduct, not with partial oxidation forming water. This increases efficiency to a value about 47 %
- Fuel synthesis & CO_2 source must fit to eachother
- Monte-Carlo simulations with evaluated CO_2 emission form industry lead to 2.5 Mio. t. fuel / a for a conserative scenario

Bio Oil

Thomas Willner,
Hamburg University of Applied Sciences, Chemical Engineering Research Group, Hamburg, Germany

Bio oils are an important intermediate product on the way from biomass to liquid fuels. These fuels are related to a new generation of biofuels based on nonfood biomass reaching drop-in standard fuel quality. Bio oils are derived from direct liquefaction (DL) pathways such as flash pyrolysis, hydrothermal solvolysis or organic solvolysis. DL is a thermochemical conversion route featuring the potential of high energy efficiency and low production costs.

The production lines from biomass to standard liquid fuels are including two process steps:

1. Bio oil production by direct liquefaction in the temperature range of 300 to 500 °C

2. Bio oil upgrading to standard liquid fuels by hydrotreating and refining

The main challenges of DL are reduction of char formation, maximization of oil yield as well as reduction of oxygen content. Regarding the oxygen content it has to be considered that typical lignocellulosic biomass is containing 44 wt.% oxygen but standard fuels nearly none.

Flash (fast) pyrolysis has the highest level of development among DL pathways. The bio oil yield up to 70 % is high but the oil quality is extremely poor due to high water content (20 to 30 %), high oxygen content (> 40 %), low combustion value (LCV 15 MJ/kg), high density (> 1 g/cm³) and poor storage stability. Thus very high effort is needed for upgrading the oil to standard fuel quality by hydrocracking and refining. A promising new variant is catalytic hydropyrolysis under hydrogen pressure directly combined with catalytic hydrogenation such as the IH2 process of GTI in Chicago/USA. The IH2 process yields up to 30 % of hydrocarbon fuel with a hydrogen demand of 5 wt.% based on dry biomass. Stated overall production costs are about 700 Euro/tonne of fuel at 2000 tonne dry feed/day scale.

Hydrothermal solvolysis is converting biomass in a water slurry reactor at about 200 bar and 350 °C. The derived bio oil at a yield of 45 % has very high viscosity (tar like), elevated combustion value (LCV 30 MJ/kg) and high density (> 1 g/cm³). Thus the effort for upgrading the oil to standard fuel quality is still quite high.

Organic solvolysis organic uses solvents as reaction media for the biomass conversion. The reaction pressure typically up to 50 bar has to be adjusted to the boiling point of the solvent at conversion temperature in the range of 300 to 400 °C. Resulting bio oils have good quality due to low viscosity, low density and elevated combustion value (LCV 30 MJ/kg). Thus the effort for upgrading the oil to standard fuel quality is quite low. A promising new variant is the READiTM process of Nexxoil (www.nexxoil.com) developed in cooperation with the Hamburg University of Applied Science in Germany. The READiTM process is combining solvolysis in a self-regenerative heavy oil sump phase with reactive distillation. No elevated pressure, no extra solvent and no catalyst are needed for the conversion step. Including upgrading the oil by hydrogenation the READiTM process yields up to 30 wt.% hydrocarbon fuel with a hydrogen demand of 2,5 wt.% based on dry biomass. Stated overall production costs are about 300 Euro/tonne of fuel at 2000 tonne dry feed/day scale. This is below today`s world market fuel prices and makes the READiTM process profitable even in times of low oil prices.

CC4E Competence Center für Erneuerbare Energien & EnergieEffizienz

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Hamburg University of Applied Sciences

Bio Oil

Direct Liquefaction of Biomass and Waste

Thomas Willner
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Chemical Engineering
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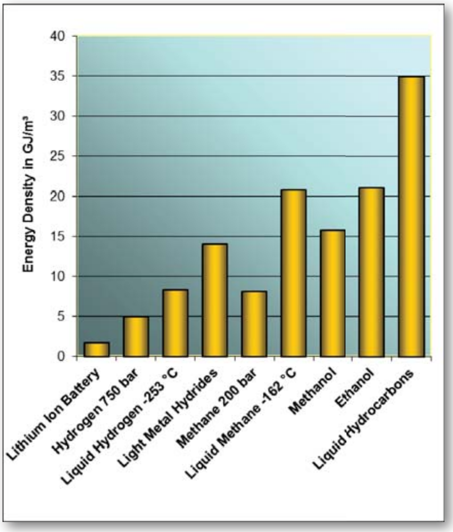
TRENDS, Aachen **4th December 2015**

Transportation: Based on Liquid Hydrocarbon Fuels (93 %)*

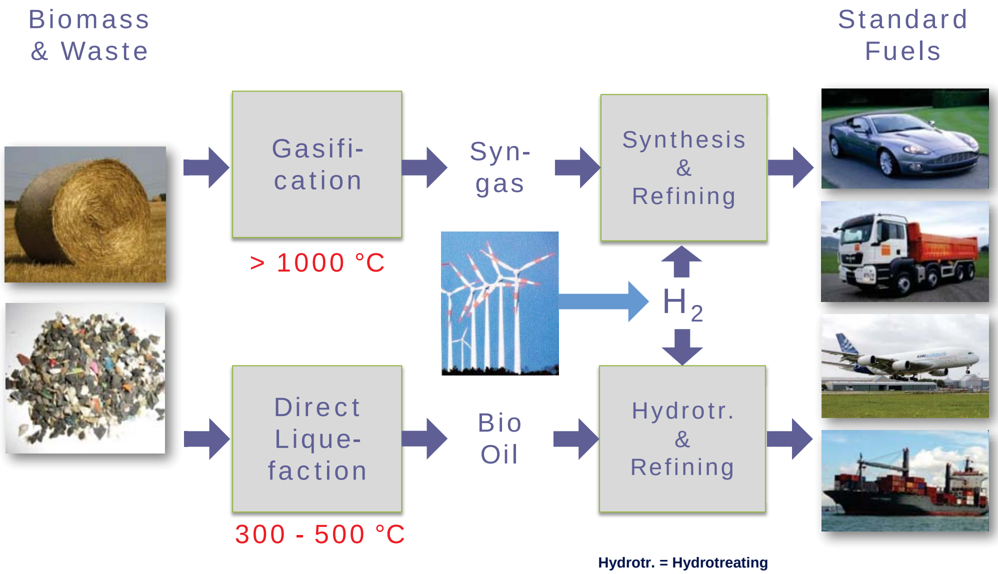


- Highest Energy Density
- Easy Handling & Transport & Storage
- Existing Infrastructure

Standard Fuels

*** Source: IEA 2015**

Chemical Pathways integrating Power to Liquid (PtL)



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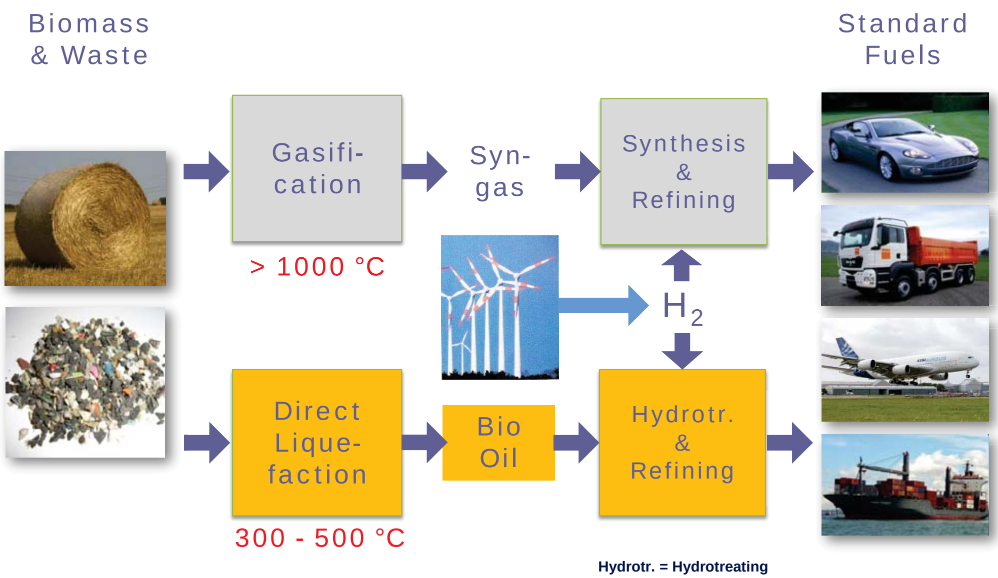
Chemical Pathways integrating Power to Liquid (PtL)



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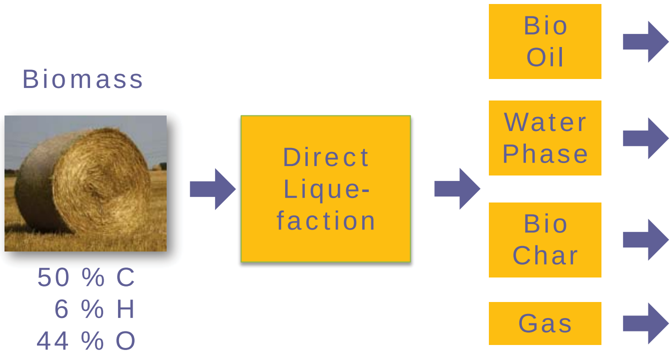
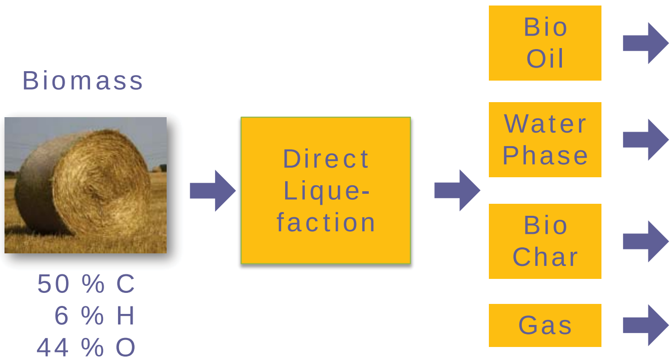
Products of Direct Liquefaction



Products of Direct Liquefaction



Main Challenges of Direct Liquefaction:

- Reduction of Char Formation
- Maximization of Bio Oil Yield
- Reduction of Oxygen Content

Bio Oil: Basic Pathways of Direct Liquefaction

Biomass

Flash Pyrolysis → Bio Oil →

Hydro-thermal Solvolysis → Bio Oil →


Organic Solvolysis → Bio Oil →

Biomass & Waste

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Bio Oil: Basic Pathways of Direct Liquefaction

Possible Combination with Hydrogen & Catalysts

Flash Pyrolysis → Bio Oil →

Hydro-thermal Solvolysis → Bio Oil →


Organic Solvolysis → Bio Oil →

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Flash Pyrolysis

➔ Flash Pyrolysis ➔

60 en%	
Bio Oil	70 %
Bio Char	15 %
Gas	15 %

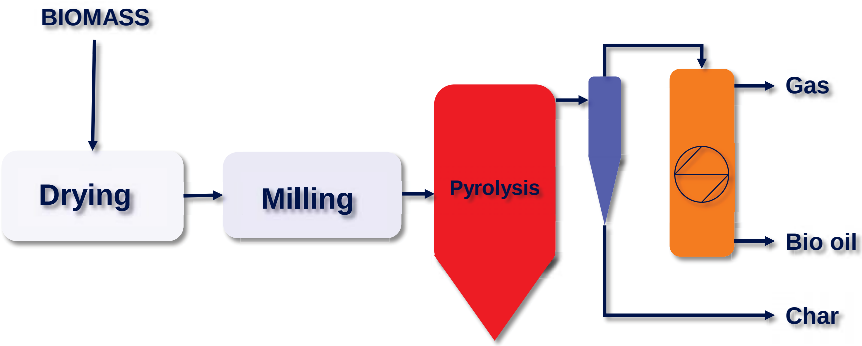
- Rapid heating of the dry biomass
- Reaction: 475 °C, 1 atm
- Evaporating the cracked molecules
- Rapid cooling of the vapors

Typical bio oil properties:

