Alternative und elektrifizierte Fahrzeugantriebe (AEF)

Alternative Vehicle Propulsion Systems (AVPS)

ANSPRECHPARTNER / ORGANIZATIONAL TEAM

Fragen, Lob und Kritik richten Sie bitte an

Questions or feedback? Contact us at

FachgruppeAEF@vka.rwth-aachen.de

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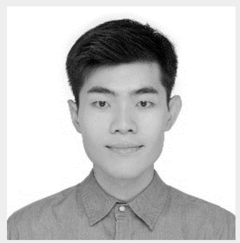

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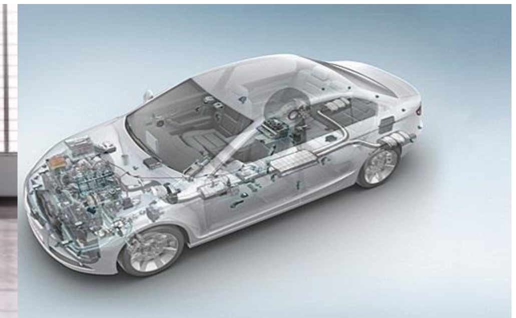
Note: DE → Deutsch (German), EN → English

VKA – Excursion 2020



Contact: Theodoros Kossioris, M.Sc. (Kossioris@vka.rwth-aachen.de)
Mehdi Hosseininasab, M.Sc. (Hosseininasab@vka.rwth-aachen.de)

Participants: 18 Students

Costs: To be announced incl. Bus transfer, Accommodations and Fees

Registration: Via email to: **exkursion_vka@vka.rwth-aachen.de**
Required Information: **Name / Matriculation Nr. / Nationality / Field of Study / Phone Nr.**

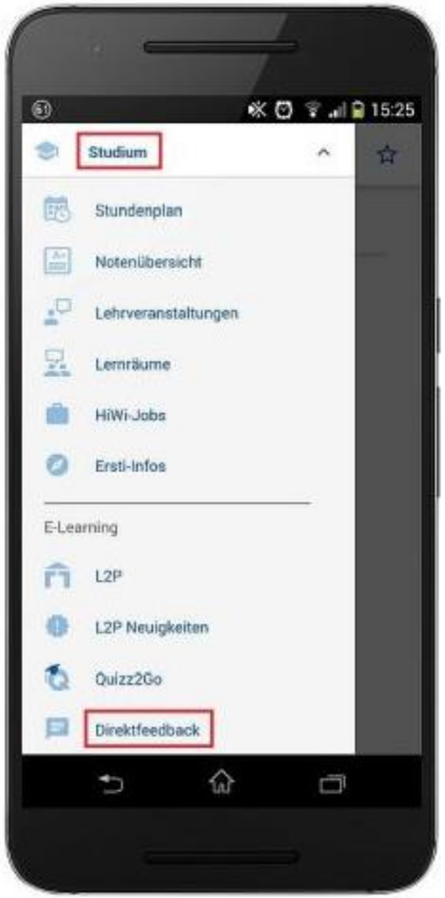
VKA – Excursion 2020
Schedule

Arrival#	Departure from	Departure time	Destination	Arrival time
1	VKA Forckenbeckstraße 4 52074 Aachen	01.06.2020 approx. 15:00	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	01.06.2020 approx. 19:30
2	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	02.06.2020 approx. 9:00	Mercedes-AMG GmbH Daimlerstraße 1 71563 Affalterbach	02.06.2020 approx. 10:30
3	Mercedes-AMG GmbH Daimlerstraße 1 71563 Affalterbach	02.06.2020 approx. 15:00	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	02.06.2020 approx. 17:00
4	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	03.06.2020 approx. 9:00	Robert Bosch GmbH 70442 Stuttgart	03.06.2020 approx. 10:30
5	Robert Bosch GmbH 70442 Stuttgart	03.06.2020 approx. 15:00	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	03.06.2020 approx. 17:00
6	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	04.06.2020 approx. 7:00	Forschungs- und Innovationszentrum (FIZ) Knorrstraße 147 80937 München	04.06.2020 approx. 10:00
7	Forschungs- und Innovationszentrum (FIZ) Knorrstraße 147 80937 München	04.06.2020 approx. 12:30	BMW Welt, Am Olympiapark 1, 80809 München	04.06.2020 approx. 13:00
8	BMW Welt, Am Olympiapark 1, 80809 München	04.06.2020 approx. 16:30	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	04.06.2020 approx. 19:00

VKA – Excursion 2020
Schedule

Arrival#	Departure from	Departure time	Destination	Arrival time
9	Jugendherberge Stuttgart Haußmannstr. 27 70188 Stuttgart	05.06.2020 approx. 9:00	MAHLE International GmbH Pragstraße 26-46, 70376 Stuttgart	05.06.2020 approx. 10:30
10	MAHLE International GmbH Pragstraße 26-46, 70376 Stuttgart	05.06.2020 approx. 15:00	VKA Forckenbeckstraße 4 52074 Aachen	05.06.2020 approx. 19:30

Do you have any questions? Use the "Direct Feedback" in the RWTH app to ask questions anonymously in real time!

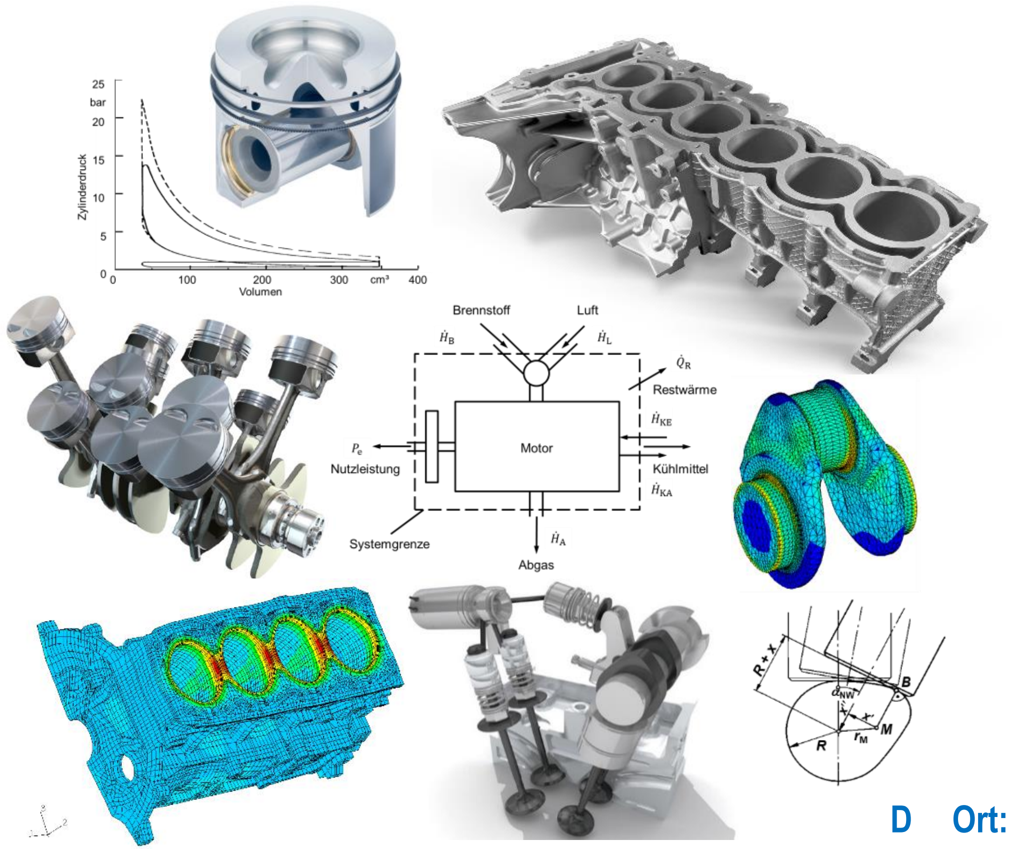


Login

To be able to use all functions, this link to an organizational unit in CAMPUS is necessary. You can then log in to your browser at https://app.rwth-aachen.de/das with your TIM ID and the corresponding password.

Access for students is via the RWTHApp. Direct feedback channels can be found under **„Studium“ > „Direktfeedback“** .

Passwort: **aef1app**



Lecture

Internal Combustion Engines: Design and Mechanics

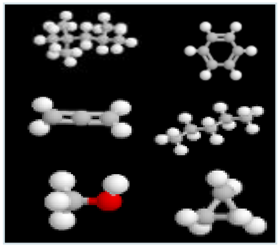
Univ.-Prof. Dr.-Ing. S. Pischinger

Heat Release Analysis
Valve Train
Energy Balance
Heat Transfer and Similarity
Mass Forces and Engine Design

D **Ort:** H04 (1385|103) **Zeit:** Wed 12:30 – 14:00 Uhr

E **Loc.:** Room TD (1300|408) **Time:** Tue 08:30 – 10:00 a.m.

INSTITUT FÜR KRAFTFAHRZEUGE

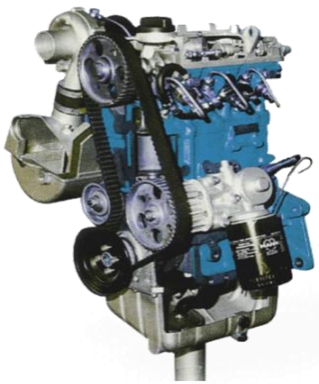


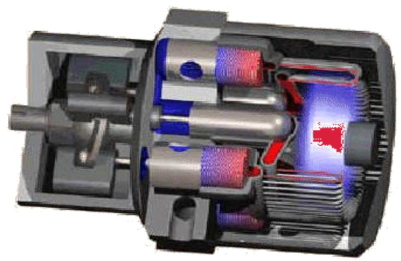
Lecture

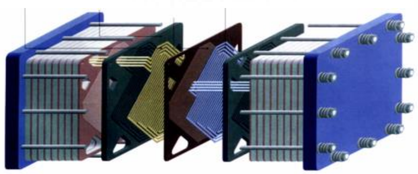
Alternative Vehicle Propulsion Systems

Univ.-Prof. Dr.-Ing. Stefan Pischinger

Univ.-Prof. Dr.-Ing. Lutz Eckstein







Energy Carriers and Properties

Fuel Characteristics
Production of Alternative Fuels
Alternative Fuels and Application

Energy Conversion Processes and Implementation

Thermodynamic Energy Conversion
Electrochemical Energy Conversion: Fuel Cells
Electrochemical Energy Conversion: Battery
Thermoelectric Energy Conversion

D	**Ort:** C.A.R.L. H04 (1385|103)	**Zeit:** Mi 14:30 – 16:00 Uhr
E	**Loc.:** EA (1270|109)	**Time:** Tue 10:30 –12:00 p.m.

Lecture

Electronics for Combustion Engines

Prof. Dr.-Ing. Jakob Andert

Electronic Influence of Combustion Engines

Key Sensors

Key Actuators

ECU Hardware

Bus Systems

Electric Machine Fundamentals

12 V / 48 V Powernet

Hybrid Technology

Loc.: H 212 (1400|212)

Time: Mo 11:30–13:00 Uhr

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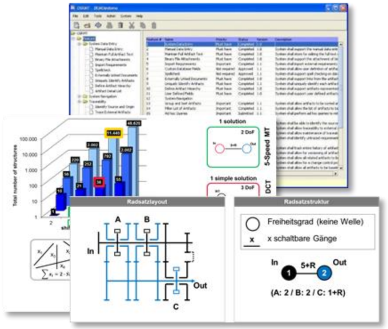

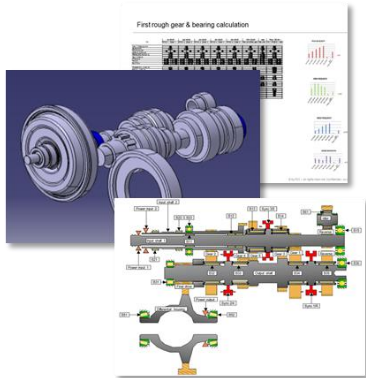

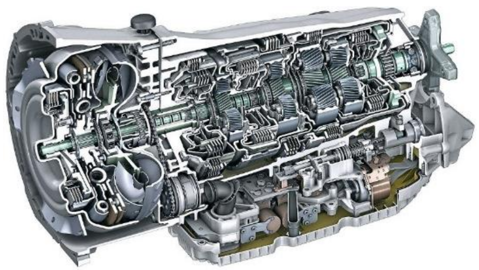
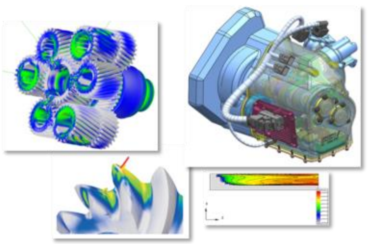


Lecture

Series Development of Transmissions for Passenger Cars and Light-Duty Vehicles

Dr.-Ing. Ingo Steinberg
Dr.-Ing. Gereon Hellenbroich

Transmission Types

Design

Components

Development Process

Testing

Series Production

Loc.: C.A.R.L. S11 (1385|211)

Time: Thu 12:30 – 14:00

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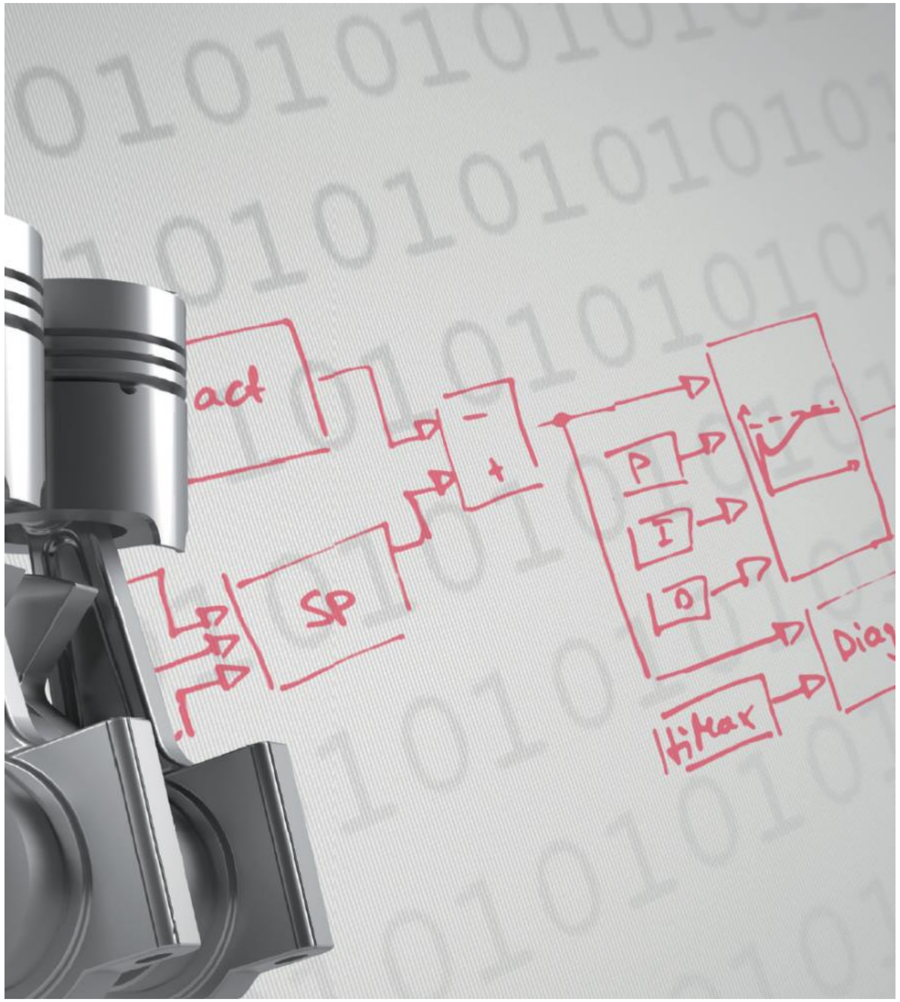