- Miscible with water (not with oil), high water content (20 - 30 %)
- High oxygen content (> 40 %), low LCV (15 MJ/kg), high density (> 1 g/cm³)

Very high effort for upgrading (hydrocracking & refining) the oil to hydrocarbon drop in fuels (standard fuels)

Flash Pyrolysis



Source: Dietrich Meier: Flash Pyrolysis and Bio Crude Upgrading. ProcessNet Presentation, Frankfurt/Main 18 Sept. 2013

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Flash Pyrolysis

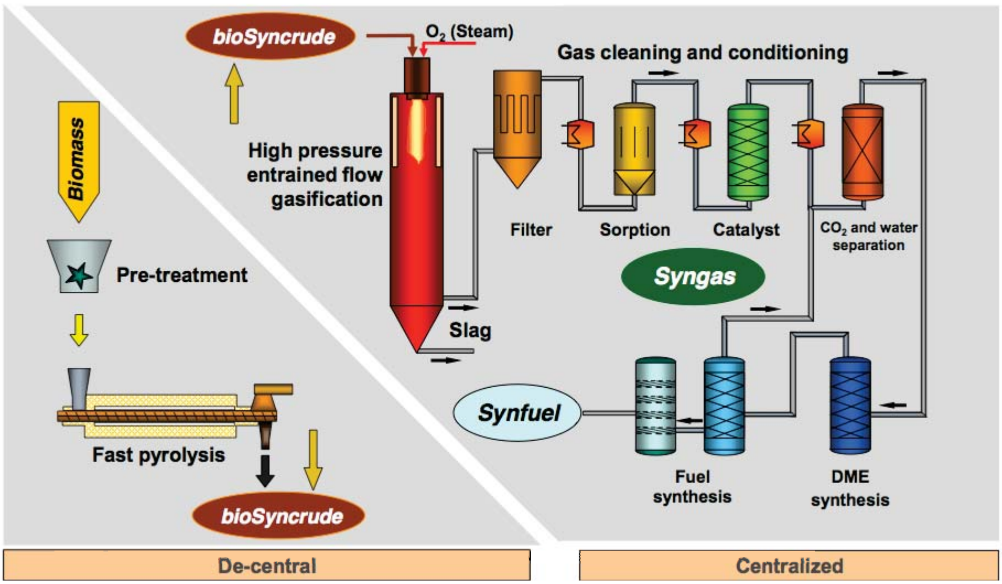
Active companies:

- BTG/Empyro (The Netherlands): Rotating cone 120 t/d
- Ensyn (Canada/USA): Fluidized bed 75 t/d
  - Envergent = Joint Venture UOP & Ensyn: Upgrading of bio oil (Hydrotreating) for drop in fuels
- Metso (Finland): Fluidized bed 200 t/d
- KiOR (USA): Fluidized bed & cat (Biomass FCC) 500 t/d
  - Upgrading of bio oil (Hydrotreating) for drop in fuels
- And others

FCC = Fluid Catalytic Cracking

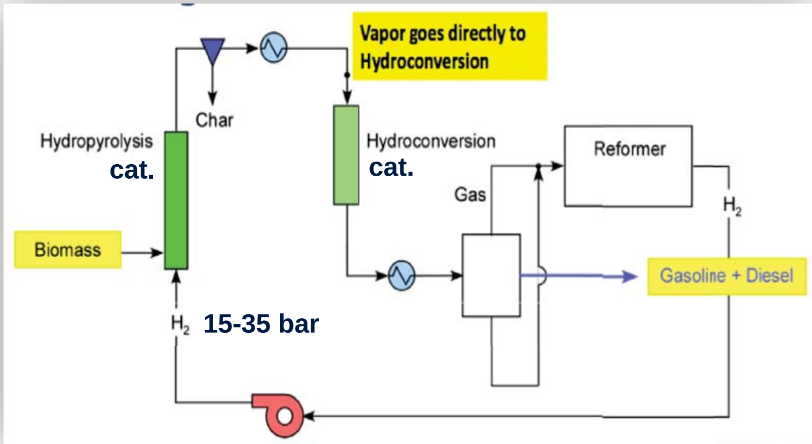
Source: Dietrich Meier: Flash Pyrolysis and Bio Crude Upgrading. ProcessNet Presentation, Frankfurt/Main 18 Sept. 2013

Flash Pyrolysis & Gasification (Bioliq / KIT in Germany)



Hydroprolysis & Hydrogenation (IH2 / GTI in USA)

50 kg/h pilot plant; 25-30% bio oil yield with <2% O (65 en%)



Source: Marker et al.: Biomass to Gasoline and Diesel Using Integrated Hydropyrolysis and Hydroconversion. DOE Technical Report. Chicago Dec.. 2012

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Economics of the IH2 GTI Process

Standard Fuels

H_2

Biomass → IH2 GTI Process → Bio oil → Refining →

Hydrogen demand: 5 wt.% of dry biomass

Production costs: 700 Euro/tonne of fuel at 2000 tonne dry feed/day scale

Sources: - Marker et al.: Biomass to Gasoline and Diesel Using Integrated Hydropyrolysis and Hydroconversion. DOE Technical Report. Chicago Dec.. 2012

- http://www.cricatalyst.com/en/catalysts/renewables/in-the-news/ih2-technology-licensed-for-demonstration-plant.html

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Hydrothermal Solvolysis

Hydro-thermal Solvolysis → 75 en%

Bio Oil	45 %
Water Phase	30 %
Bio Char	< 1 %
Gas	25 %

- Biomass water slurry
- Reaction: 350 °C, 200 bar

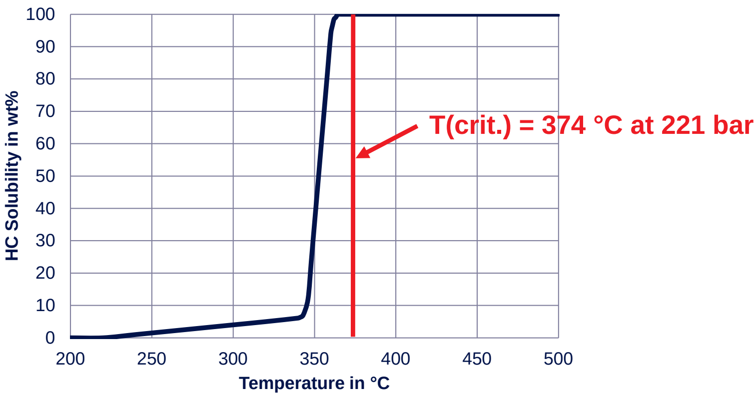
Typical bio oil properties:

- High viscous or tar like solid at 20 °C
- Oxygen 15 %, LCV 30 MJ/kg, high density (> 1 g/cm³)

Quite high effort for upgrading (hydrocracking & refining) the oil to hydrocarbon drop in fuels (standard fuels)

Hydrothermal: Solvolytic Effect

Solvolytic effect due to strong increase of HC solubility in water near critical point



Source: Michael Modell: Reforming of organic substances in supercritical water. Extended Abstracts of the Battery Division/Energy Technology Group of the Electrochemical Society, Spring Meeting, St. Louis, Missouri, 11-16 May 1980; pp 1332-1334

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Hydrothermal + CO/H_2 + Cat.:

LBL-Process: Lawrence Berkley National Laboratories, CA, USA, 1982-85

Wood slurry in water (20% solids)

- **Pre-Hydrolysis:**

180 °C, H_2SO_4 pH 1,7, 45 min

- **Subsequent reaction conditions:**

350-380 °C, 170-240 bar, CO/H_2,

Na_2CO_3 pH 8, 5-60 min

ca. 30 % Bio oil yield (waf)

ca. 1% Char

Bio oil = bitumen like, Density >1

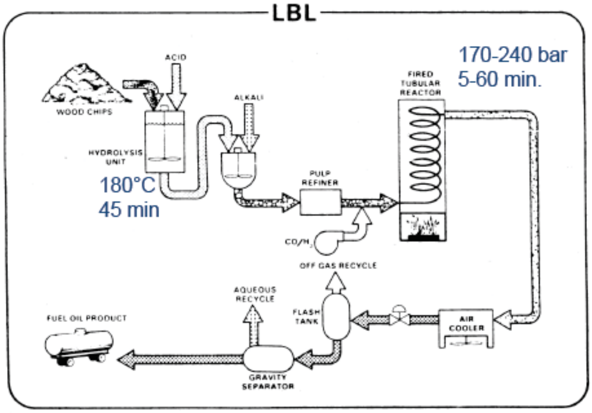
H/C 1,1-1,2

Oxygen 15-19%

LCV appr. 32 MJ/kg

BOM Pilot Plant in Albany, OR, USA

3 t/d Wood



Source: Douglas C. Elliott: Description and Utilization of Product from Direct Liquefaction of Biomass. Biotechnology and Bioengineering Symp. No. 11, 1981, pp 187-198

BOM = Bureau of Mines

Hydrothermal: HTU (Hydrothermal Upgrading): Shell 1990

e. g. Wood slurry in water

300-350 °C, 120-180 bar

5-20 min

45 % (75 en%) Bio oil yield (waf)

25 % Gas (> 90 % CO_2)

20 % H_2O + 10 % Organics (acidic)

<1% Char

Bio oil = Tar (solid below 80 °C)

H/C 1,1

Oxygen 10-18%

LCV appr. 30 MJ/kg

Suitable for both dry and wet biomass

Pilot plant of Biofuel B.V. (Goudriaan) in Apeldoorn/NL

100 kg/h wet Biomass, 8 kg/h Bio oil

Source: F. Goudriaan, J. E. Naber (Biofuel B.V.): HTU Diesel from Wet Waste Streams: Presented at the Symposium New Biofuels, Berlin, May 2008

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Hydrothermal

Active companies:

- Licella (Australia): Cat HTR Process 120 t/d under constr.
- Altaca (Turkey): CatLiq Process 200 t/d under constr.
- Steeper Energy Group (Denmark, Canada):
  Cat. Hydrofaction Process 0,2 t/d
- And others

HTR = Hydrothermal Reactor

Organic Solvolysis

→ Organic Solvolysis →

65 en%

Bio Oil	40 %
Water Phase	30 %
Bio Char	15 %
Gas	15 %

- Dry biomass
- Reaction: 350 °C, 1 - 50 bar
- Organic solvent as reaction medium

Typical bio oil properties:

- Low viscous oil
- Oxygen 20 %, LCV 30 MJ/kg, medium density (0,9 g/cm³)

Quite low effort for upgrading (hydrotreating & refining) the oil to hydrocarbon drop in fuels (standard fuels)

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Organic Solvolysis + CO/H_2 + Cat.:

PERC-Process: Pittsberg Energy Research Center, USA, 1980-84

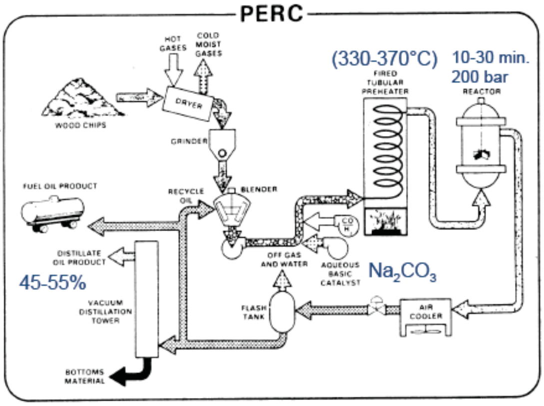
Wood slurry in recycleoil (<10% solids)
330-370 °C, 200 bar, CO/H_2
H_2O/Na_2CO_3 , 10-30 min

45-55 % Bio oil yield (waf)
ca. 1% Char

- **High demand of CO**
- **Deactivation of catalysts**
- **Difficult separation of oil/water/char**
- **Sealing problems**
- **Bio oil = high viscous & not stable (repolymerisation)**

BOM-Pilot Plant in Albany, OR, USA

3 t/d Wood



Quelle: Douglas C. Elliott: Description and Utilization of Product from Direct Liquefaction of Biomass. Biotechnology and Bioengineering Symp. No. 11, 1981, pp 187-198

BOM = Bureau of Mines

Organic Solvolysis + H_2 + Cat.:

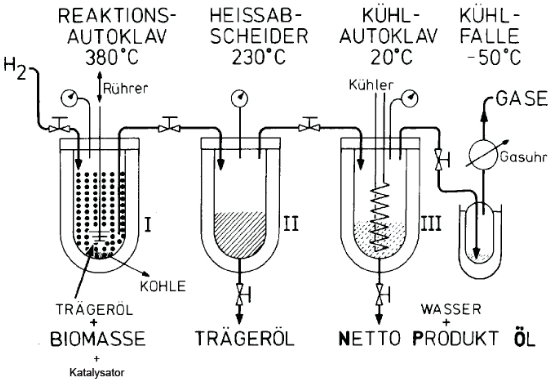
Thünen Institute Process, Hamburg, 1984

Wood slurry in recycleoil (66% s.)
380 °C, >100 bar H_2
Pt/Pd cat.

36 % Net bio oil yield (waf)
25 % Water phase (acidic)
38 % Gas (CO_2, CO, C_1-C_4)
5 % Char
4 % H_2 demand

- **Bio oil low viscous**

Batch, bench scale 2 Liter



Sources: D. Meier, K. Fuchs, O. Faix: Direct Hydroliquefaction of Spruce Wood into Light- and Middle-Distillate Oils. Paper presented at IGT Symp. “Energy from Biomass and Wastes X”, Washington D.C., USA, 1986

D. Meier: Verfahren zur Biomasseverflüssigung, Möglichkeiten und Grenzen. Vortrag auf der FGK-Fachtagung „Direktverflüssigung von Biomasse und Kunststoffen“, Magdeburg, 2007

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Organic Solvolysis with Tetralin (Hydrogen Donor) or Recycleoil: Meier zu Köcker, TU Berlin, 1990

Wood slurry in recycleoil (20% solids)

Reaction (Extraction):

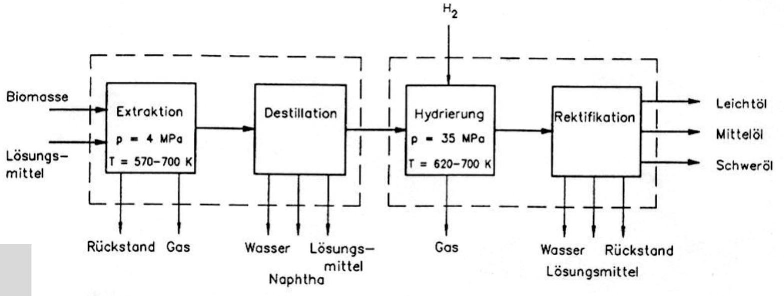
370-400 °C, 40 bar

Subsequent hydrogenation of the boi oil:

350-430 °C, 350 bar H_2

Continuous labscale plant (tube reactor):

1,5 kg/h Biomass



48 % Bio oil yield before hydrogenation

25 % Water phase (acidic)

5 % Naphtha

19 % Gas (CO_2, CO, C_1-C_4)

3 % Char

•Bio oil before hydrogenation:

83% C, 6,9% H, 0,2% N, 9,8% O; H/C = 1,0; O/C = 0,09, LCV 34,5 MJ/kg

•H2 demand for hydrogenation = 2 % until product oil H/C = 1,5

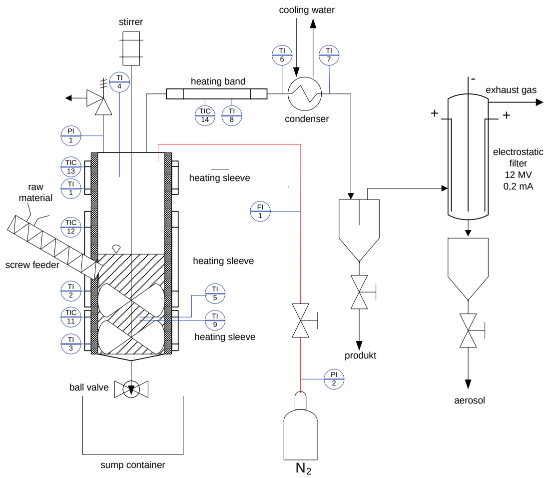
Source: A. Nelte, H. Meier zu Köcker: Kontinuierliches Verfahren zur Gewinnung flüssiger Kohlenwasserstoffe aus pflanzlichen und kommunalen Abfällen. Chem.-Ing.-Tech. 62 (1990) Nr. 5, S. 414-415

Organic Solvolysis in a Stabilized Sump Phase: READi^{TM} Process

Cooperation of Hamburg University of Applied Sciences (HUAS) and NEXXOIL

Biomass

Waste



Bio oil

Principle of process: Reactive distillation, 1 atm, 350-400 °C, no H_2, no cat.

Organic Solvolysis in a Stabilized Sump Phase: READi™ Process

Cooperation of HUAS and NEXXOIL

Reaction conditions for wood:

350 °C, 1 atm

40 % Bio oil yield
30 % Water phase (acidic)
15 % Gas
15 % Char

Bio oil properties:
20 % O; LCV 30 MJ/kg (65 en%)
Low viscosity (4 mm²/s at 40 °C)
Low density (< 1 g/cm³ at 20 °C)

Subsequent hydrogenation of the boi oil:

350-400 °C, 50-150 bar H_2

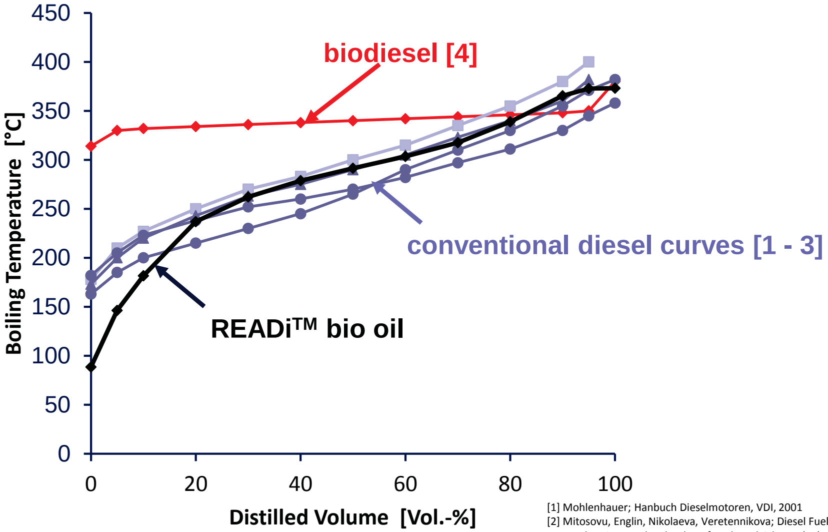
Continuous operating liquefaction plants
up to 200 kg/week pilot plant scale

Batch and continuous operating hydrogenation plants.

Reactor size up to 1,8 Liter

Organic Solvolysis in a Stabilized Sump Phase: READi™ Process

Cooperation of HUAS and NEXXOIL



[1] Mohlenhauer; Hanbuch Dieselmotoren, VDI, 2001
[2] Mitosovu, Englin, Nikolaeva, Veretennikova; Diesel Fuel with higer destillation range, chemistry and technoloy of Fuels and Oils, 17 (11), 610-614, Spinger, 1981
[3] Aral AG, Dieselkraftstoff, Fachreihe Forschung und Technik, Bochum, 1995
[4] www.wearcheck.de, 2010

V047/CVO/RSO

Economics of the READi^{TM} Process

Cooperation of HUAS and NEXXOIL

Standard Fuels

Biomass → READi^{TM} Process → Bio oil → Hydrotreating & Refining (H_2) → Standard Fuels

Hydrogen demand: 2,5 wt.% of dry biomass

Production costs: 300 Euro/tonne of fuel at 2000 tonne dry feed/day scale

World market fuel price level: 450 Euro/tonne

Source: Nexxoil

Hamburg University of Applied Sciences / Campus Bergedorf

Tailor-Made Fuels from Biomass

Challenges and Opportunities fro Catalysis

Walter Leitner

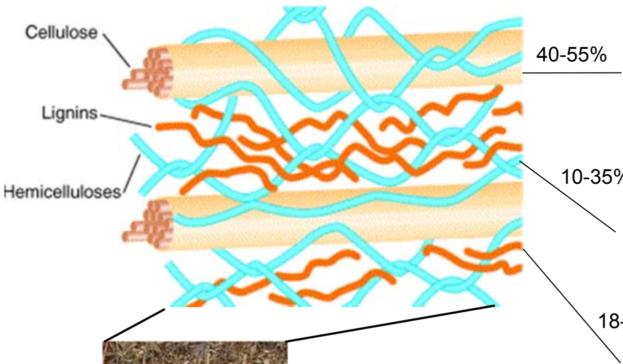
Institut für Technische und Makromolekulare Chemie

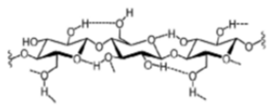
RWTH Aachen University

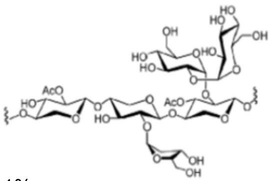
TMFB Tailor-Made Fuels from Biomass

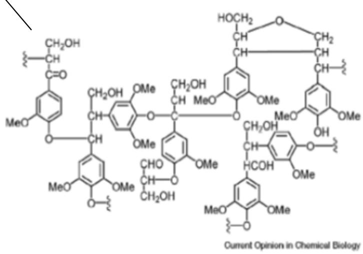
TRENDS 2015
Aachen, 4. Dezember 2015

Biomass as Feedstock: Lignocellulose



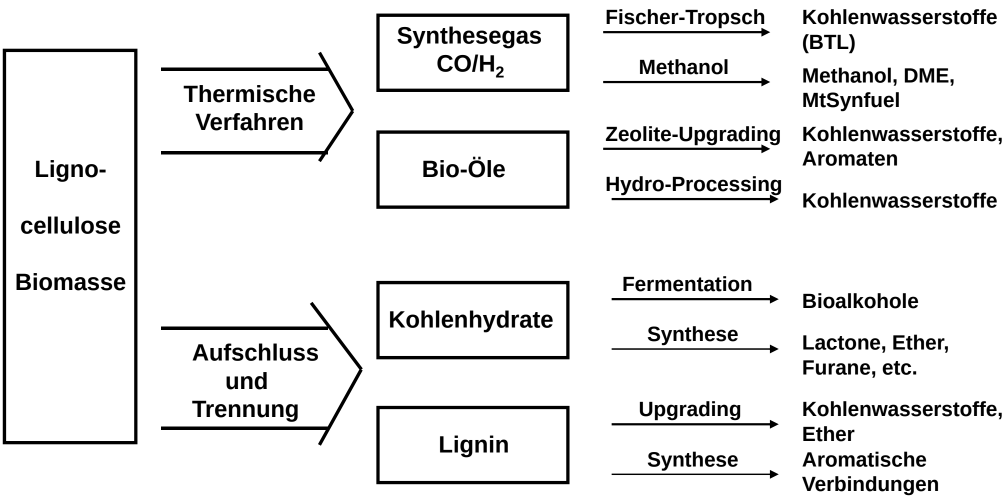






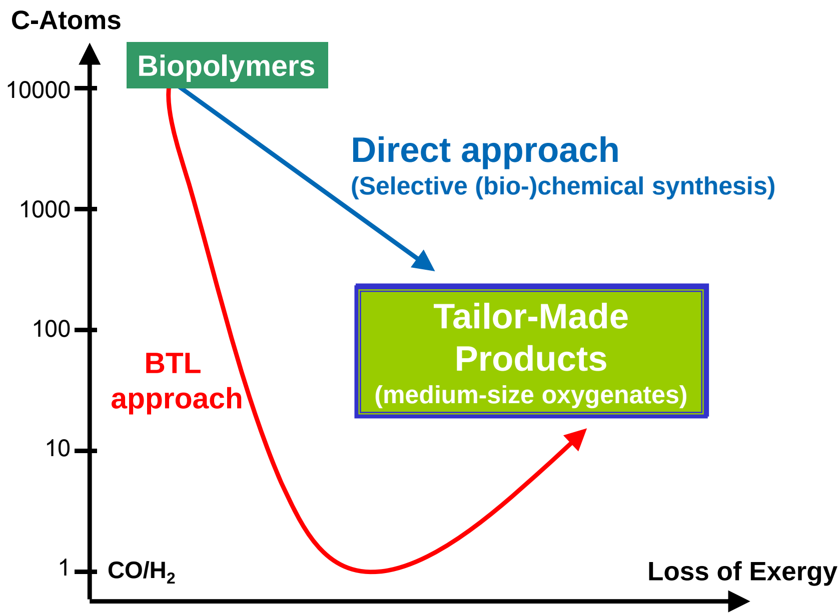
Sustainability of biomass ressources, see:
C. Sommerville et al., *Science* **2010**, *329*, 790.
C&E News, July 7, **2014**, 18-19