Lecture

Software for Combustion Engines

Dr.-Ing. Johannes Richenhagen

Software-Development-Process

Architecture Development

Requirements Development

Modeling of Software, Code Generation, Integration

Toolchain Development

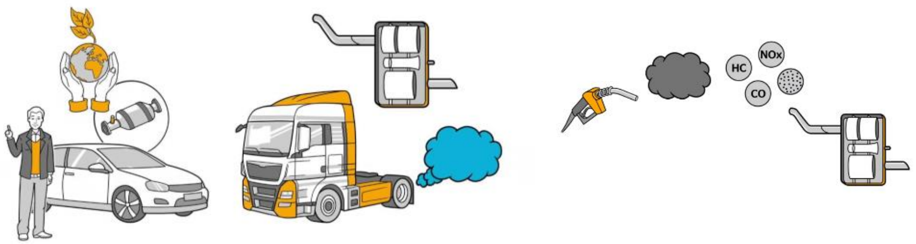
Software-Testing

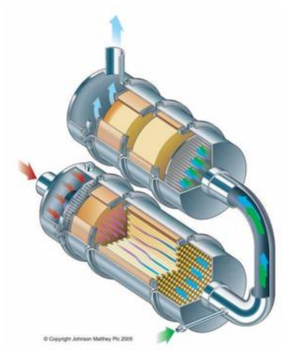
Vehicle / Powertrain Application

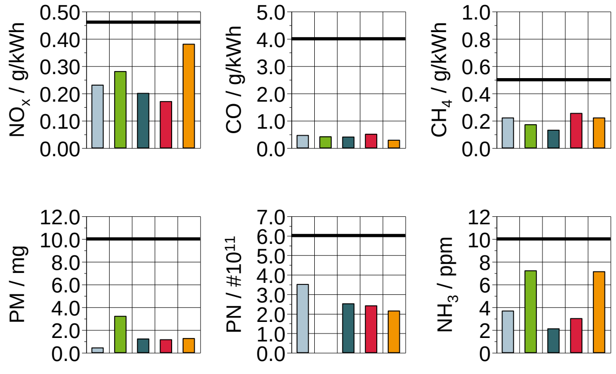
Agile Development Methods

Loc.: TD (1300|408)

Time: Di 10:30–13:00 Uhr







Lecture

Catalytic Exhaust Gas Aftertreatment of Internal Combustion Engines

Dr. Lynzi Marie Robb

Fundamentals of Exhaust Gas Aftertreatment

Structure of Motor Vehicle Exhaust Gas Aftertreatment Components

Oxidation and 3-Way Catalyst

NOx-Storage Catalyst

SCR-Catalyst

Particulate Filter

Complex Exhaust Gas Aftertreatment Systems

Loc.: SE 002 (1580|002) **Time:** Mo 10:30–12:00 Uhr

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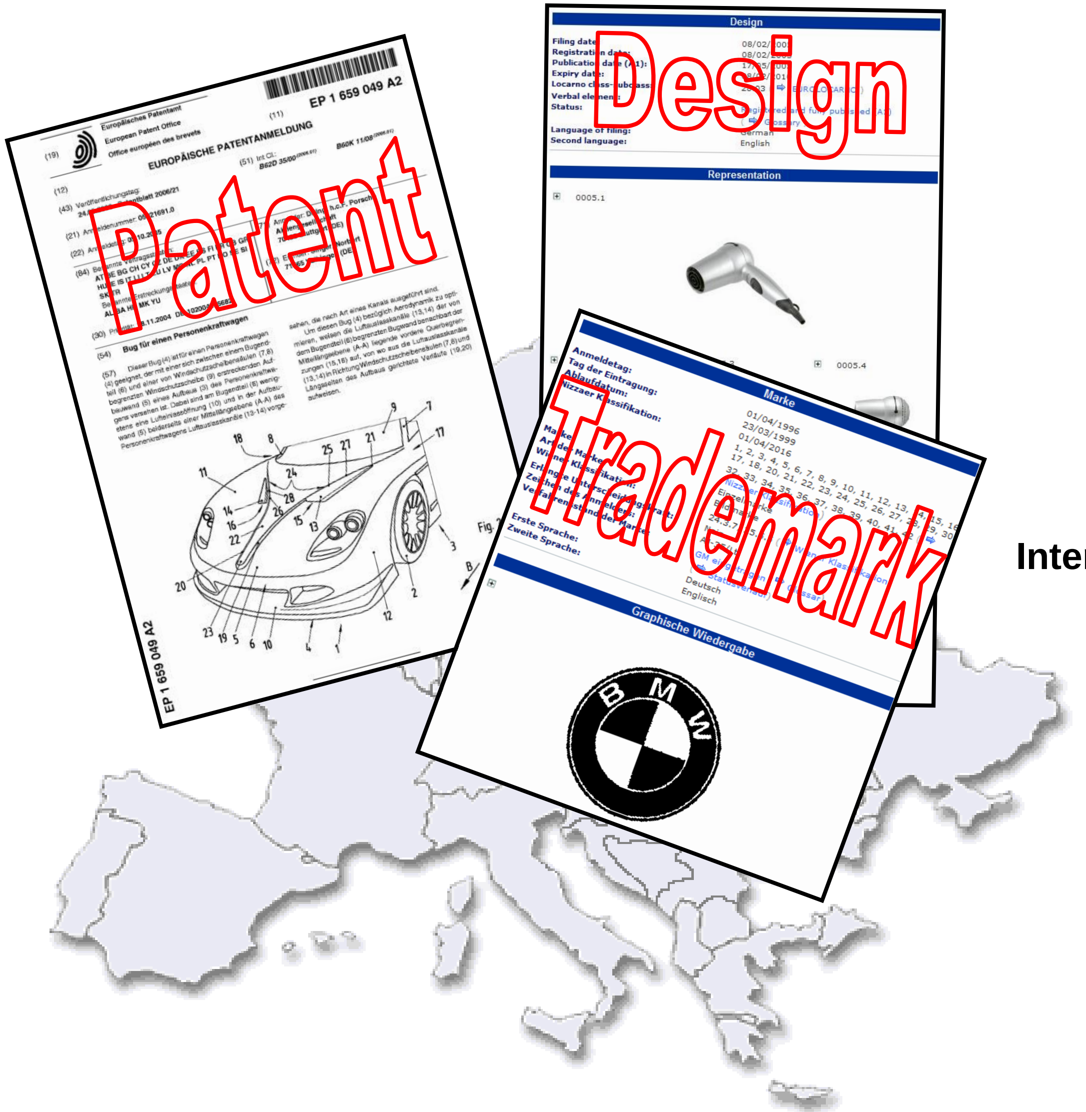

Lecture

International Patent, Trademark and Registered Design Rights

Dipl.-Ing. Matthias Rößler, LLM

Introduction to International Innovation Protection

International Contracts concerning Intellectual Property

System of the Patent Cooperation Treaty (PCT)

European Patent Convention

European Trademark Regulations

Community Design Regulations

Loc.: PPS H2 (2315|001) **Time:** Wed. 14:30–16:00

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Lecture

Acoustics of Mobile Propulsion Systems

Dr.-Ing. Christoph Steffens

Acoustic Fundamentals

Acoustic Measurement Equipment

Acoustic Behavior of Combustion and Electric Engines

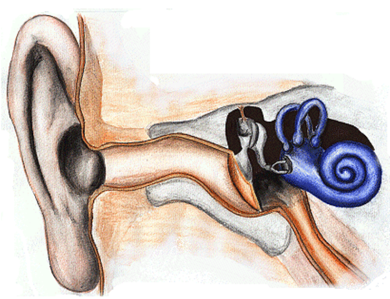
Acoustic Assessment of Propulsion Concepts

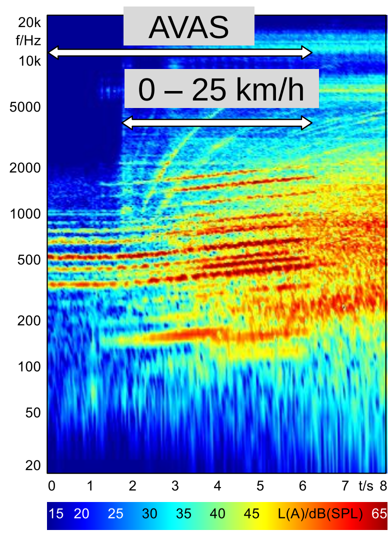
Sound Quality

Simulation

Legal Requirements

Sound Design





Loc.: C.A.R.L. S11 (1385|211)

Time: Tue 08:30 – 10:00

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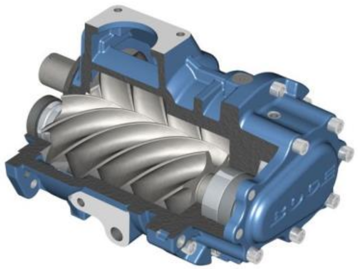
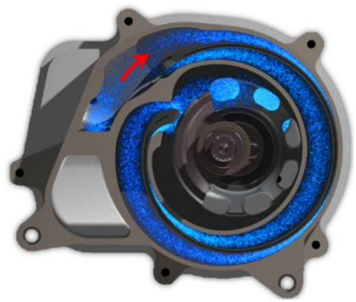
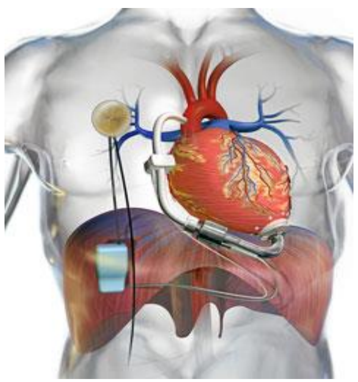
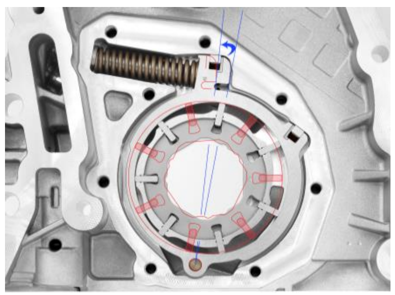








Lecture

Pumps and Compressors

Dr. Klaus Hoff

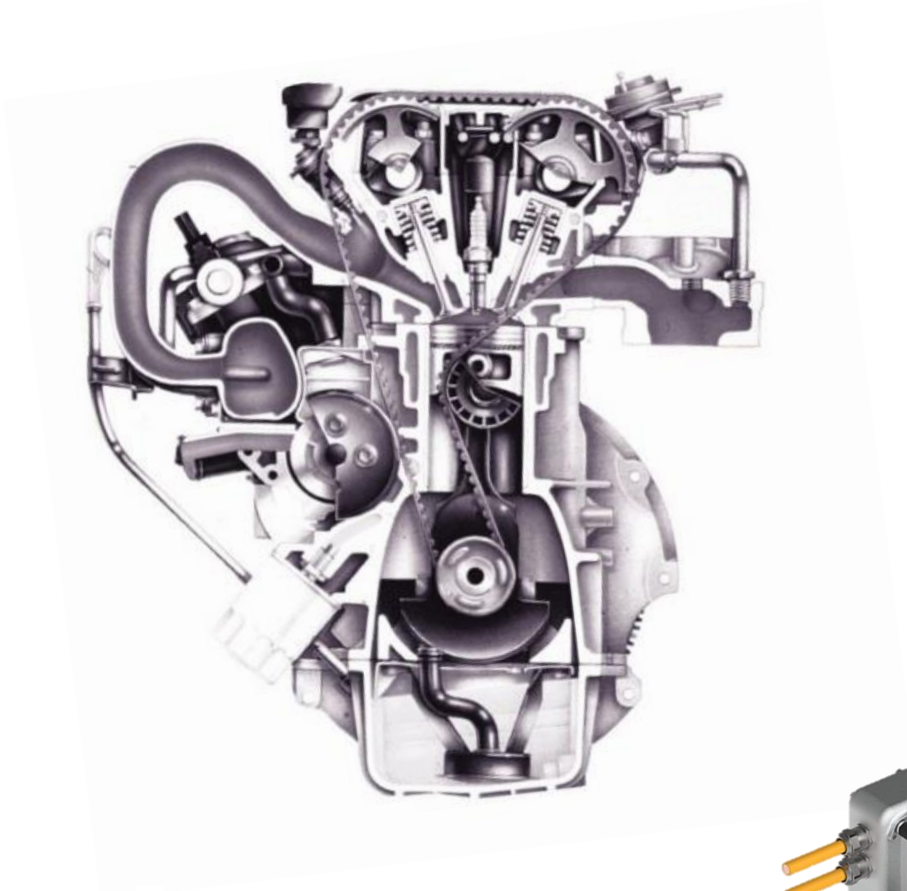
Design and Construction Characteristics

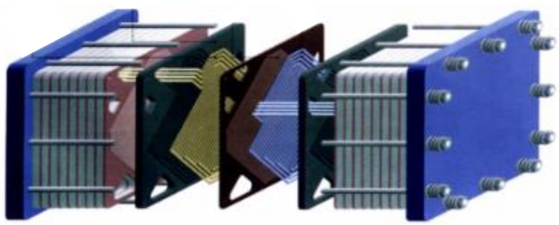
Classification according to Design Features and Calculation

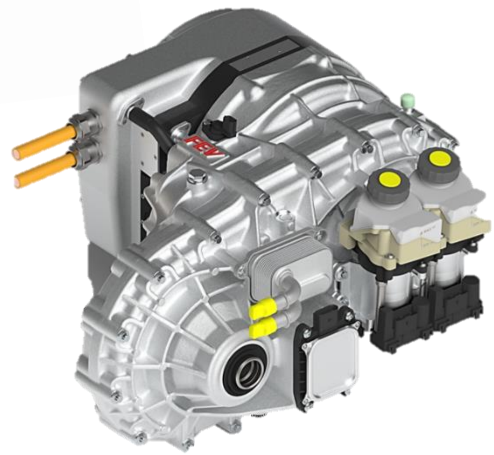
Regulations

Loc.: S12 (1385|212)