Biomass as Feedstock: Lignocellulose

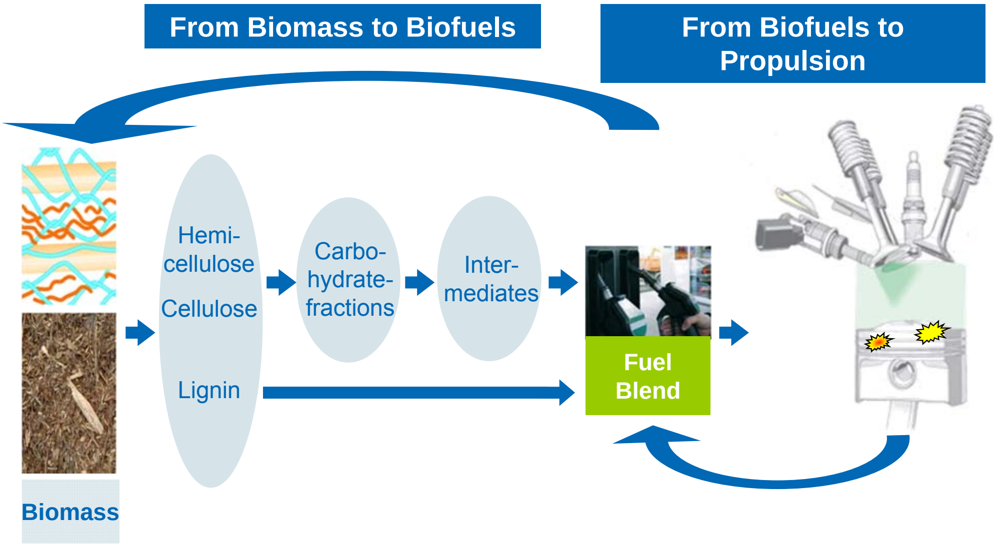


Quelle: W. Leitner, in: Zukunft der Energie, Springer-Verlag 2008
nach G.W. Huber, S. Iborra, A. Corma (2006): Chemical Reviews 106, 4044-4098.

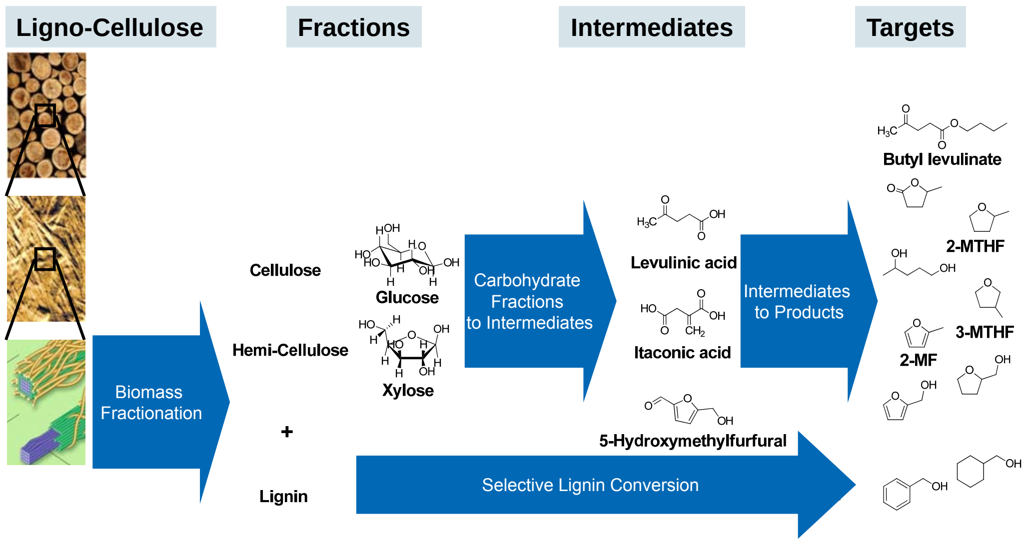
Tailor-Made Fuels and Products



The Fuel Design Process

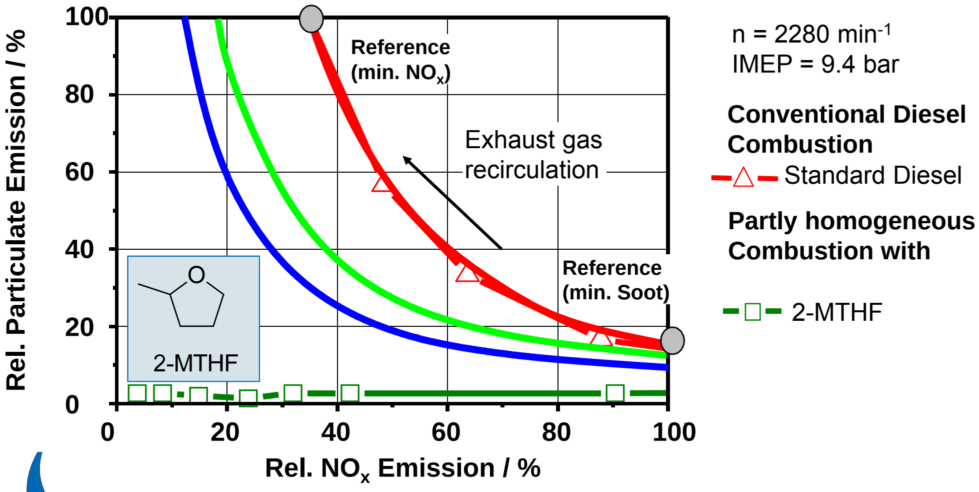


Pathway Design akin Retrosynthetic Analysis



F. Geilen, B. Engendahl, A. Harwardt, W. Marquardt, J. Klankermayer, W. Leitner, *Angew. Chem. Int. Ed*, **2010,** *49*, 5510-5514 .

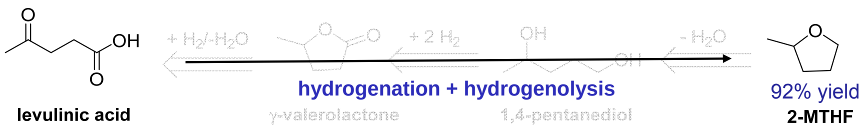
Fuels for Compression Ignition Engines

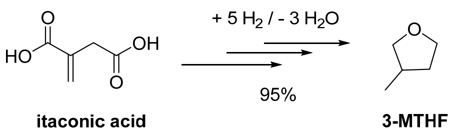


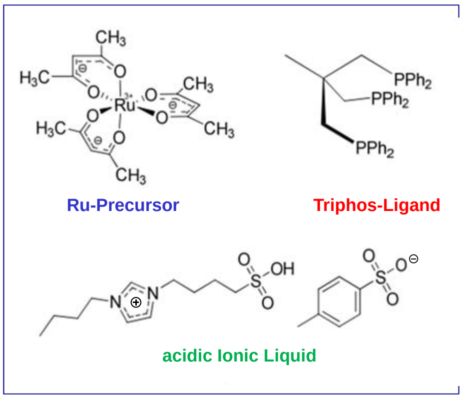
Towards NOx and soot-free combustion

S. Pischinger, J. Klankermayer, et al.: Energy Fuels, vol. 25 (10), pp. 4734–4744, 2011
S. Pischinger, J. Klankermayer, W. Leitner, et al.: MTZ, vol. 12, pp. 54-60, 2010

Selective Transformation *via* Multifunctional Catalysis

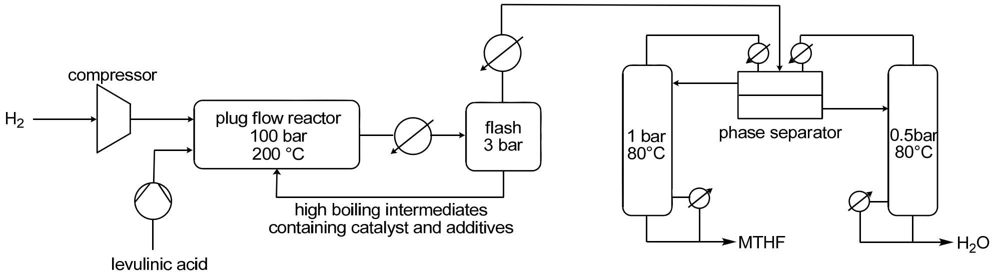






F. Geilen, B. Engendahl, A. Harwardt, W. Marquardt, J. Klankermayer, W. Leitner, *Angew. Chem. Int. Ed,* **2010,** *49*, 5510-5514 .

Integrated Process Design



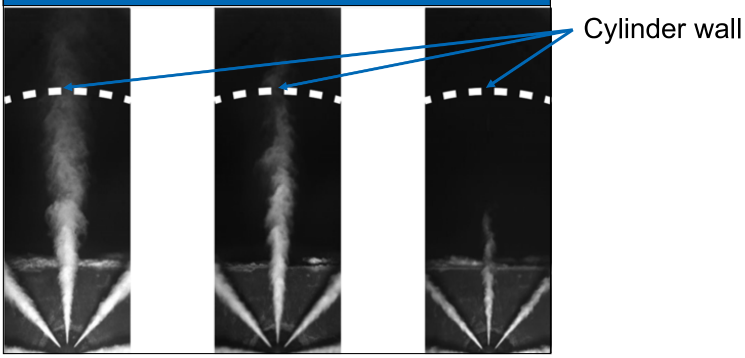
typical biphasic product mixture

- continous flow process
- integrated catalyst recycling
- heteroazeotrope distillation

F. Geilen, B. Engendahl, A. Harwardt, W. Marquardt, J. Klankermayer, W. Leitner, *Angew. Chem. Int. Ed,* **2010,** *49*, 5510-5514 .

Fuels for Compression Ignition Engines

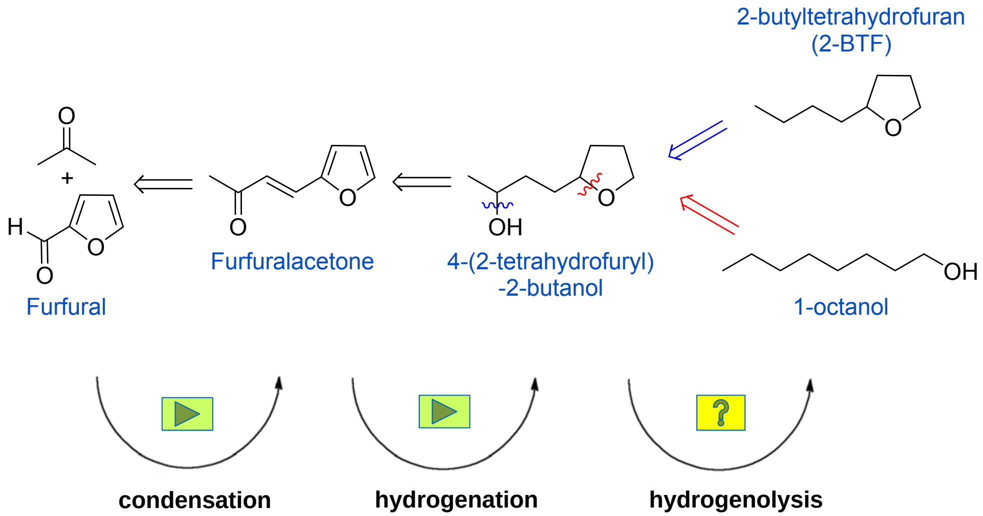
Fuel specific mixing and evaporation



Diesel	Butyl levulinate	2-MTHF	
80-360 °C	232 °C	80 °C	Boiling Temp.
0.027 kg/s	0.034 kg/s	0.025 kg/s	Surface Tension
2.0-4.5 mm^2/s	2.0 mm^2/s	0.5 mm^2/s	Viscosity

Kneer et al.: Atomization Spray, vol. 21 (3), pp. 221-235, 2011

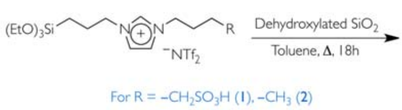
Pathway Design Beyond C6

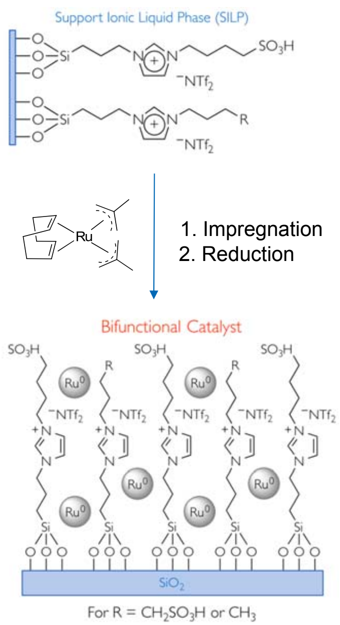


J. Julis, W. Leitner,
Angew. Chem. Int. Ed. **2012**, *51*, 8615 –8619.

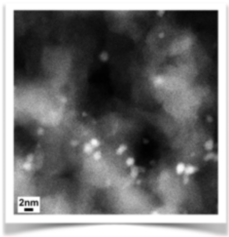
Heuser, B., Jakob, M., Kremer, F., Pischinger, S. et al.,
SAE Technical Paper 2013-36-0571, **2013**, doi:10.4271/2013-36-0571.

Multifunctional Nanoparticle Catalysts



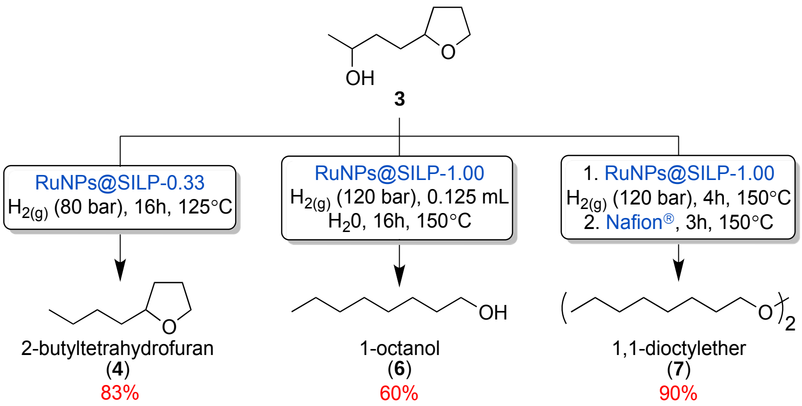


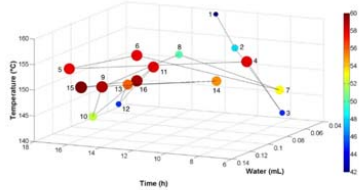
STEM of RuNPs@SILP-1.00
NP Size = 1.7±0.4 nm



K. L. Luska, J. Julis, E. Stavitski, D. N. Zakharov, A. Adams, W. Leitner,
Chem. Sci.. **2014**, *5*, 4895-4905.

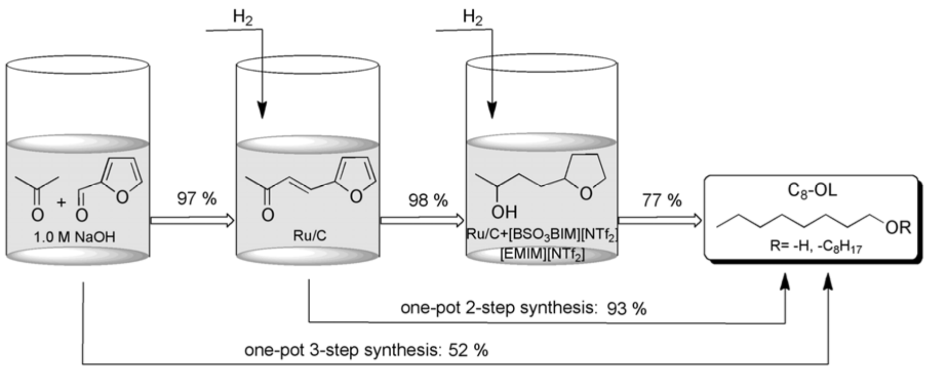
Selective C-O Bond Cleavage





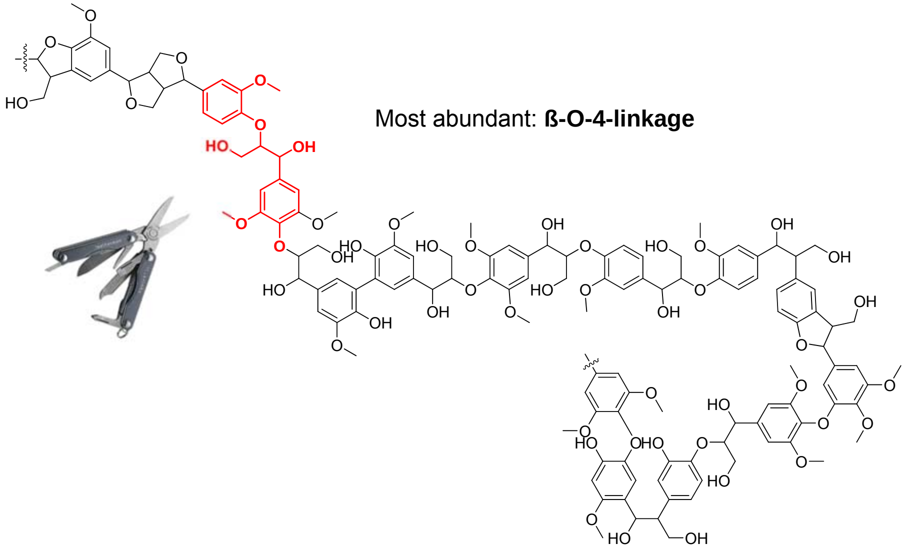
K. L. Luska, J. Julis, E. Stavitski, D. N. Zakharov, A. Adams, W. Leitner,
Chem. Sci.. **2014**, *5,* 4895-4905.

Integrated Process



J. Julis, W. Leitner,
Angew. Chem. Int. Ed. **2012**, *51*, 8615 – 8619.

The Lignin Challenge

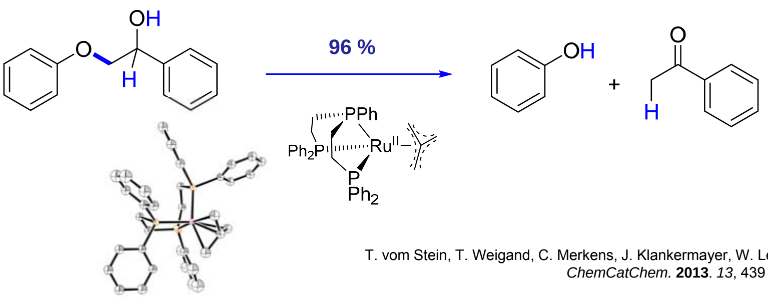


Most abundant: **ß-O-4-linkage**

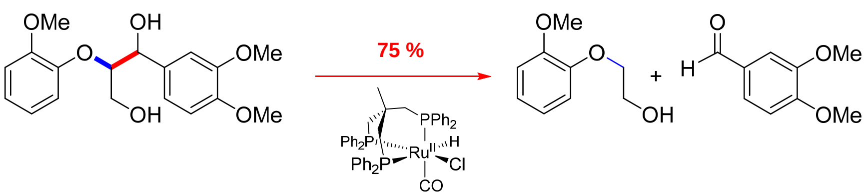
Prof. Dr. Walter Fuchs
Ordinarius für Technische Chemie, RWTH Aachen
"Zur Chemie des Lignins",
Springer Verlag Berlin, 1926

J. Zakzeski, P. C. Bruijnincx, A. L. Jongerius, B. M. Weckhuysen, *Chem. Rev.* **2010**, *110*, 3552.

C-O vs C-C Cleavage in Lignin Models

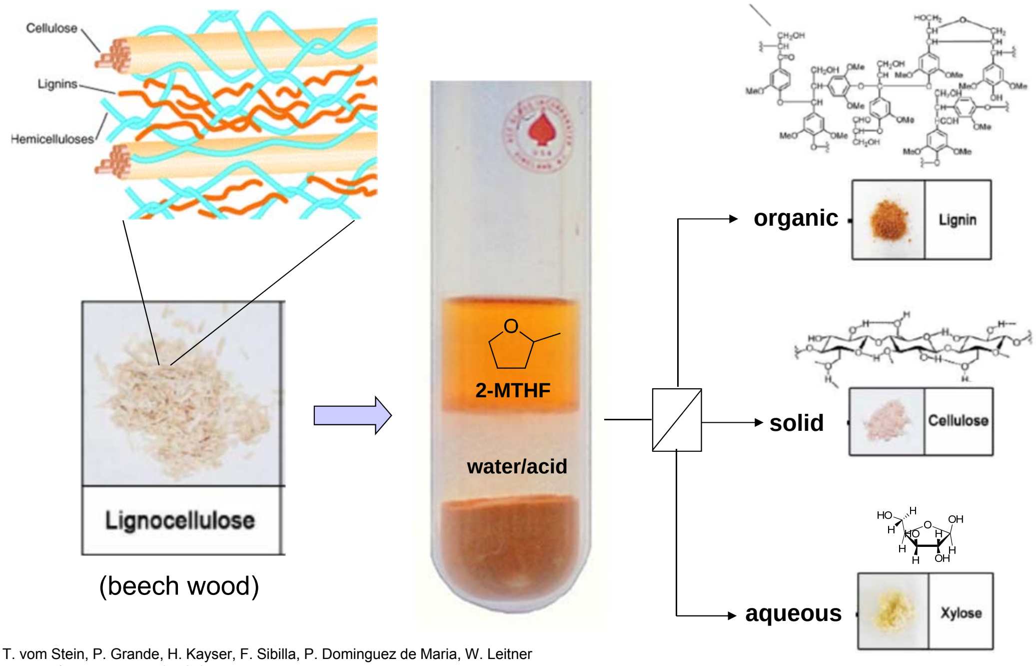


T. vom Stein, T. Weigand, C. Merkens, J. Klankermayer, W. Leitner, *ChemCatChem.* **2013**. *13*, 439 - 441.



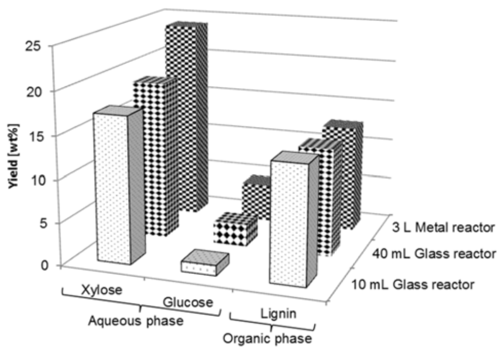
T. vom Stein, T. den Hartog, J. Buendia, S. Stoychev, J Mottweiler, Carsten Bolm, Jürgen Klankermayer, Walter Leitner, *Angew. Chem.* **2015,** in press