Time: Do 10:30–12:00 Uhr







Lecture

Mobile Propulsion Fundamentals

Univ.-Prof. Dr.-Ing. Stefan Pischinger

Combustion Engines

Fuel Cells

Electrical Machines

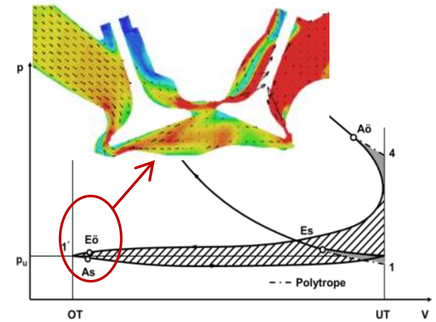
Classification

Characteristic Values

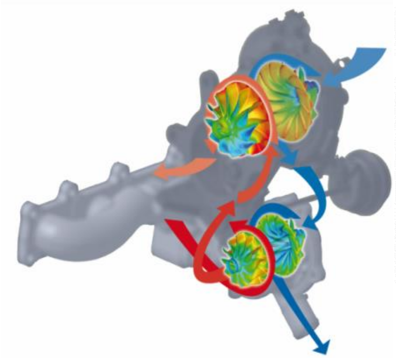
Operational Behavior

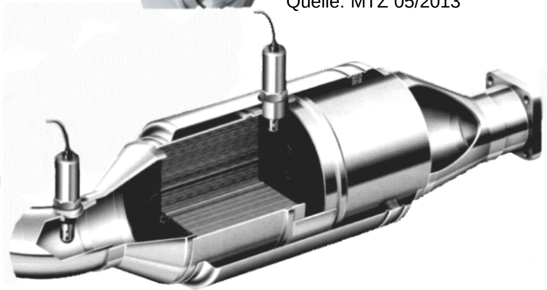
Winter Term

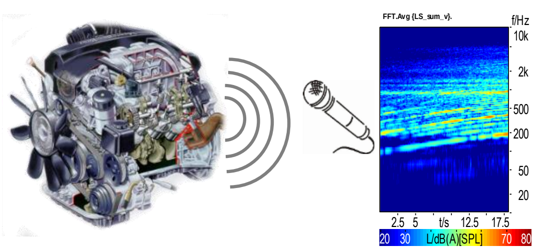
Lecture
Internal Combustion Engines II
Univ.-Prof. Dr.-Ing. Stefan Pischinger



Quelle: MTZ 05/2013







Charge Cycle

Turbocharging

Exhaust Gases and Exhaust Gas Aftertreatment

Engine Management

Mixture Formation

Engine Acoustics

Winter Term

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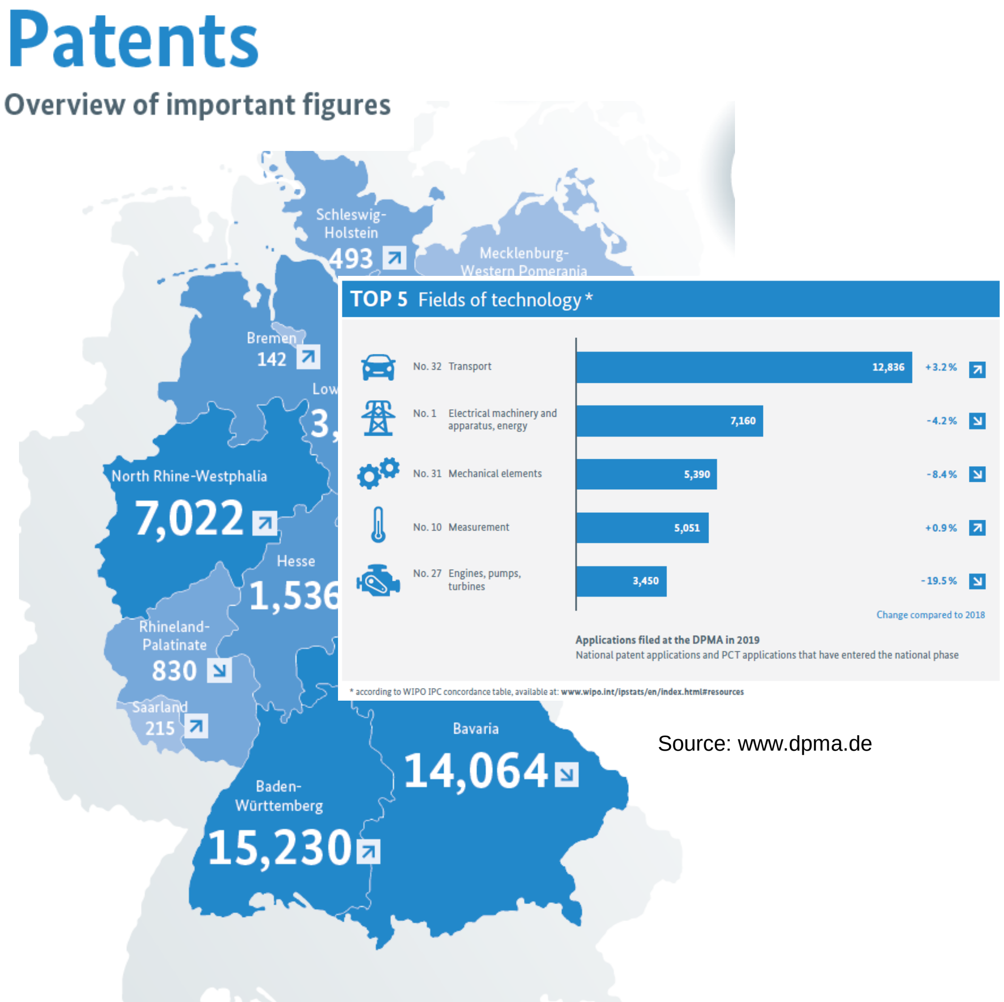

Source: www.dpma.de

Lecture

Fundamentals of Patent and Utility Model Law

Dipl.-Ing. Matthias Rößler

Basics of German Patent and Utility Model Law

Granting, effect and enforcement of technical Intellectual Property rights in Germany

Licensing contract law

German Employee Invention Act

Winter Term

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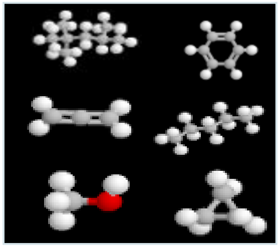
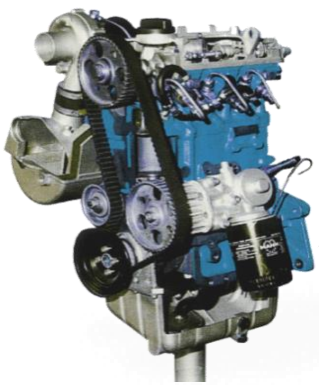
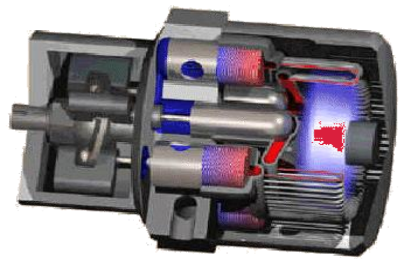






Lehrstuhl für Verbrennungskraftmaschinen

Lecture

Alternative Vehicle Propulsion Systems

Univ.-Prof. Dr.-Ing. S. Pischinger

Energy carriers and properties
Properties of fuels
Production of alternative fuels
Alternative fuels and applications

Energy conversion cycles and realization
Thermodynamical energy conversion
Electrochemical energy conversion: Fuel cell
Electrochemical energy conversion : Battery
Thermoelectrical energy conversion

INSTITUT FÜR KRAFTFAHRZEUGE

Univ.-Prof. Dr.-Ing. L. Eckstein

Content of lecture

Content of lecture II (ika)

Introduction – energy conversion chain

Definition

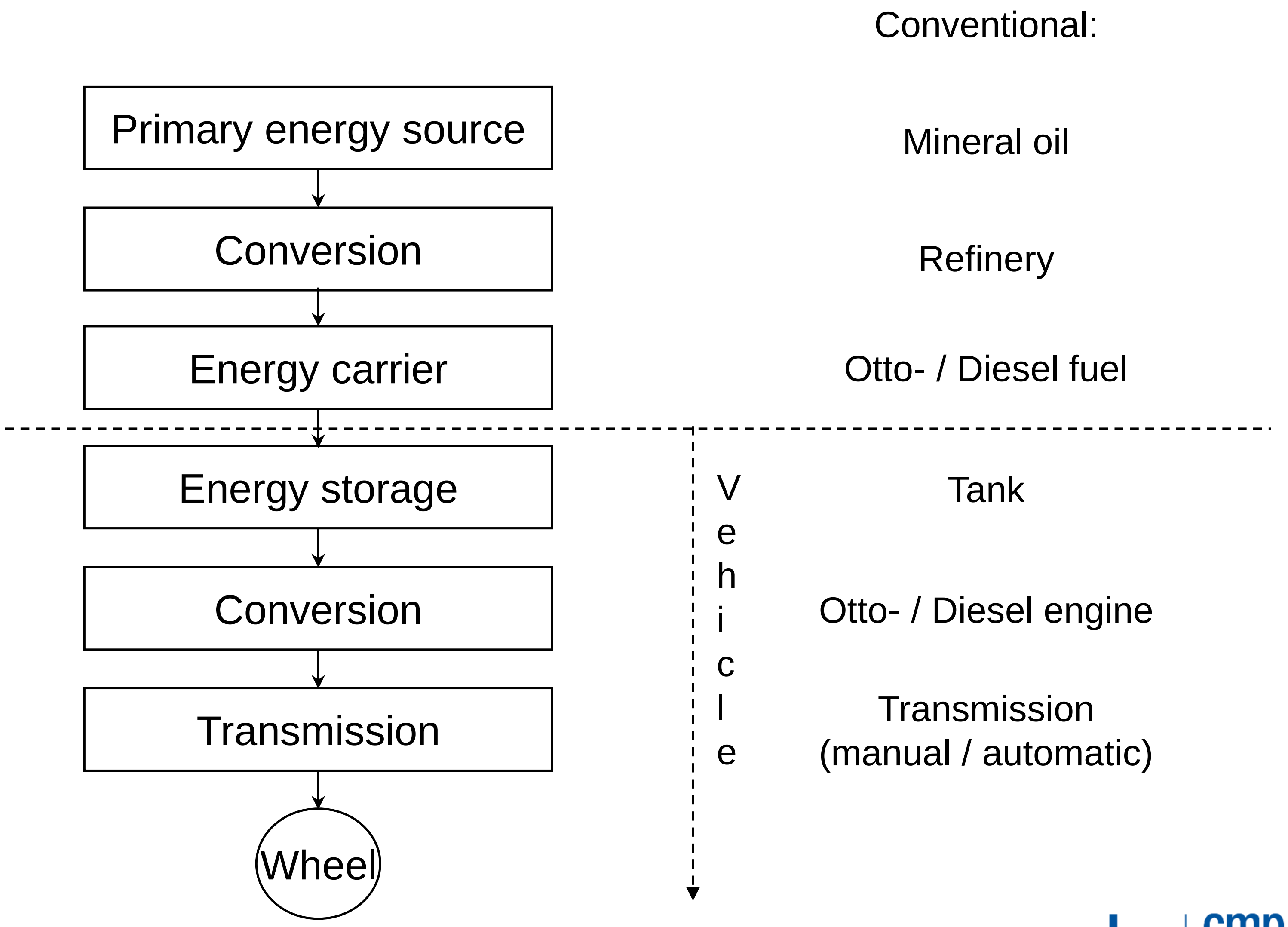
- 98 % of today's vehicle propulsion systems consist of:
  - Liquid fuel tank
  - Internal combustion engine
    - Otto engine
    - Diesel engine
  - Speed converter / torque converter
    - Manual transmission + clutch
    - Automatic transmission + torque converter
  - Propulsion systems, that consist of other components are termed as:

    Alternative vehicle propulsion systems

Well to Wheel

- Consideration of complete energy conversion chain

Energy conversion chain (well to wheel)

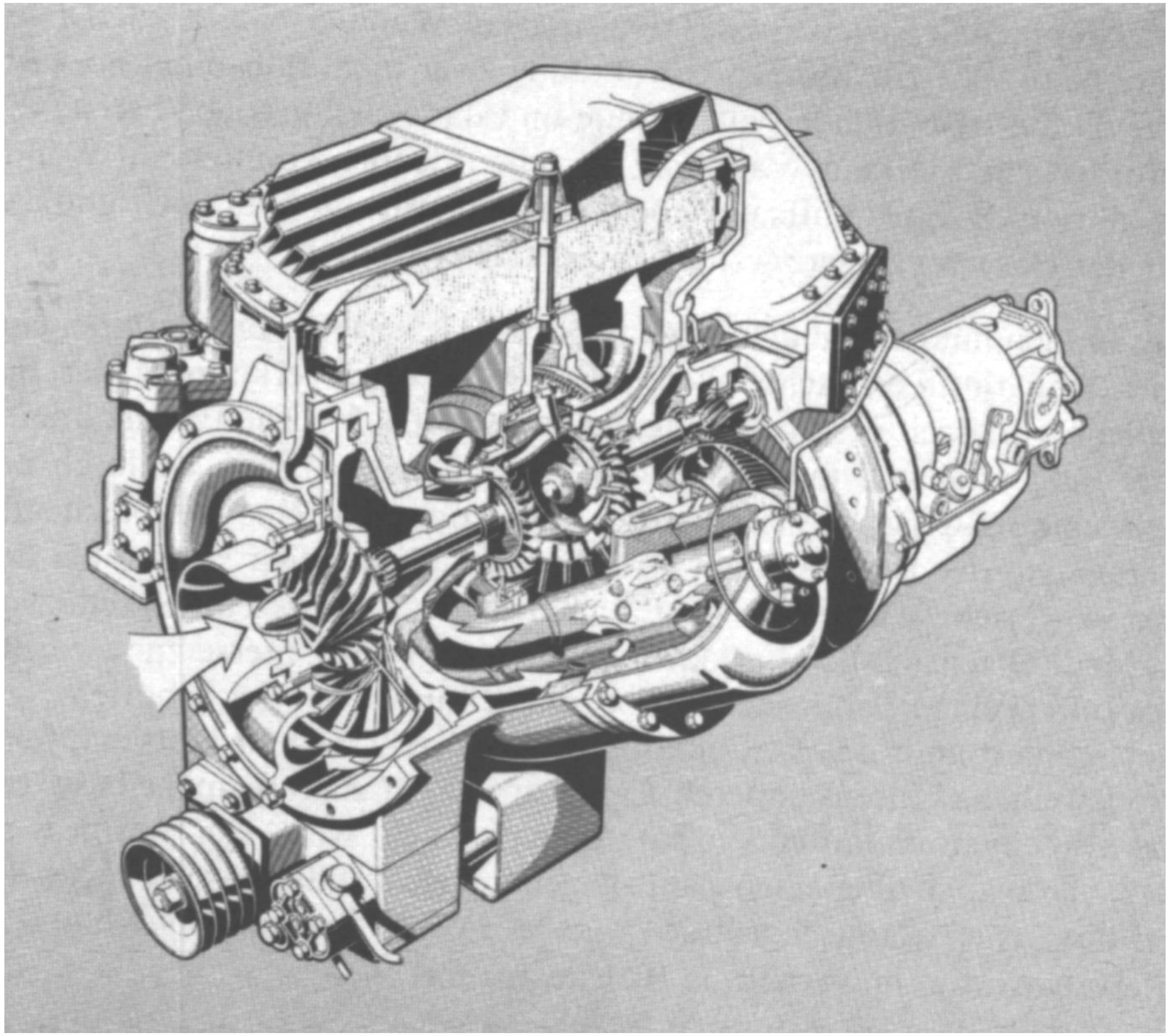


Rankine-Cycle in steam engine
Application

California Clean Car (1975)