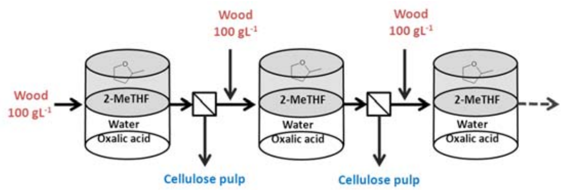
The OrganoCat Process

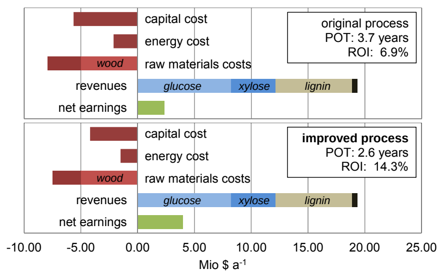


T. vom Stein, P. Grande, H. Kayser, F. Sibilla, P. Dominguez de Maria, W. Leitner
Green Chem. **2011**, *13,* 1772-1777

The OrganoCat Process

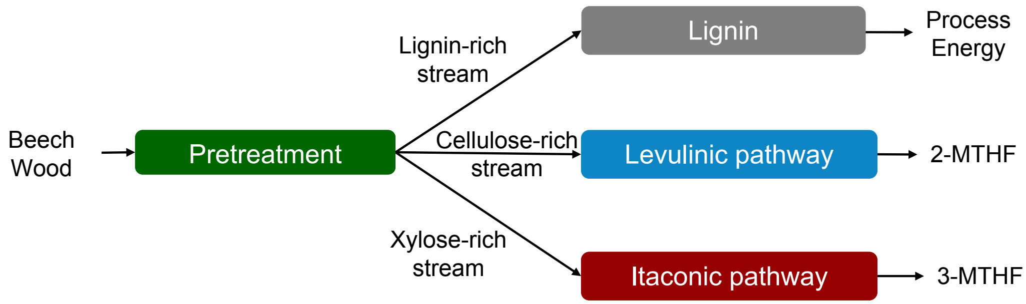






P. Grande, J. Viell, N. Theyssen, W. Marquardt, P. Dominguez de Maria, W. Leitner
Green Chem. **2015**, *17*, 3533-3539.

The TMFB Reference Process



→ Detailed Analysis of Energy and Materials Flow (Ökoinstitut Freiburg and AVT)

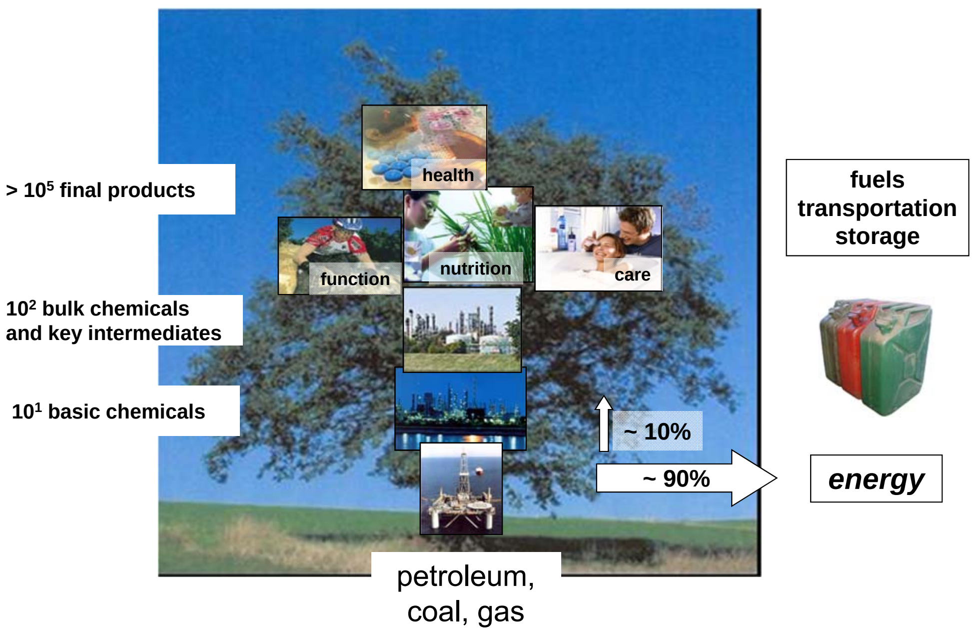
→ Debottlenecking (ITMC, BioVT, CVT, LTT, PT)

Integrated research 2013 - 2014

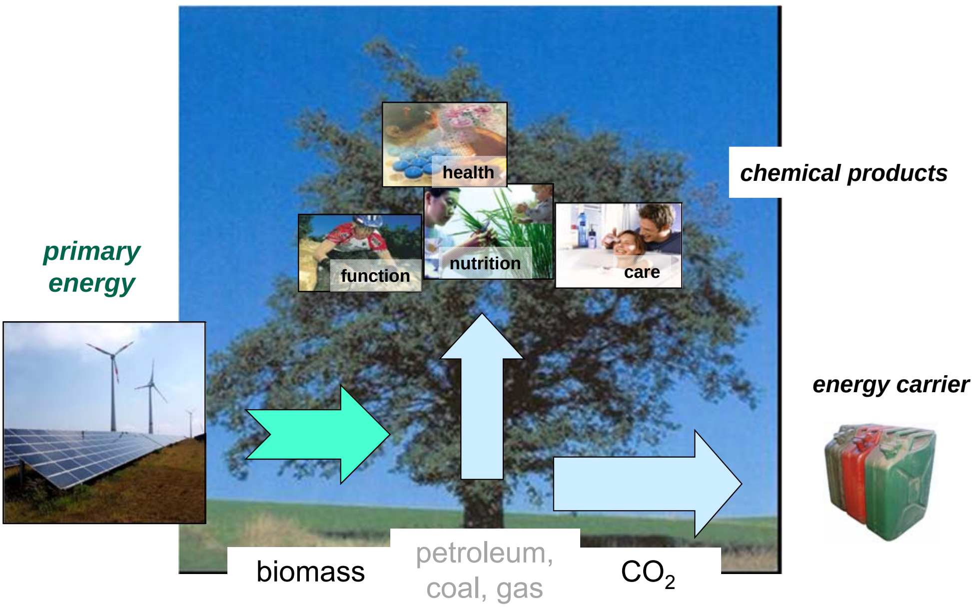
⇒ Increased mass efficiency by 30%

⇒ Decreased energy requirements by 40%

⇒ Identified main targets for new pathways



Diversification of Energy Systems and Carbon Ressources



Harnessing renewable energy with CO_2 for the chemical value chain
J. Klankermayer, W. Leitner, *Philosophical Transactions of the Royal Society A*, **2015**, *in press.*

ITMC RWTH

The TMFB Advisory Board

TMFB Tailor-Made Fuels from Biomass | RWTH AACHEN UNIVERSITY

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- Energy Biosc. Institute – **Alexis Bell** – Chemical Engineering
- University of Notre Dame – **J. F. Brennecke** – Chemical Engineering
- Universidad de Valencia – **Avelino Corma** – Chemistry
- Princeton University – **Frederick L.Dryer** – Combustion Science
- Univ. Wisconsin – **J. A. Dumesic** – Chemical and Biological Eng.
- Tech.-Univ. of Denmark – **Jochen Förster** – Biology Science
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- Shell – **Hans Gosselink** – Regional Manager Innovation & Research
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- Bayer – **Leslaw Mleczko** – Division Manager Process Technology
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- DECHEMA – **Kurt Wagemann** – Chief Executive Officer
- Shell – **W. Warnecke** – Head of Global Fuel Development

4. TMFB International Conference

"Low Carbon Fuels – From Production to Propulsion"

June 21rd - 23rd, 2016

- Annual TMFB International Workshop starting in 2008
- incl. Meeting of the International Advisory Board
- Transition into an International Conference in 2012
- Over >250 international scientists and decision makers from industry and academia

Grid Services of Battery Electric Vehicles

Michael Dronia,
Research Center for Energy Economics

Introduction

In order to reduce global warming, Greenhouse Gas (GHG) emissions must be reduced [1]. Once combined, Electric Vehicles (EVs) and renewable energy sources offer the potential to substantially decrease such GHG-emissions [2]. Powered by energy from renewable sources EVs can significantly decrease the GHG-footprint of road transportation (german: Verkehrswende) and increase its energy efficiency from 15 % to 85 % due to higher powertrain efficiency of EVs.

The EV market is emerging with an increasing number of EV models and a growth in the sale numbers of EV units [3]. With the increasing amount of EVs and an ongoing battery development, specific costs for batteries are decreasing. Therefore, it is expected that future average vehicles will have higher battery capacities than the one's today.

Challenges for the power grid and impact of EVs

The additional electrical energy consumption of EVs will not have a big impact, since it comprises only about 0.3 % of Germany's total energy consumption in 2030. Thus, the grid load increases by approximately 3 % due to EVs. Although this does not appear as a high number, this load is mainly added to the distribution grid, which in turn imposes challenges and can lead to additional investments in power supply system [4].

The future energy system is marked by a high fluctuating power generation through renewable power plants and decreasing conventional power generation. This development will lead to power imbalances and consequently to periods of oversupply or undersupply. EVs have a significant storable/shiftable capacity and therefore can be used for power balancing. Through intelligent charging of EVs the power consumption could be controlled, the integration of renewables supported and investments reduced [5] [6]. Such an intelligent charging management system (CMS) is developed in the project ePlanB.

Field test of the charging management system

The aim of the project is to develop an intelligent CMS for EVs. In order to generate optimized charging plans the system takes several input data from participants, the distribution system operator, renewable power production forecasts and energy prices into account [7].

The system is tested at a park and ride station in Buchloe, Germany. It comprises fourteen EVs from six different OEMs which are given to commuters. The project lasts over a time period of three years and will end in June 2017. It is funded by the Bavarian Ministry of Economic Affairs and Media, Energy and Technology and executed by the Lechwerke AG, LEW Verteilnetz GmbH, Research Center for Energy Economics, the city of Buchloe and the county of Ostallgaeu.

In the future, this technology can be used for energy and power management systems of EV charging station conglomerations (e.g. in car parks) with the goal to lower costs by reducing power peaks (lower cost for power peaks in case of registered power measurement), reduce grid fees and thus, reduce overall costs for EV charging stations. Furthermore, it could be used to charge EVs during times of a higher availability of renewable energy in order to decrease the effective carbon dioxide emission footprint and support the integration of renewables into electrical grid. An assessment of the effectiveness of the CMS, in spite of the aforementioned limitations, will be conducted based on the collected data during the two-year long field test.

References

[1] Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2014 Synthesis Report Chapter," 2014.

[2] D. B. Richardson, "Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration,"2013.

[3] Clean Energy Ministerial, Electric Vehicle Initiative, International Energy Agency, "Global EV Outlook - Understanding the Electric Vehicle Landscape to 2020," 2013.

[4] P. Nobis and S. Fischhaber, "Belastung der Stromnetze durch Elektromobilität," Forschungsstelle für Energiewirtschaft, München, 2015.

[5] P. Nobis, F. Samweber and S. Fischhaber, "Electric Mobility as a Functional Energy Storage in Comparison to On-Site Storage Systems for Grid Integration," Energy Procedia Volume 73, pp. 94-102, June 2015.

[6] F. Samweber, S. Köppl, S. Fattler and F. f. Energiewirtschaft, "Grid optimization with electric mobility in a cross-system," in 1st International ATZ-Conference Grid Integration of Electric Mobility (unpublished), Berlin, 2016.

[7] M. Dronia and M. Gallet, "Field test of charging management system (unpublished)," in 5th Conference on Future Automotive Technology , Fuerstenfeld, 2016.

TRENDS 2015
Transition to Renewable Energy Devices & Systems

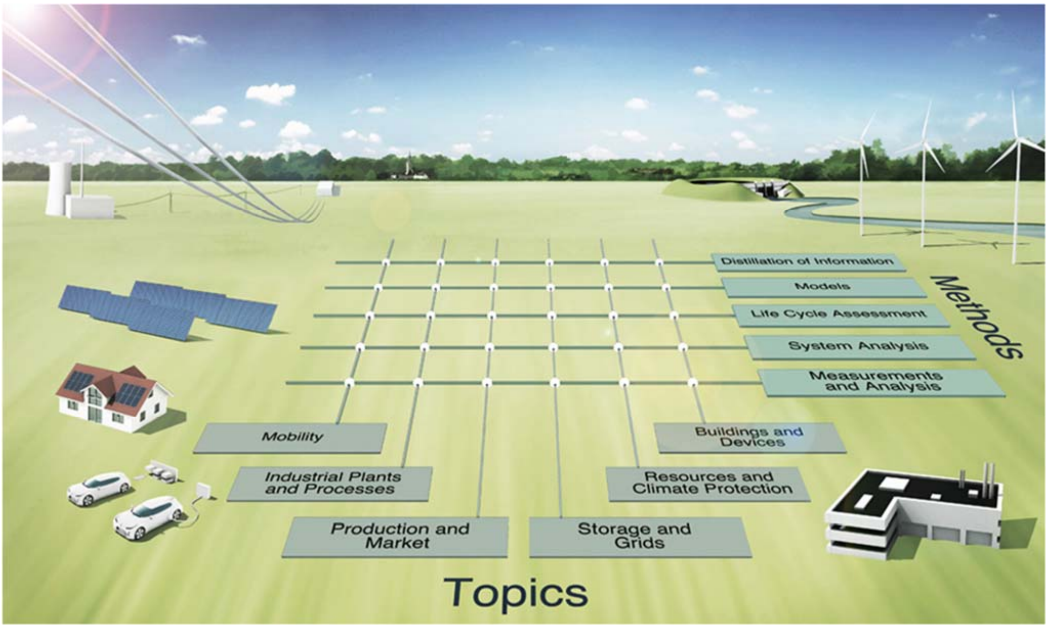
Grid Services of Battery Electric Vehicles

Michael Dronia, Research Center for Energy Economics

Aachen, 04.12.15

Forschungsstelle für Energiewirtschaft e.V. FfE

Research Center for Energy Economics (FfE)



Portrait of the FfE

www.ffe.de

- Founded in 1949
- Since 1969 in Munich
- Independent Institute with focus on latest questions in the field of energy economics
- Scientifc director: Prof. Wagner

FfE Forschung schafft Wissen

Forschungsstelle für Energiewirtschaft e.V. FfE

Table of Content

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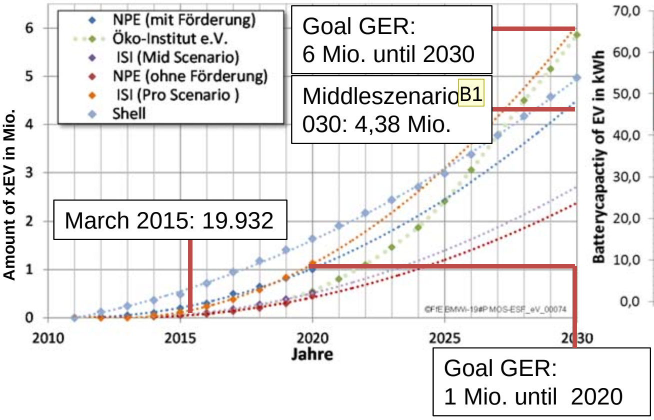
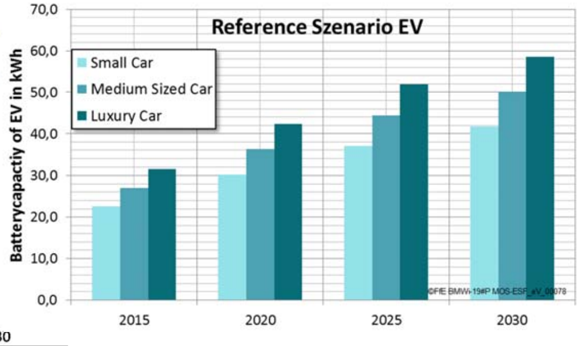
Forschungsstelle für Energiewirtschaft e.V. FfE

Status quo and Prediction on registered BEV and battery capacity





- Today: ~ 20.000 EV
- 2030: ~ 1,32 Mio. BEV

- Today: ~ 26 kWh
- 2030: ~ 50 kWh

Folie 5

B1 Middleszenario? Denglish?
Benutzer; 24.03.2016

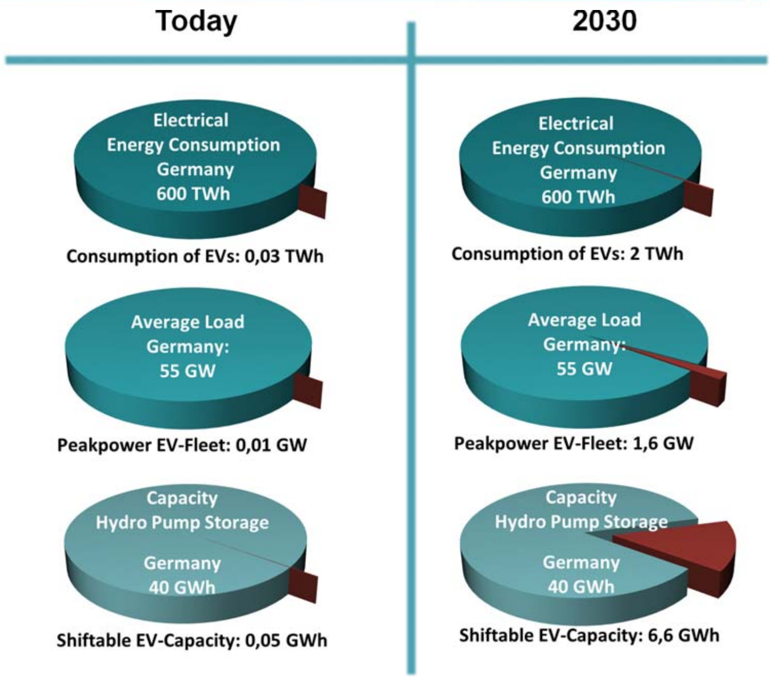
Electric Mobility:
Simple calculation of Key Figures

www.ffe.de

Energy Consumption

Grid Load

Storable Energy



Electric Mobility in Transmission Grids

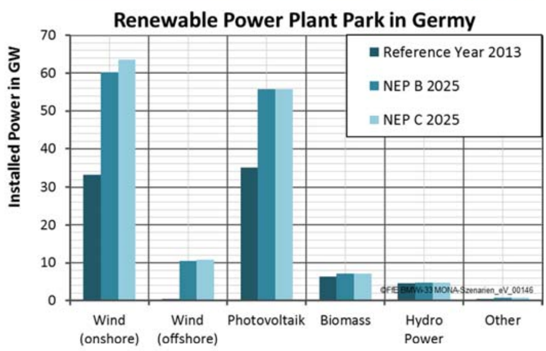
www.ffe.de

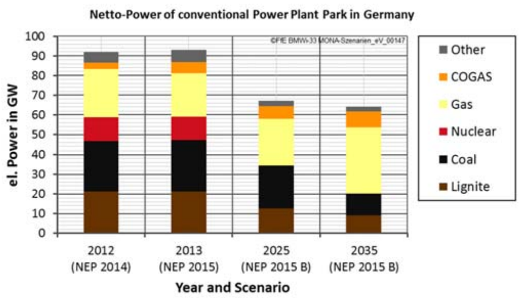
Current situation

- Increasing renewable power
- Decreasing conventional power
- Electrification of the whole energy system

Effects on the Distribution Grid

- High fluctuating power genereration by renewable power plants
  - ➢ Times of oversupply and undersupply
  - ➢ Shut down/Storage/ Load shifting
- Volatility leads to power imbalances
  - ➢ Balancing power necessary
  - ➢ Option for electric vehicles





Electric Mobility and power balancing

Scenario

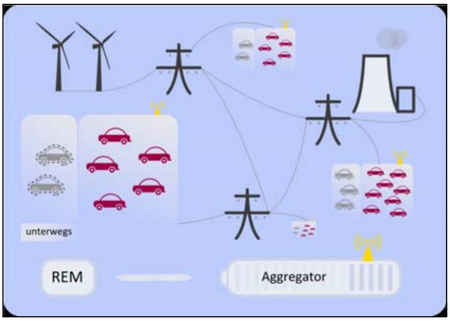


Figure: MOS2030

Potential

- PRL and n-SRL could be financially attractive[1,2,3]

  BUT:
- Strong competitors: Power2Heat, Power2Gas, Second-Life-Batteriesstoragesystems[2]
- Potentially low reliability of single vehicle
- User acceptance

➢ Impact on futures balancing power market is questionable[3]

1) *Vehicle-to-grid regulation based on a dynamic simulation of mobility behavior*, David Dallinger, Daniel Krampe, Martin Wietschel, Fraunhofer-Institut für System- und Innovationsforschung ISI, 2010
2) *Energiewirtschaftliche Betrachtung von Lademodellen für Elektroautos*, FFE, 2012
3) *Begleitforschungs-Studie Elektromobilität: Potentialermittlung der Rückspeisefähigkeit von Elektrofahrzeugen und der sich daraus ergebenden Vorteile*, Moritz Richter, Lutz Steiner, TU Darmstadt

ePlanB

Field test of the charging management system in the project ePlanB

Pictures by LEW / Christina Bleier

Landkreis Ostallgäu · Buchloe · LEW Lechwerke · LVN · FfE · Bayerisches Staatsministerium für Wirtschaft und Medien, Energie und Technologie

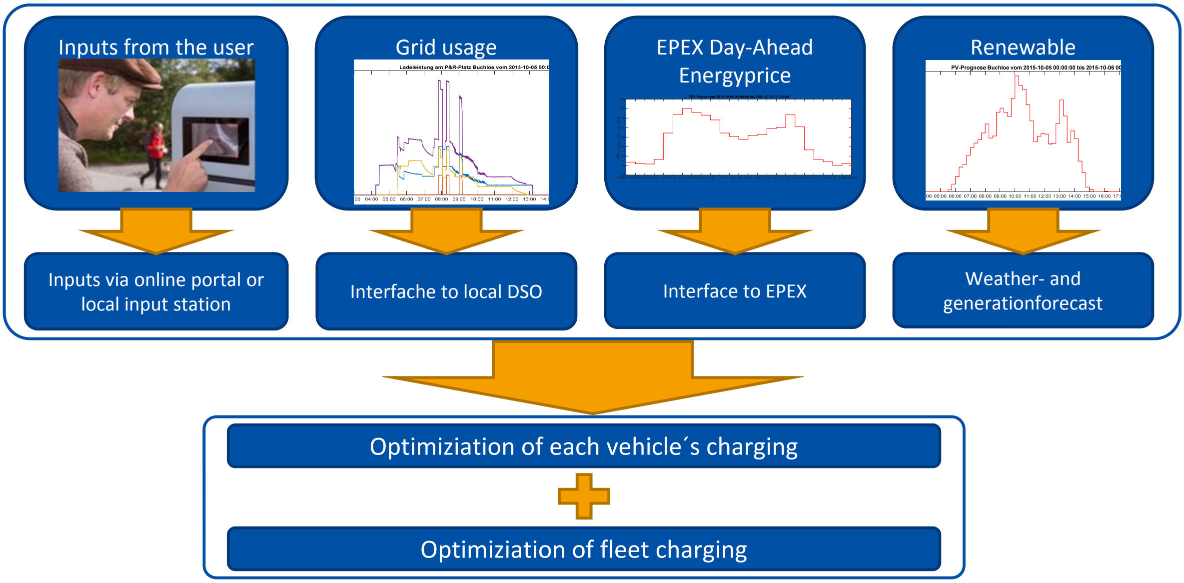
Introduction

> **Aim**: development of an intelligent charging management system for electric vehicles
> Duration: **Juli 2014 to June 2017**

> **Project Partner**:
> Forschungsstelle für Energiewirtschaft (FfE), Landkreis Ostallgäu, Stadt Buchloe, Lechwerke AG, LEW Verteilnetz GmbH.