Steam engine in Citroen
(self made,1979)

Daimler-Benz high temperature gas turbine



Variable compression
Saab variable compression SVC, 5-Zyl. (2000)

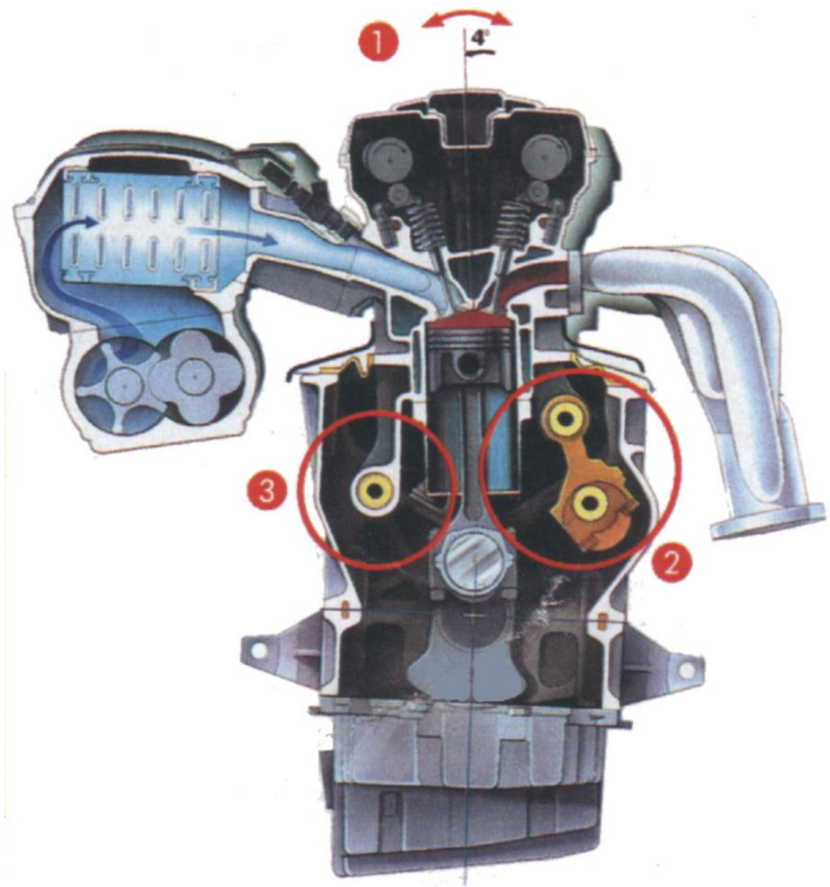
ε = 8 ... 14

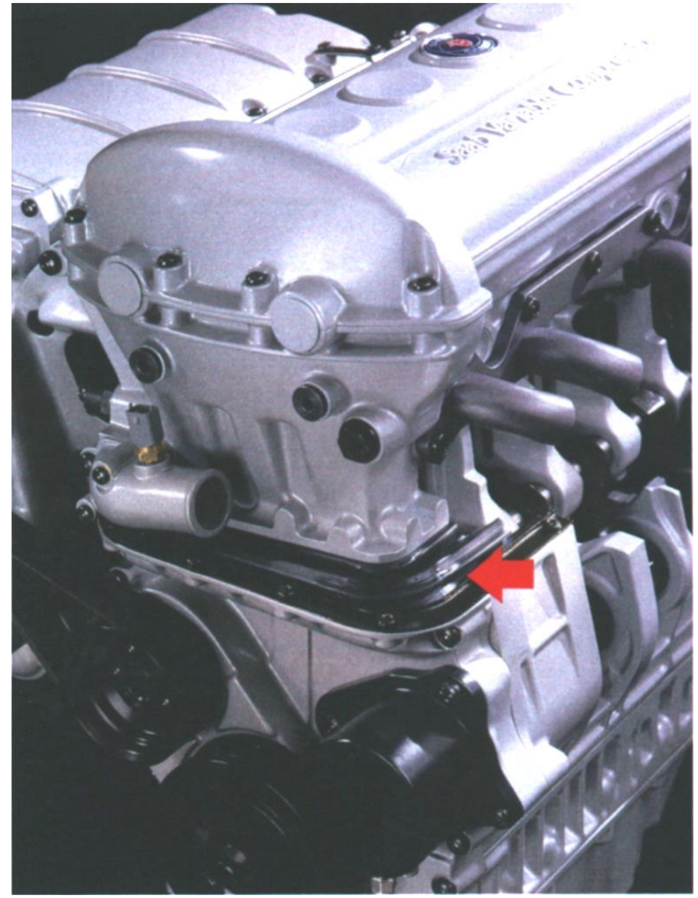
$p_{\mathrm{sau,max}}$ = 2.8 bar (mech. boost)

V_{h} = 1.6 l

$p_{\mathrm{me,\,max}}$ = 23.8 bar

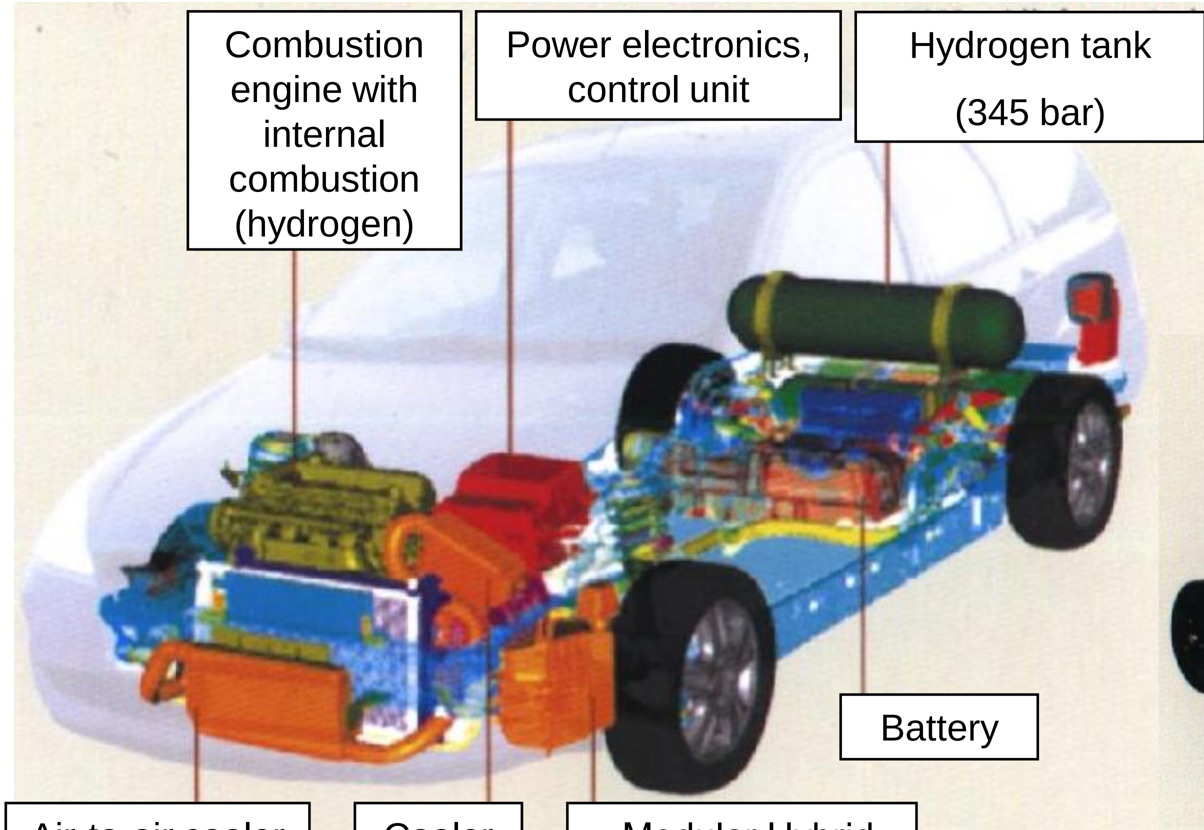
P_{e} = 168 kW

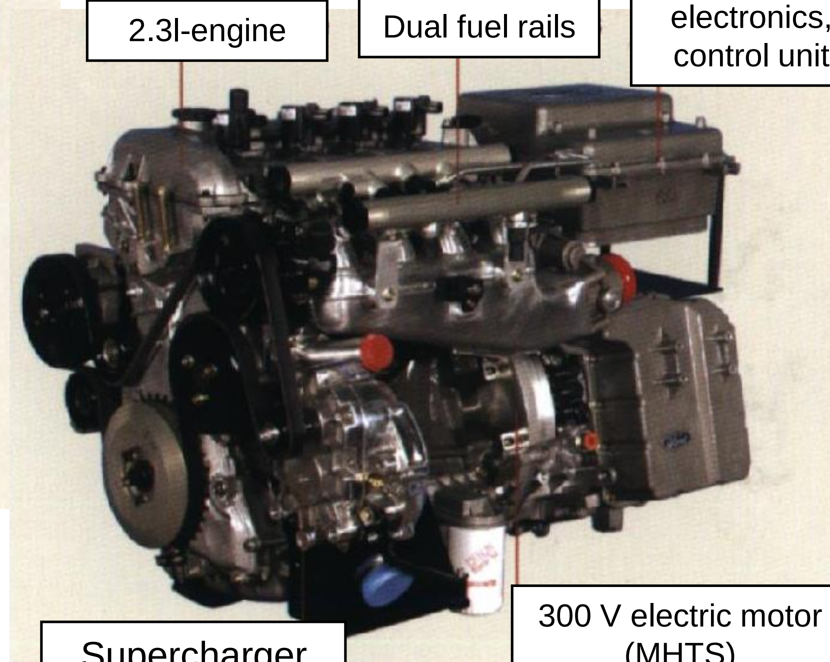




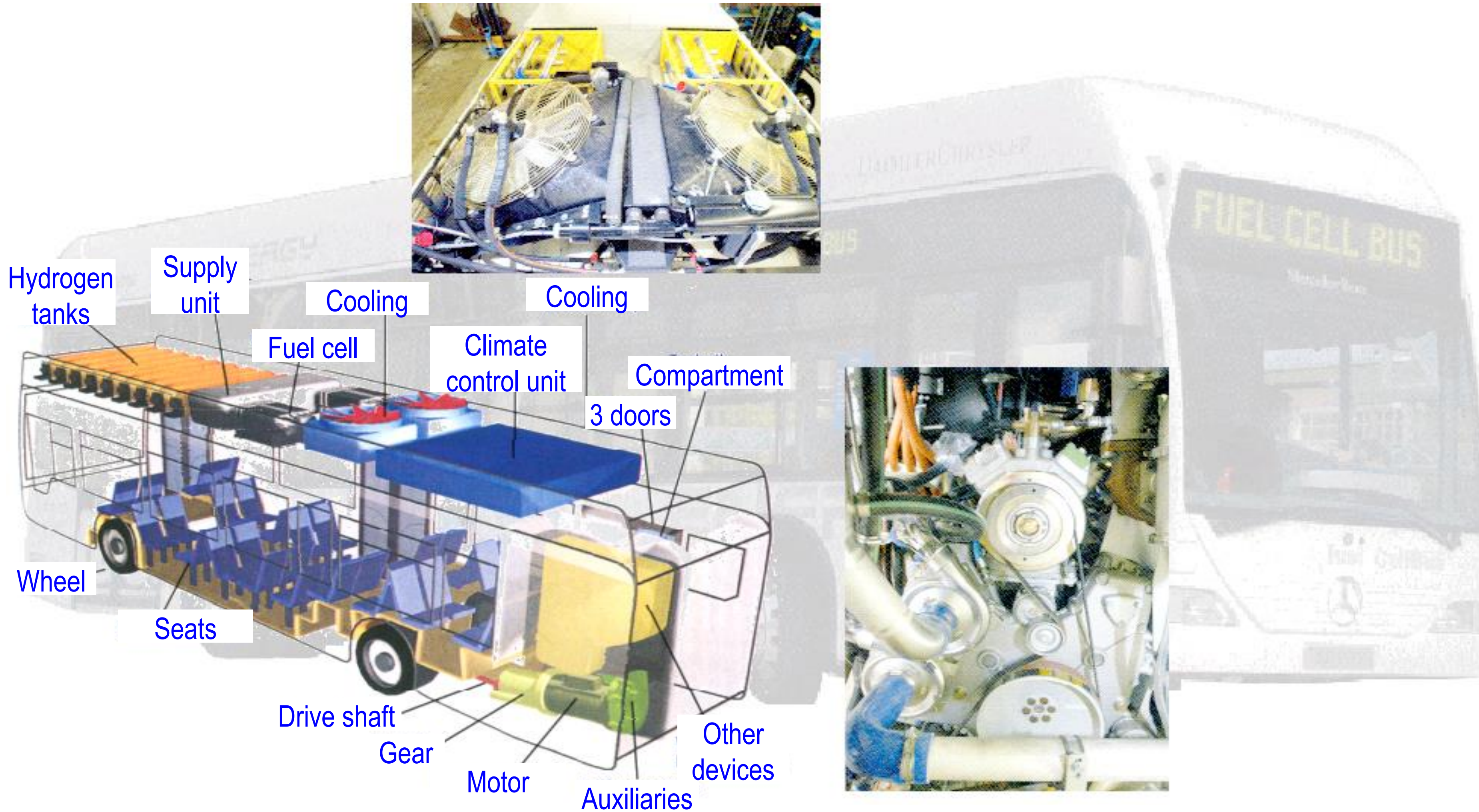
Source: http://www.saabnet.com

Hydrogen hybrid vehicle
(Ford H2RV)