Pictures by LEW / Christina Bleier

Intelligent Charging Management



Charging infrastructure

> Installation of 16 charging points at a P+R-Station in Buchloe
> 14 Charging points are reserved for project participants
> 2 charging points are free for public usage

Pictures by LEW / Christina Bleier

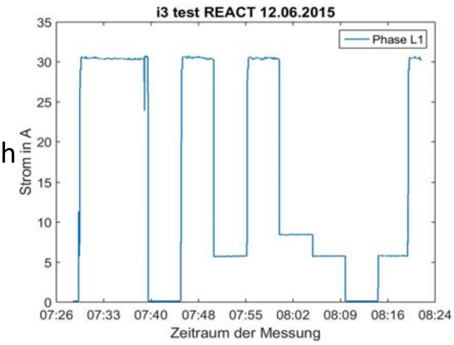
BEVs in the project

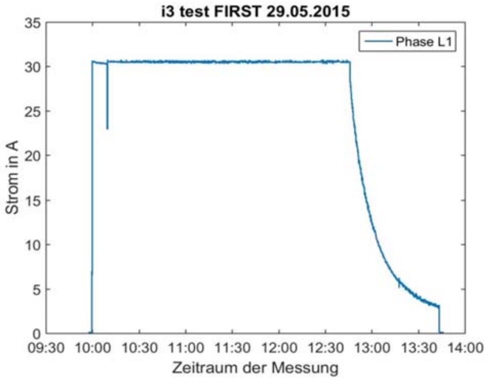
No.	Modell	Dealer
2	Renault ZOE	AUTOHAUS FISCHER
2	Mitsubishi i-MiEV	auto sangl
3	Nissan Leaf	AUTOHAUS SCHALLER
3	BMW i3	Reisacher
2	Smart fortwo ed	AUTOHAUS ALLGÄU
3	VW E-Golf	AUTOSINGER

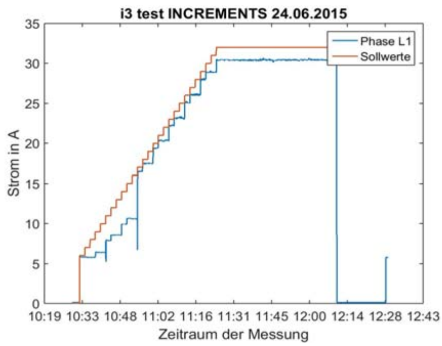
Pictures by LEW / Christina Bleier

Charging characteristic

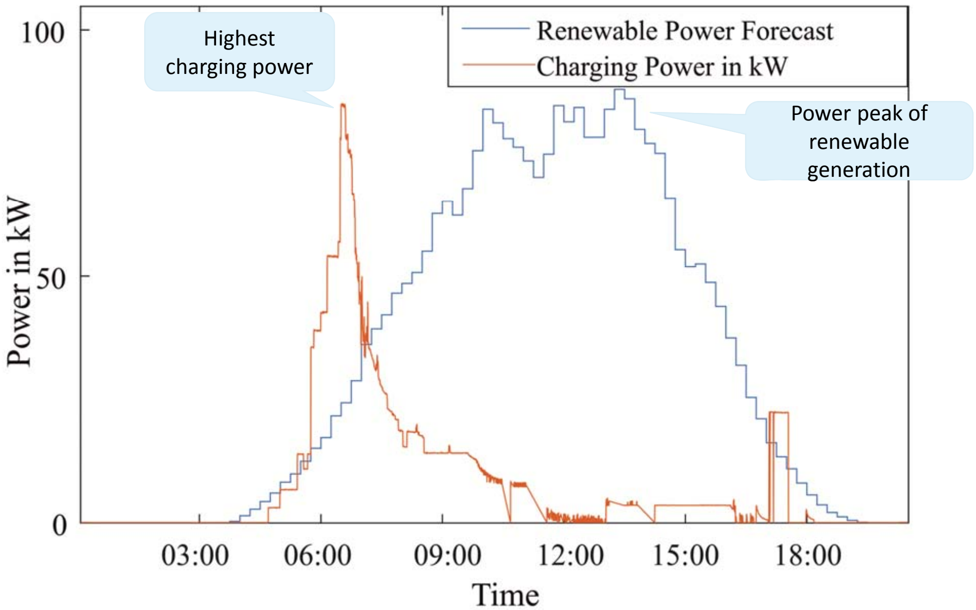
- Measuring the charging characteristic of each BEV in the project in several test procedures
- Different charging characteristics have to be considered in the charging management system



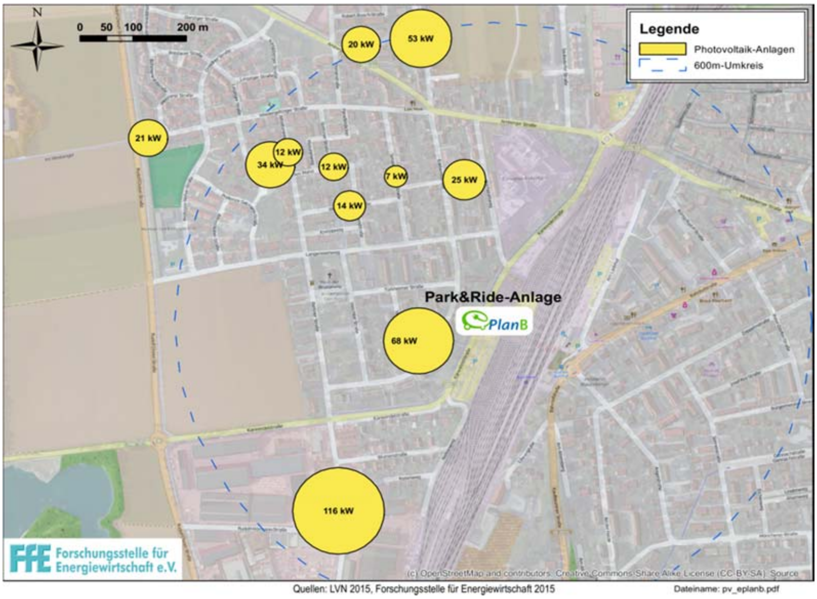




1. Phase: uncontrolled charging

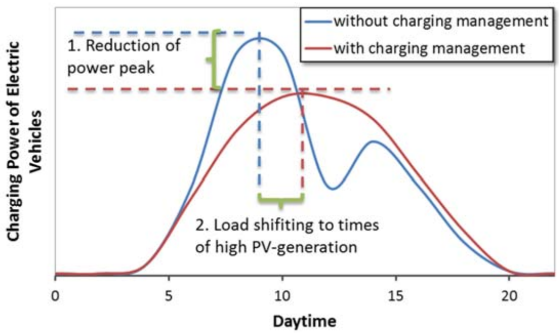


Installed PV systems in the area that are considered by the forecast

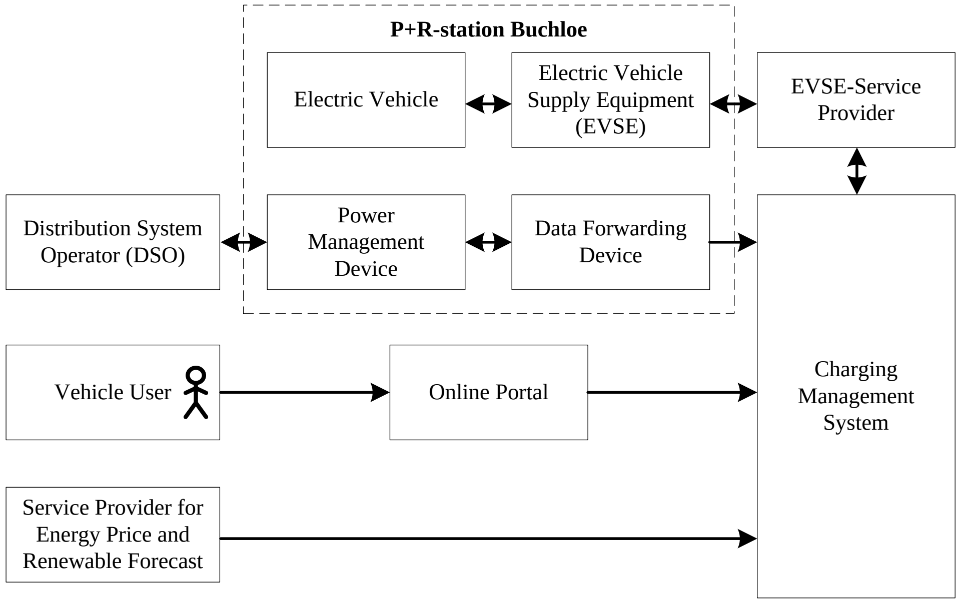


2. Phase: controlled charging

- Charging via an intelligent charging management system
- Charging is shifted to times of high PV-production
- Participants have to give the system information regarding battery state of charge and planned departure time
- Participants can give input via web-portal or locally installed HMI-terminal

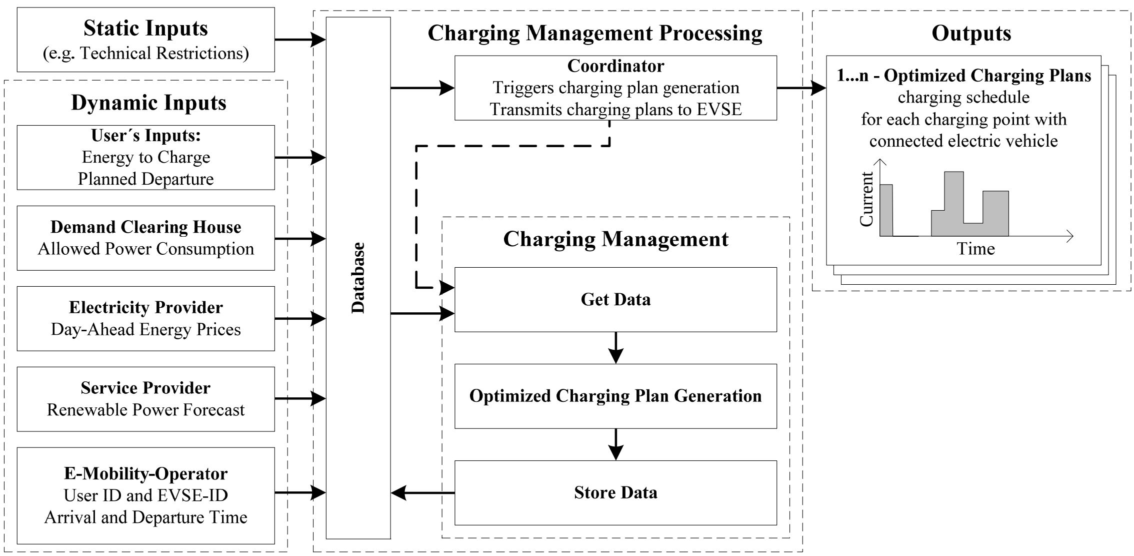


Charging Management Interfaces



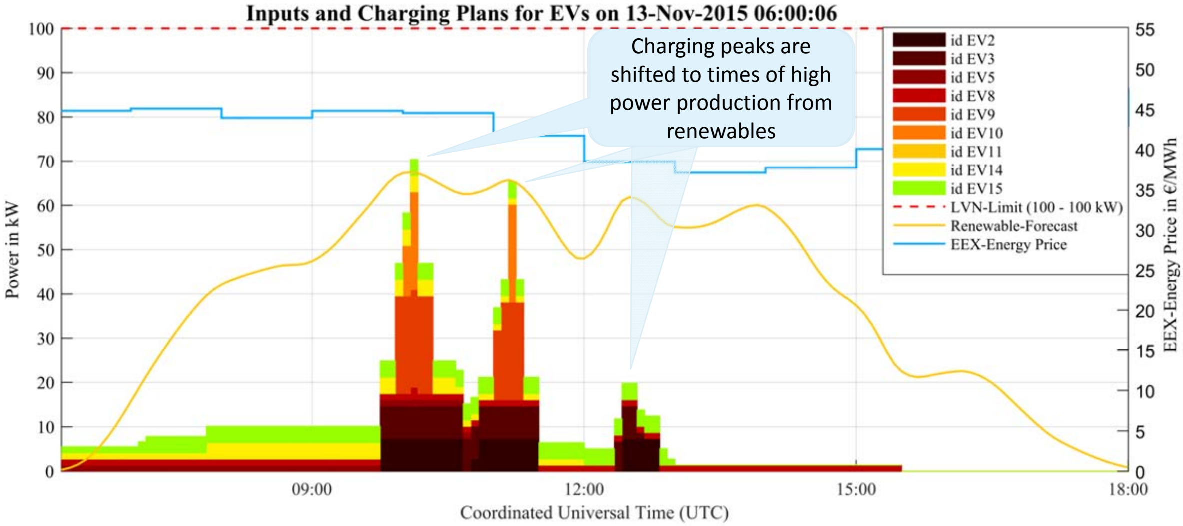
PlanB

Charging Management Processing



PlanB

Example for optimized Charging Plans



Project Participants

Pictures by LEW / Christina Bleier

Thanks for your Attention.

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