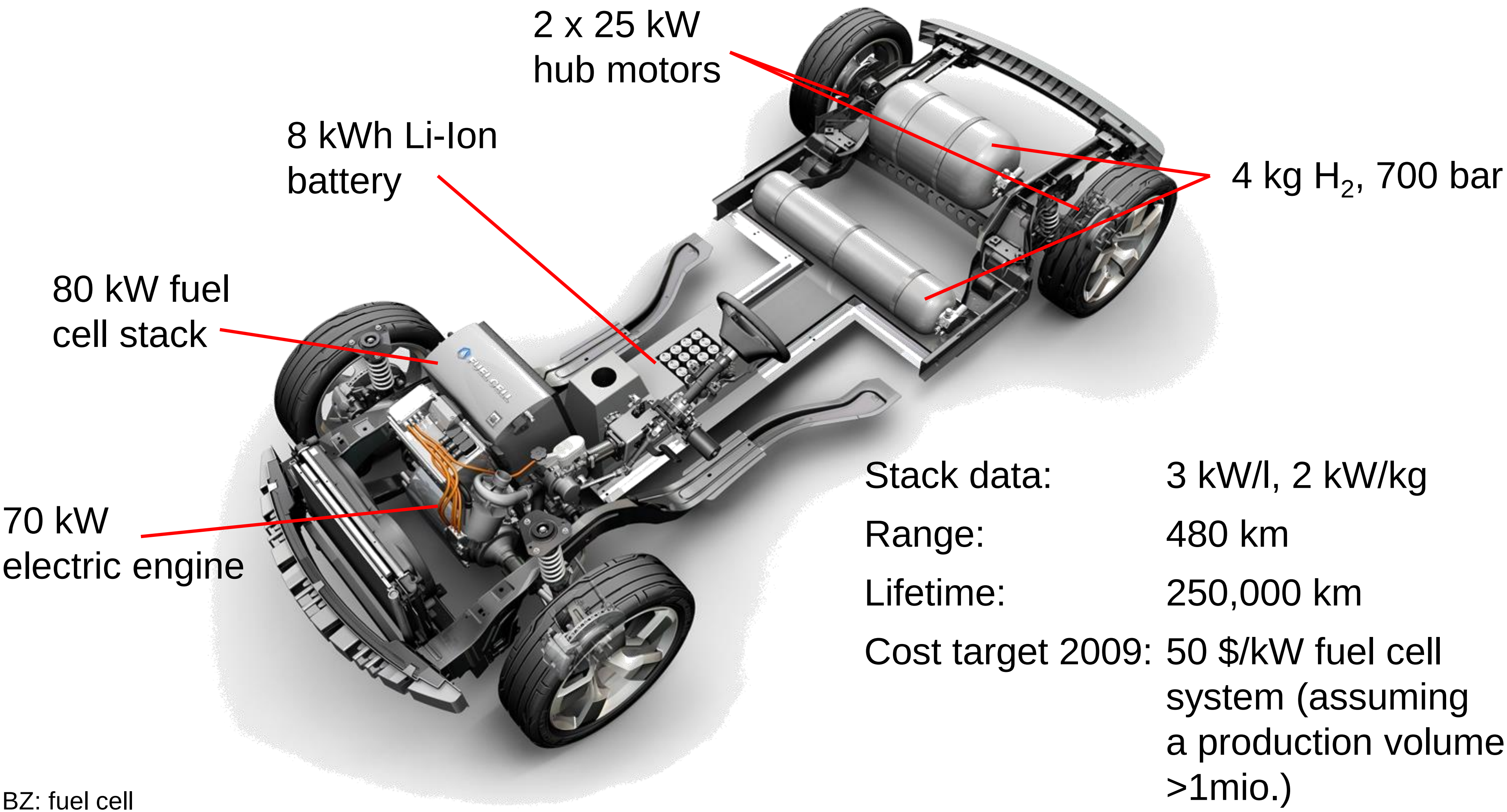


Daimler fuel cell bus (Development 2003 / series 2009)



BMW vehicle with hydrogen engine (2006)

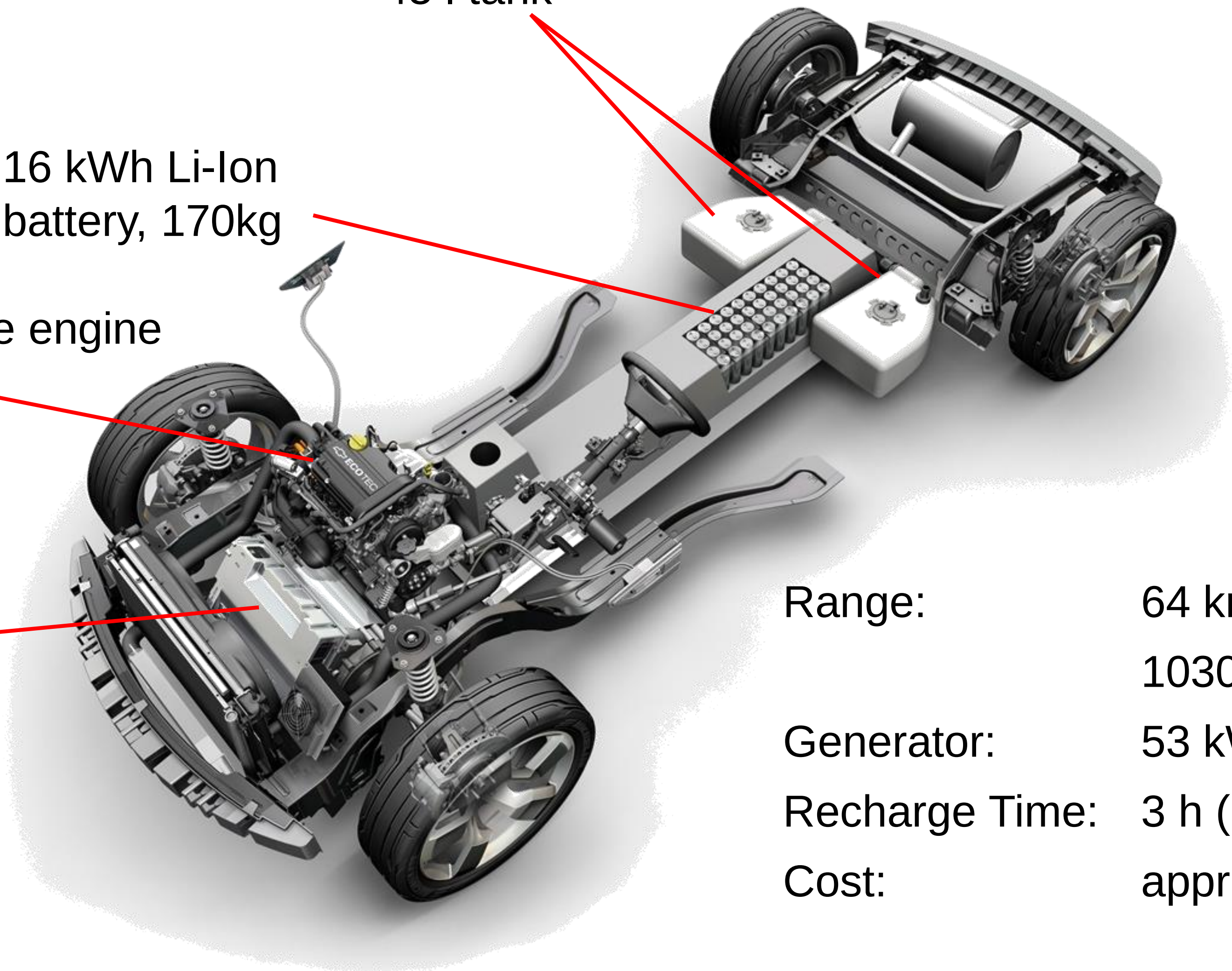
GM E-Flex fuel cell vehicle (2007)



Stack data:	3 kW/l, 2 kW/kg
Range:	480 km
Lifetime:	250,000 km
Cost target 2009:	50 $/kW fuel cell system (assuming a production volume >1mio.)

BZ: fuel cell

GM Volt (2009)



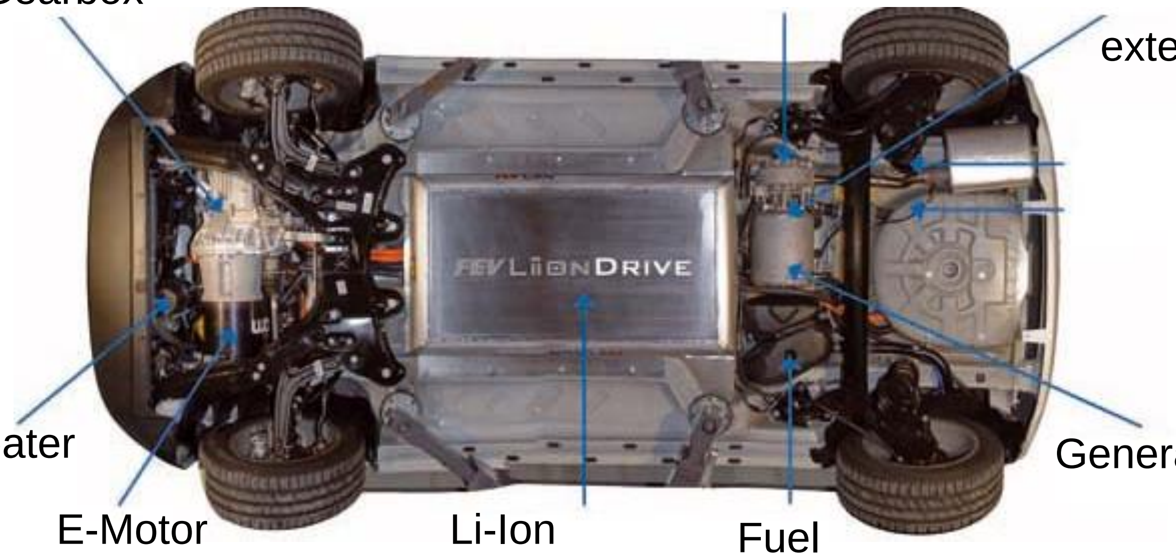
Range:	64 km electric
	1030 km total range
Generator:	53 kW
Recharge Time:	3 h (220 V outlet)
Cost:	approx. $40,000

Tesla Model S

- Four pole three-phase induction motor with copper rotor
- Curb weight: 2100 kg
- Energy consumption 18.1 kWh/100km

Battery capacity in kWh	75 (2017)	85	100D	P100D
Driving range NEFZ in km	401	520	632	613
0 to 100 km/h in sec	5.8	4.4	4.3	2.7
Maximum velocity in km/h	225	225	250	250
Maximum Power in kW	235	270	310	449

FEV Plug-In Hybrid with Range Extender



E-Motor:

- 75 KW
- Maximum speed 120 km/h
- Acceleration from 0 to 100 km/h in less than 10 s

Accumulator:

- 12 KWh Li-Ion accumulator for 60 km urban traffic

Range extender:

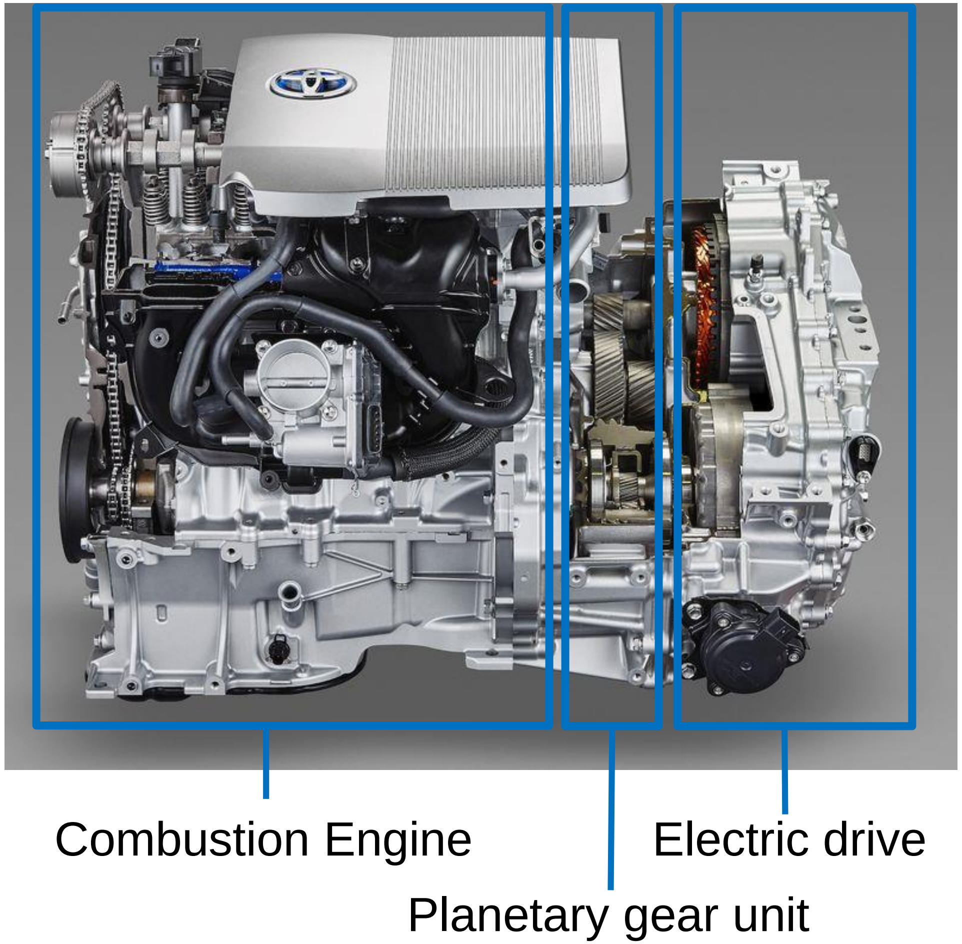
- 20 KW Wankel engine
- Range with range extender 300 km

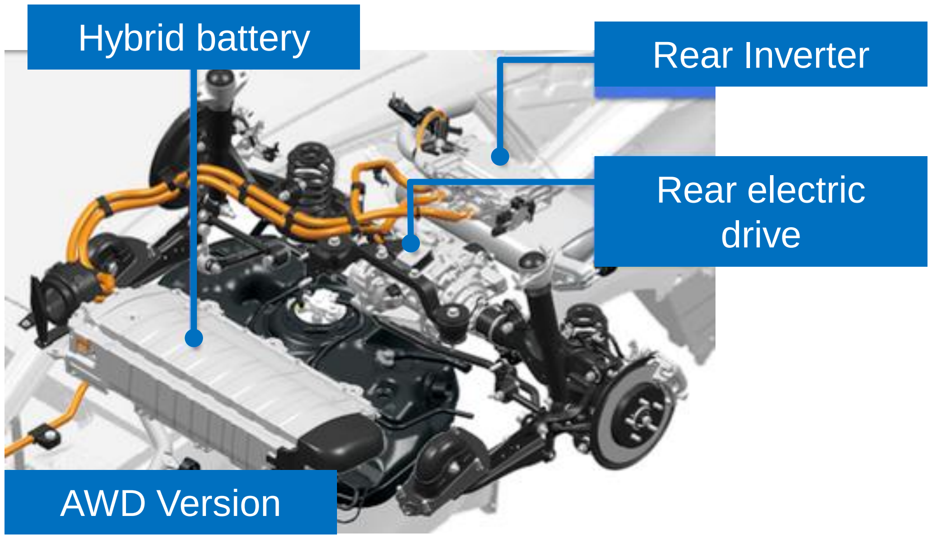
BMW i3 (Range Extender) (since 2013)

- E-Motor: Synchronous electric machine
- Range Extender: 2-cylinder-Otto

Technical Data	
Battery capacity (Li-Ion) in kWh	18.8
Vehicle mass in kg	1315
Electrical travel distance (NEDC) in km	170
Maximum range (most efficient driving mode) in km	ca. 340
0 to 100 km/h in sec	7.9
Maximum velocity in km/h	150
Maximum power (E-Motor) in kW (hp)	125 (170)
Maximum power (Range Extender) in kW (hp)	25 (34)

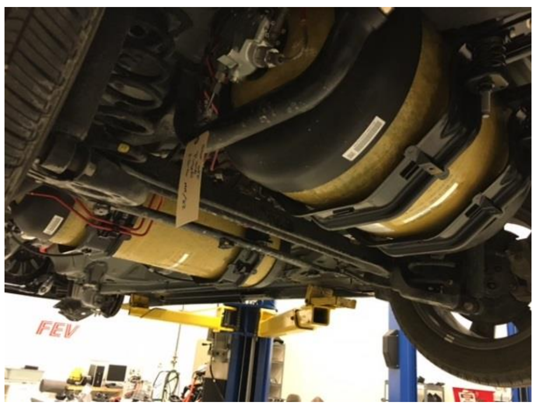
Cutaway model of a Toyota hybrid propulsion system (Toyota Prius IV, since 2016, Prius I 1997)





Quelle: Greencarsreports.com 2016 Toyota Prius: A Few Details On Engine and Hybrid System

Toyota Mirai – Fuel cell vehicle (2014)

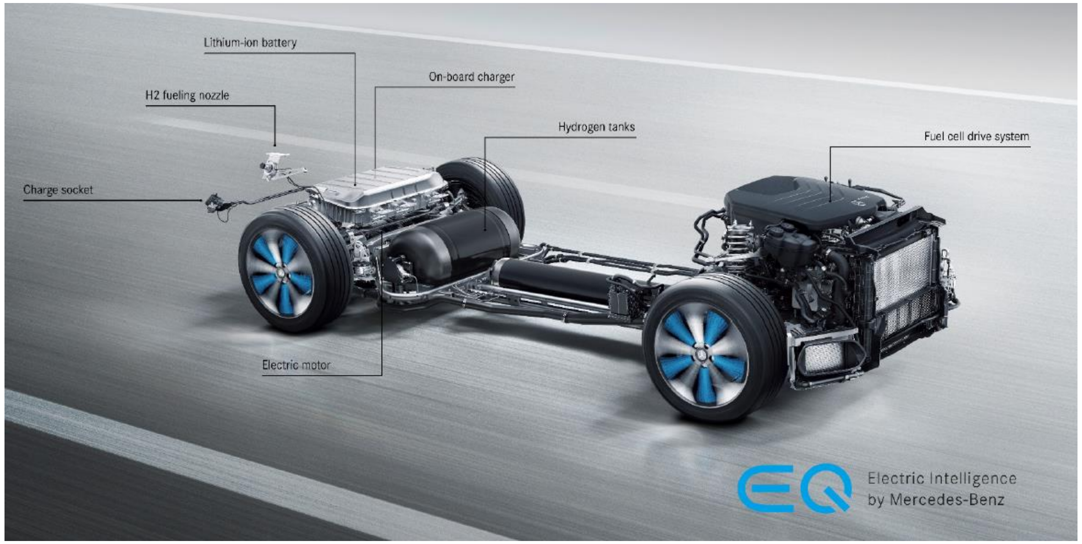


- Electric machine:
  Synchronous electric machine
- 370-cell stack

Technical Data	
Battery capacity (Li-Ion) in kWh	1.6
Vehicle weight in kg	1850
Price in € (ca.)	79,000
Maximum travel distance (most efficient driving mode) in km	ca. 500
0 to 100 km/h in sec	9.6
Maximum velocity in km/h	178
Maximum Power (E-Motor) in kW (hp)	114 (155)
Refueling in min	5

Source: http://www.toyota.com/fuelcell/fcv.html

Mercedes-Benz GLC F-Cell (2018)



Vehicle Data		
Maximum velocity	160	km/h
Maximum Power	147	kW
H_2 tank capacity	4.4	kg
Battery capacity (Li-Ion)	13.7	kWh
Max. travel distance	437 (48 battery only)	km
Vehicle weight	2130	kg
Price	799 p.m (leasing only)	€

Sources: The New Mercedes-Benz Fuel Cell Plug-in-Hybrid Drive – 27th Aachen Colloquium Automobile and Engine Technology 2018
https://www.adac.de/der-adac/motorwelt/reportagen-berichte/auto-innovation/mercedes-glc-fuel-cell-test

Hyundai Nexo (2018)

Propulsion system and Fuel Cell Stack Data		
Max. Power (E-Motor)	120 (160)	kW (hp)
Battery Power Output	40	kW
Fuel Cell Power Output	95	kW
Number of cells in FC stack	440	-
Stack Density	3.1	kW/L
Cold-Start Temperature	-30	° C

Vehicle Data		
Maximum velocity	179	km/h
Acceleration from to 100 km/h	9.2	sec
H_2 tank capacity	156.6 (3 x 52.2)	L
Battery capacity (Li-Ion)	1.56	kWh
Max. travel distance	756 (NEDC) 666 (WLTP)	km
Refueling time	5	min
Vehicle weight	1,814-1,873	kg
Price	69,000	€

Source: https://www.hyundai.news/eu/press-kits/all-new-hyundai-nexo-technical-specifications/

Content of lecture

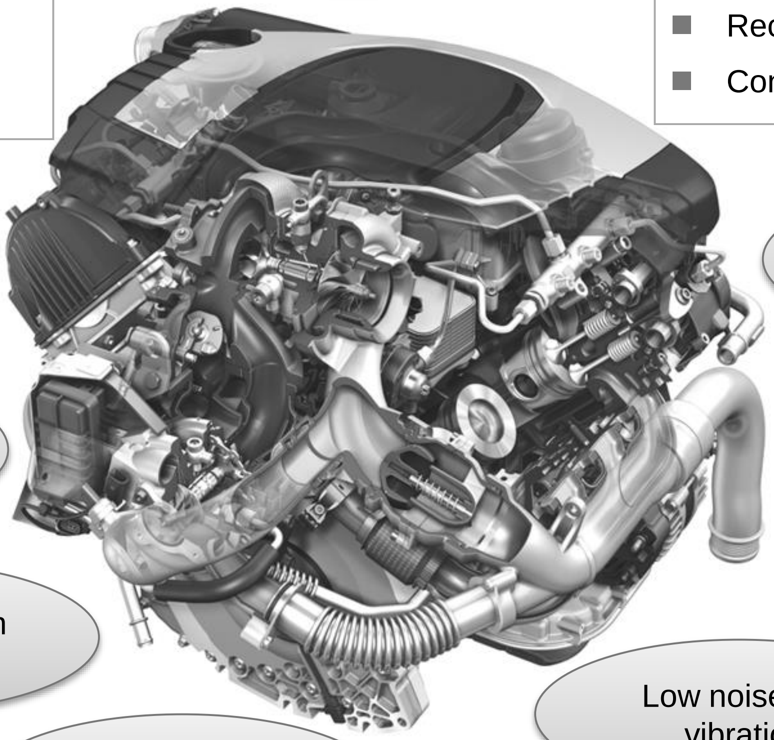
Requirements for mobile propulsion systems

Customer Use

- Driving pleasure
- Low vehicle and operational costs
- Quality / reliability
- Comfort

Environmental demands / laws

- Pollutant emissions
- CO_2 emissions (greenhouse effect)
- Recycling
- Conserving resources



Durability

High specific power and torque

Compact, lightweight

Low production costs

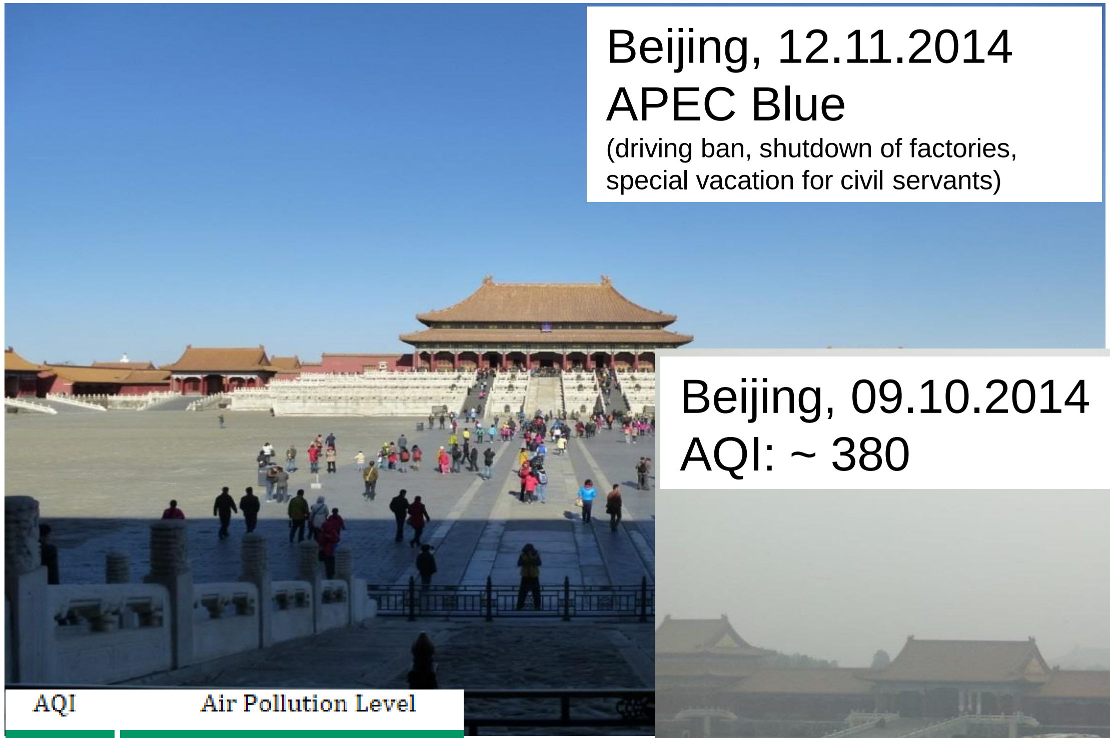
Short development times

Low noise and vibration

Low CO_2 and pollutant emissions

Low fuel consumption

Atmospheric load due to exhaust gases



Beijing, 12.11.2014
APEC Blue
(driving ban, shutdown of factories, special vacation for civil servants)

Beijing, 09.10.2014
AQI: ~ 380

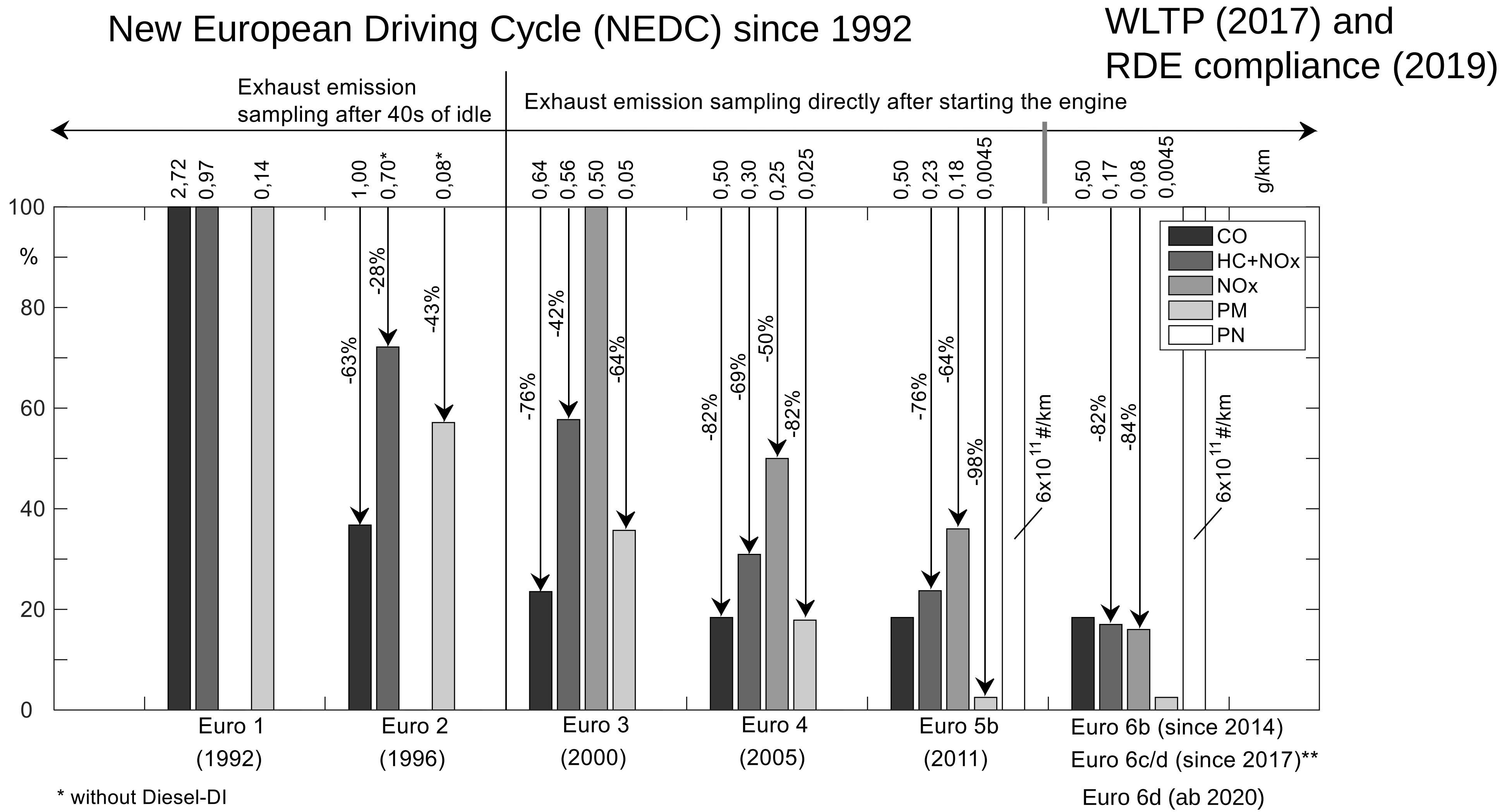
Beijing, 01.12.2015
AQI: ~ 440

AQI	Air Pollution Level
0 - 50	Good
51 -100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
300+	Hazardous

Legal motivation for alternative propulsion

- Limitation of toxic emissions through state regulation
  - EU6 temp, EU7, TIER 2 Bin 2 (USA)
- Penalties for car producers when their fleets CO2 emissions exceed a limit
  - In the EU the fleet’s CO2 emission limit is set at 95 g/km from 2020/20 with a penalty of 95 € per g/km for every vehicle produced
- Tax incentives for vehicle with lower CO2-Emissions
  - In Germany CO2-based car taxes start in 2009, CO2-based fine in Europe
- EU-Guideline to renewable energy sources
  - Rate of renewable energies used in transportation sector (10% until 2020)
- Lower taxes for bio fuels
  - Lower taxes for pure Bio diesel and E-85 in Germany until 2015, CNG/LPG till 2018
- Emissions dependent road charge
  - Road charge on highways for trucks in Germany
  - Congestion charge for cars in London
- Local emission dependent driving ban
  - Pollution-free zone in German cities
- Purchase incentives / promotion
  - Subsidy for electric vehicles
  - Tax benefits for e-company cars

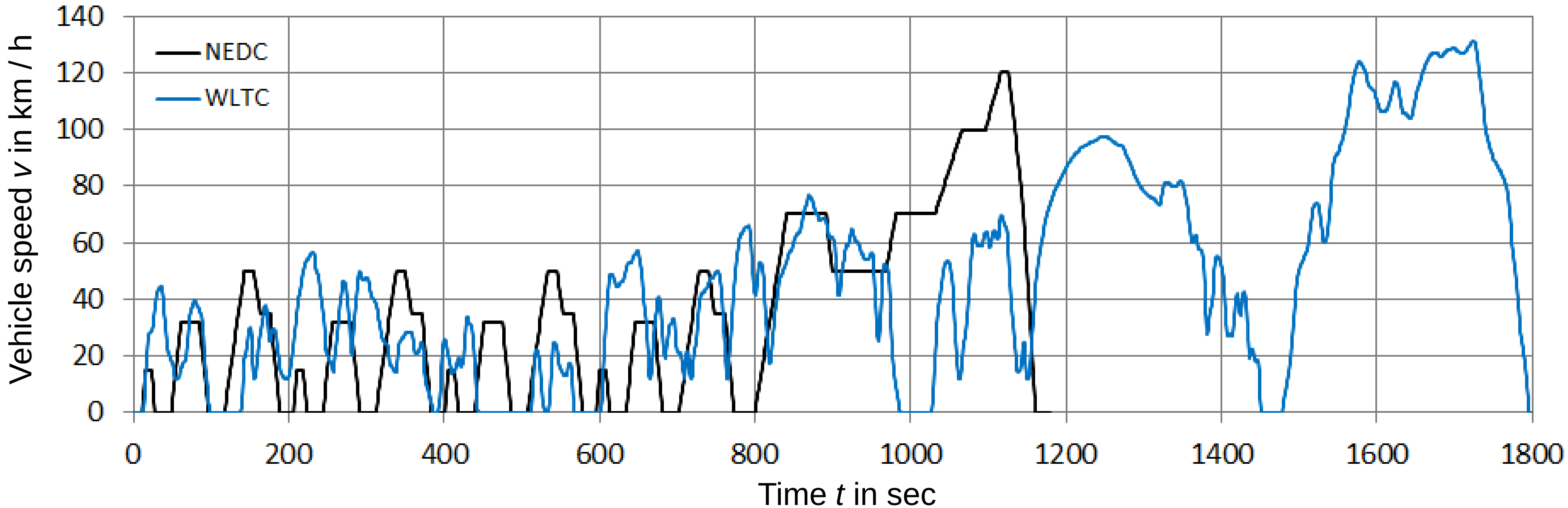
Development of the European Pollutant Emission Limits for Passenger Car Diesel Engines



* without Diesel-DI
** Change from NEDC to WLTC

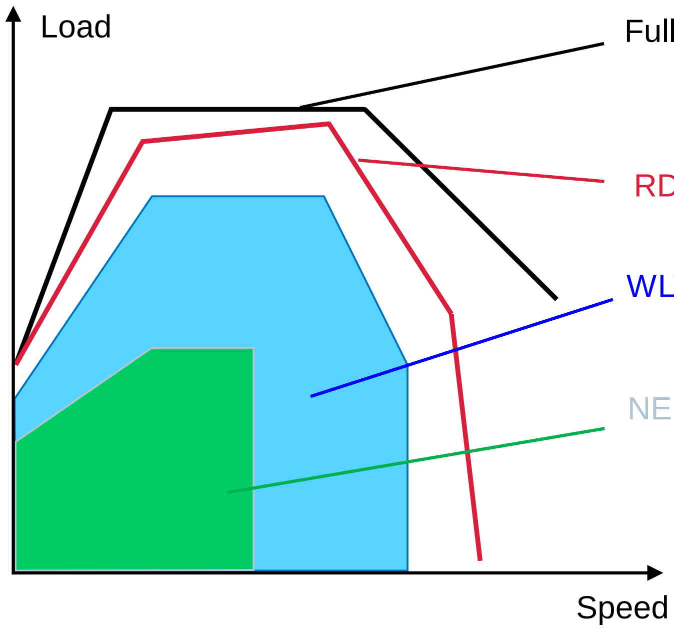
Worldwide harmonized Light vehicles Test Procedures (WLTP)

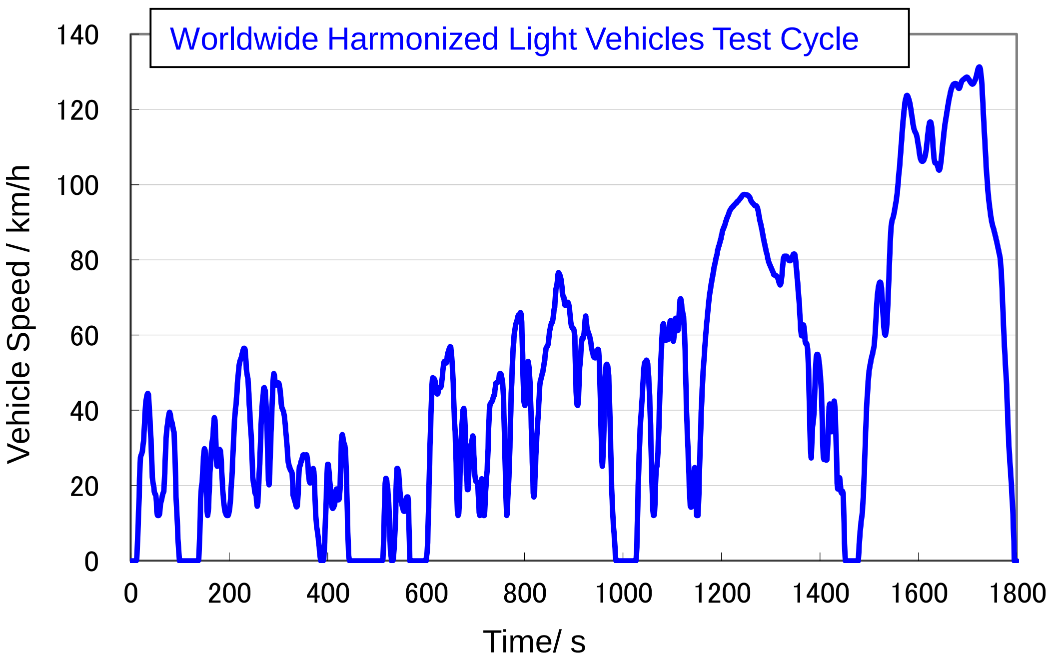
Parameter	NEDC	WLTP
Test duration	1180 s	1800 s
Test phases	Urban / Extra Urban	Low-, Middle-, High- und Extra-High
Max. speed	120 km/h	131,3 km/h
Max. acceleration	1,04 m/s²	1,6 m/s²
Test route length	11 km	23,262 km



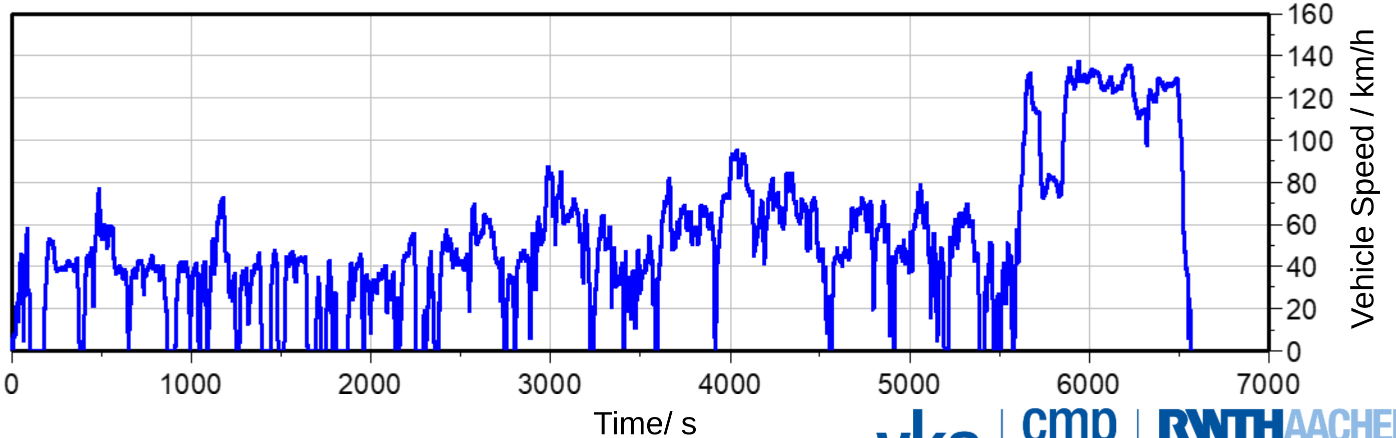
- The same cycle for cars and light commercial vehicles, but with different switching points

Introduction of new test procedures
Worldwide harmonized Light vehicles Test Procedures (WLTP) and RDE





RDE (Real Driving Emissions):

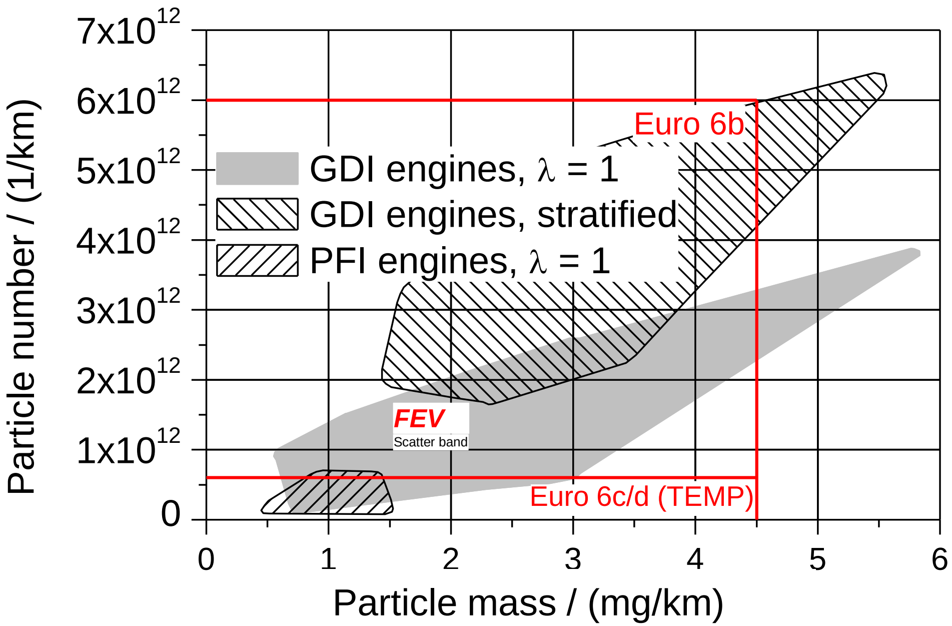


Partikelemissionen von Ottomotoren - Motivation

Legislative Requirements

Europe: Euro

- 6b - 09/2014: $6*10^{12}$ particles/km (DI) (NEFZ)
- 6c - 09/2017: $6*10^{11}$ particles/km (DI) (WLTP)
- 6d TEMP – 09/2017: $6*10^{11}$ particles/km (DI) (WLTP + RDE compliance)



Customer Acceptance

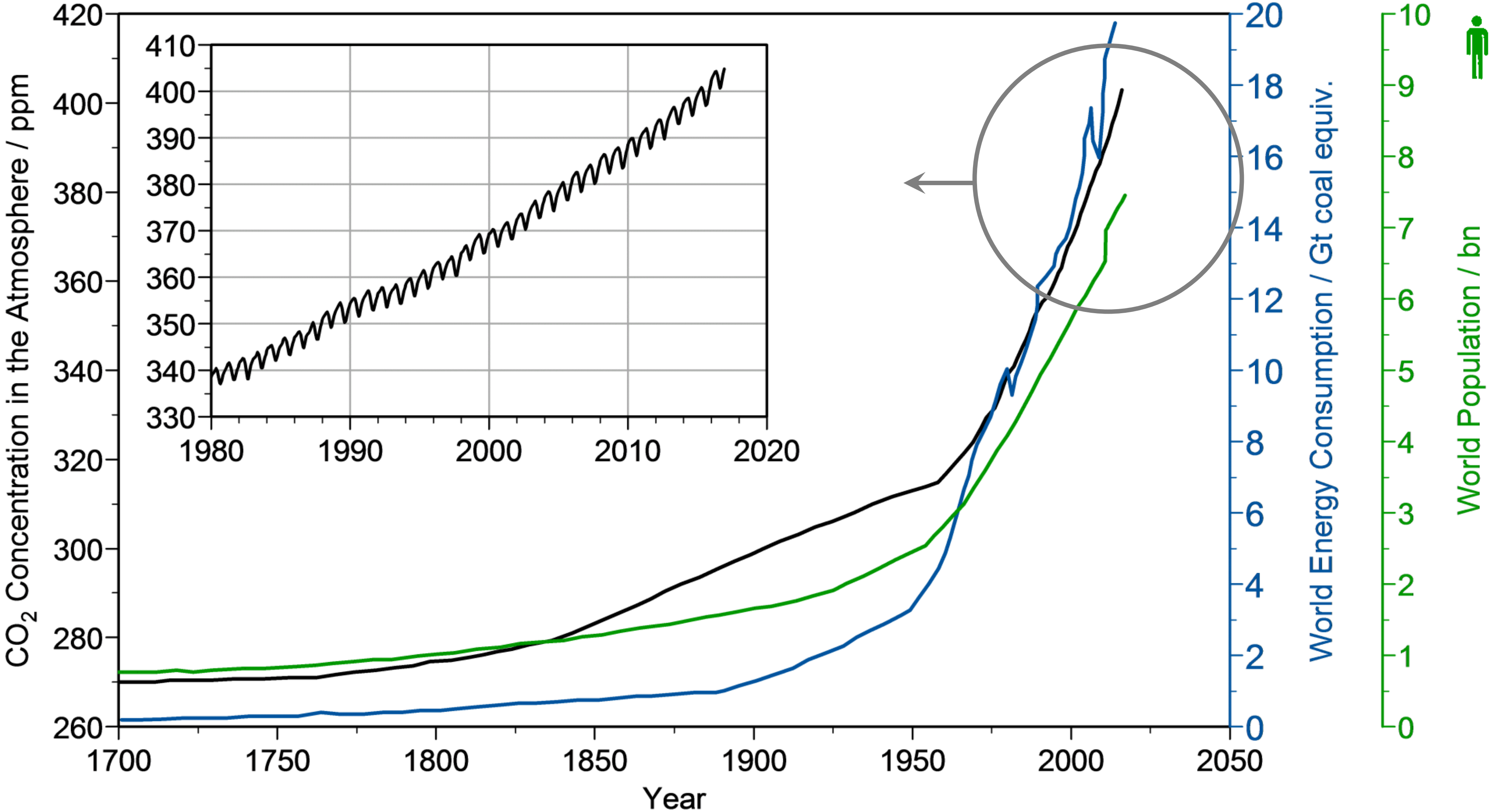
Diesel with DPF

Gasoline PFI

Gasoline DI

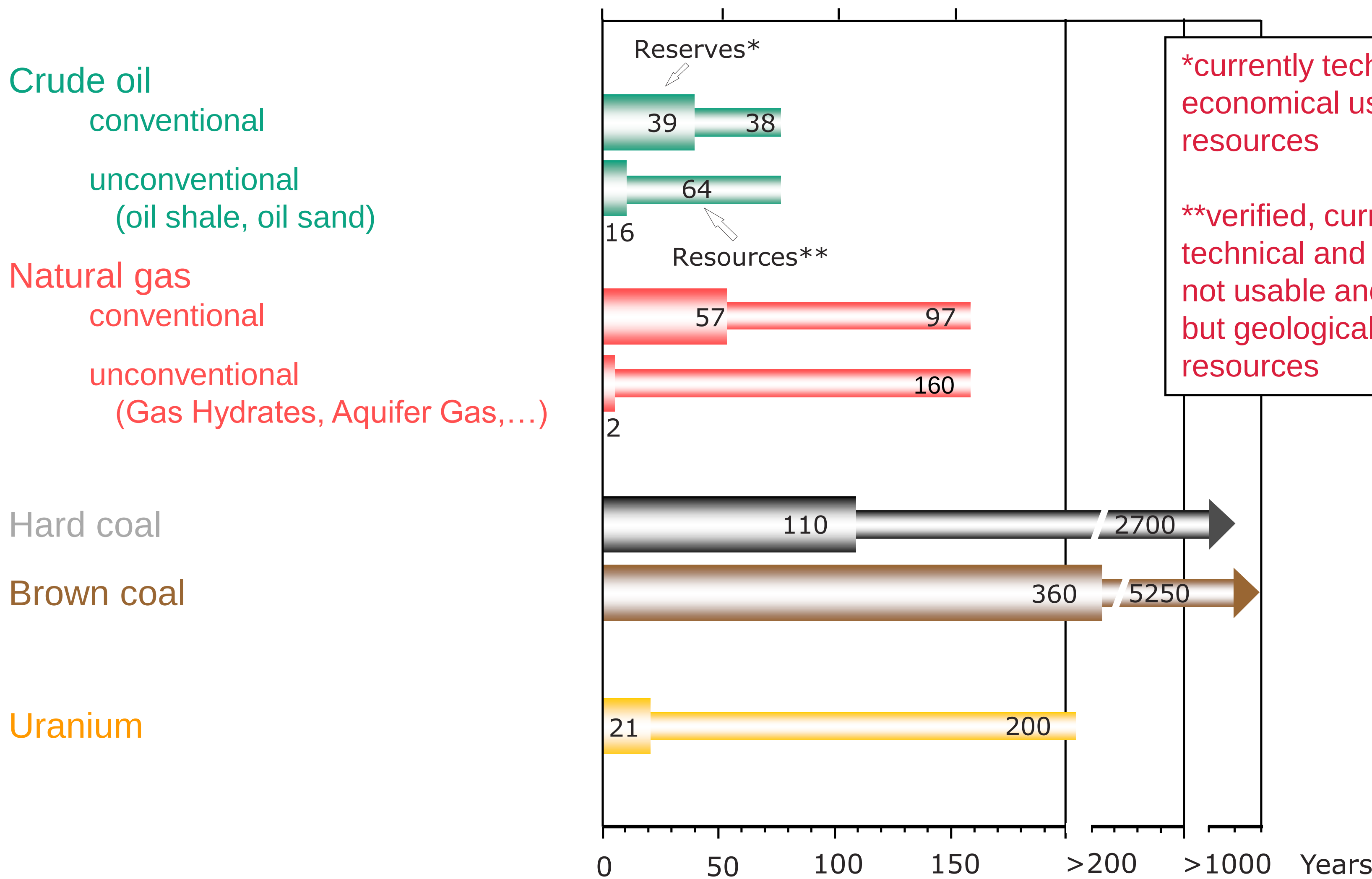
Legislative and customer demands require particle emission reduction for gasoline engines

World population, consumption of primary energy, CO_2-emissions



Sources: Deutsche Stiftung Weltbevölkerung 2017, International Energy Agency 2016, National Oceanic and Atmospheric Administration 2017

Reach/Coverage of Fossil and Nuclear Energy Sources (current consumption)

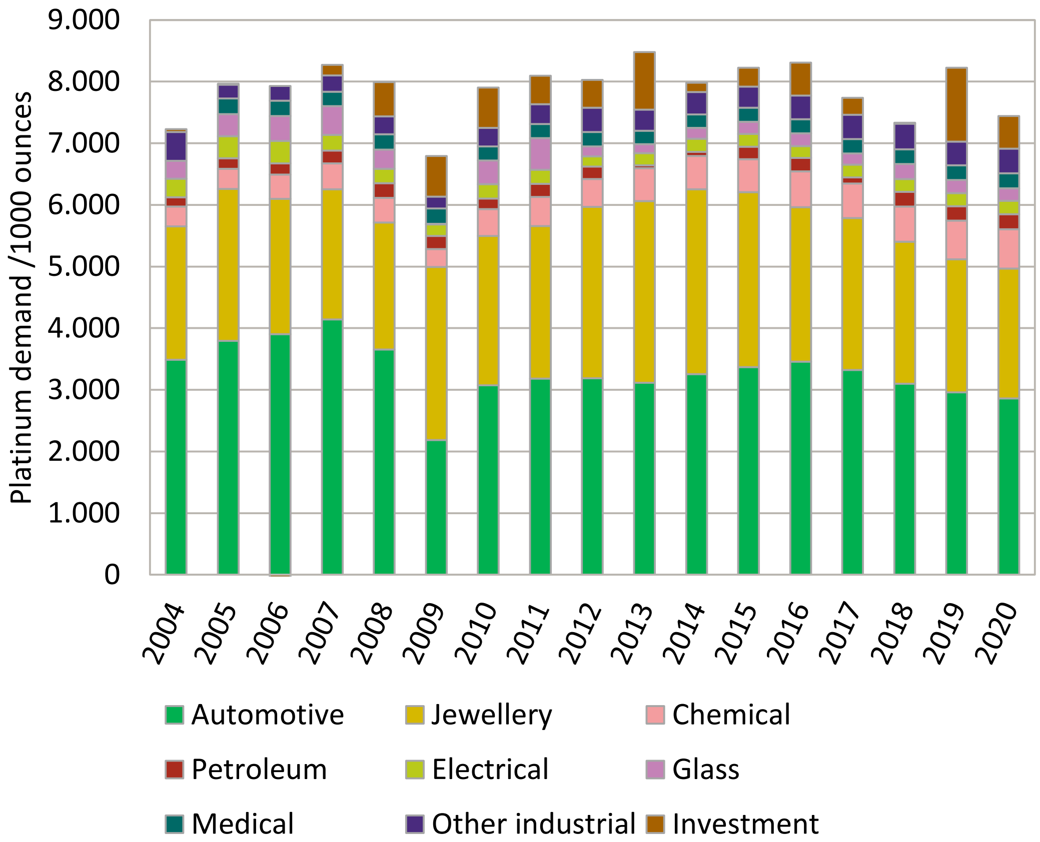


*currently technical and economical useable resources

**verified, currently technical and economical not usable and not verified but geological possible resources

Source: Energiestudie 2017 – Daten und Entwicklungen der deutschen und globalen Energieversorgung, BGR

Automotive platinum consumption



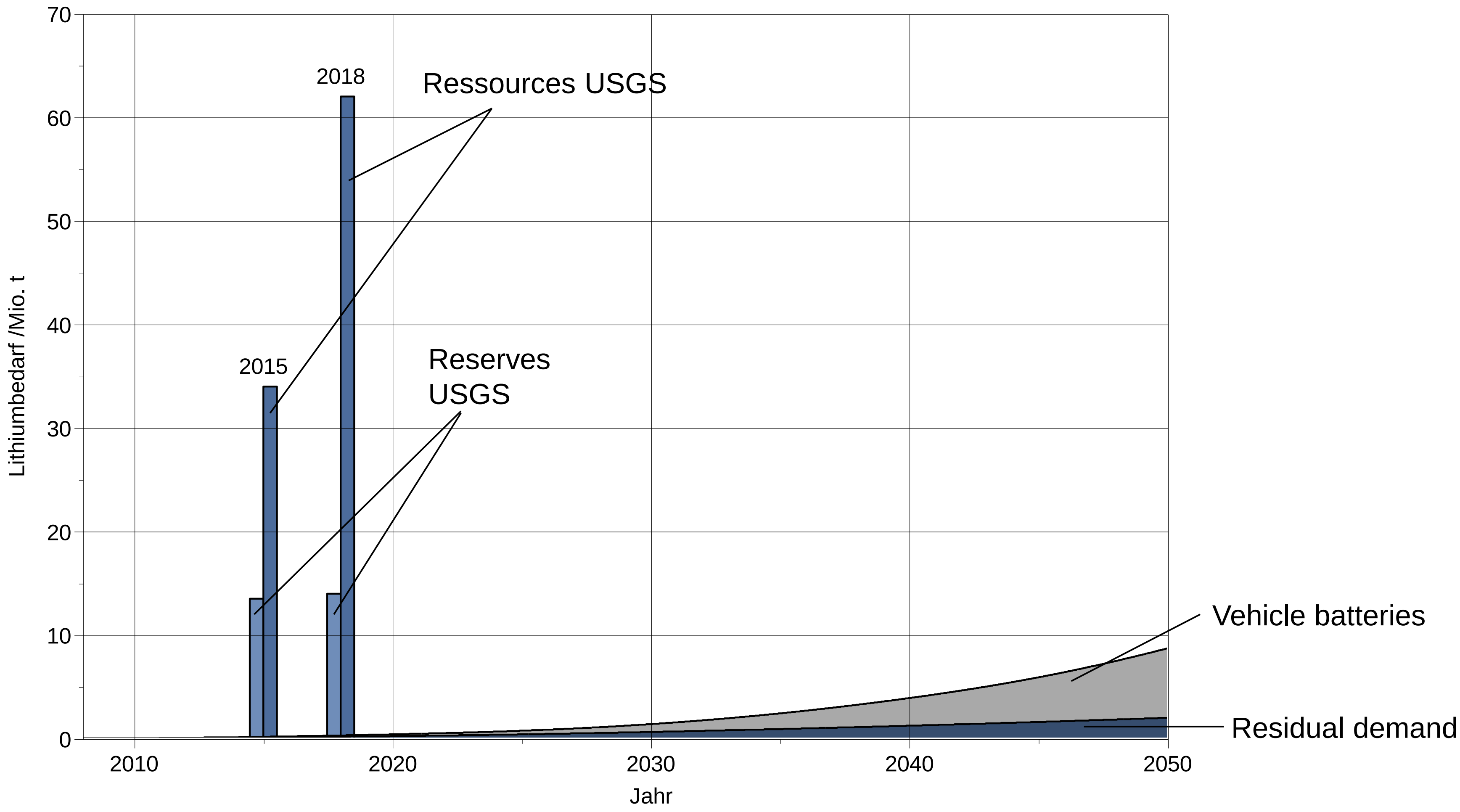
Usage of platinum per vehicle

- fuel-cell technology
  - beginning: up to 1000 g
  - now: 10-20 g (ca. 0.1 mg Pt/cm²)

- Exhaust gas after treatment for combustion engines
  - approx. 4-5 g Pt/vehicle (Europe)
  - up to 25 g Pt/vehicle (Diesel, US Tier 2 Bin 5)

Source: World Platinum Investment Council: Quarterly Q3 2019 / Johnson Matthey xls-2004-to-2012

Lithium availability – demand scenario: almost complete substitution by hybrids and pure electric vehicles



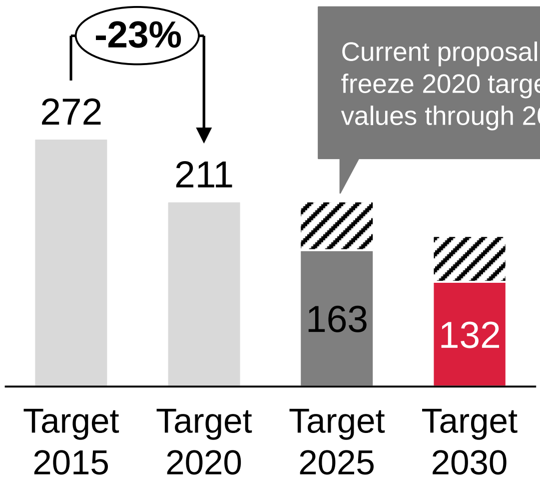
Source: Fraunhofer ISI - Lithium für Zukunftstechnologien, 2009
USGS: U.S. Department of Interior – U.S. Geological Survey – Mineral Commodity Summeries 2009 and 2016

Intensification of CO2 emission targets (2015 – 2030)

CO_2 Emissions Regulation

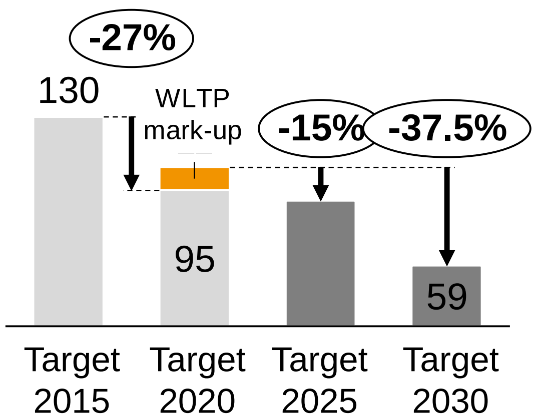
confirmed | Target suggestion (examination) | Scenario*

EPA 2-Cycle
CO_2 emission in g/mi



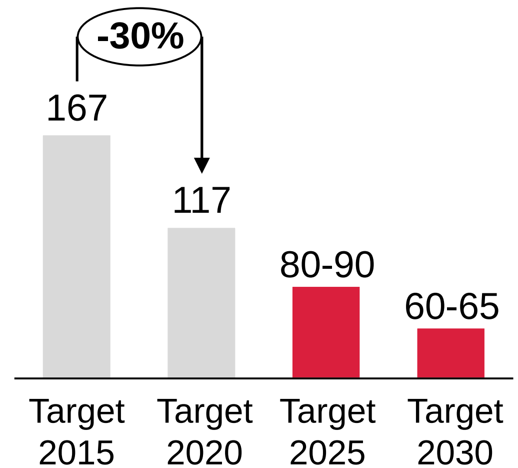
Passenger cars and small utility vehicles

NEDC (WLTP from 2021)
CO_2 emissions in g/km



Passenger cars

NEDC
CO_2 emissions in g/km

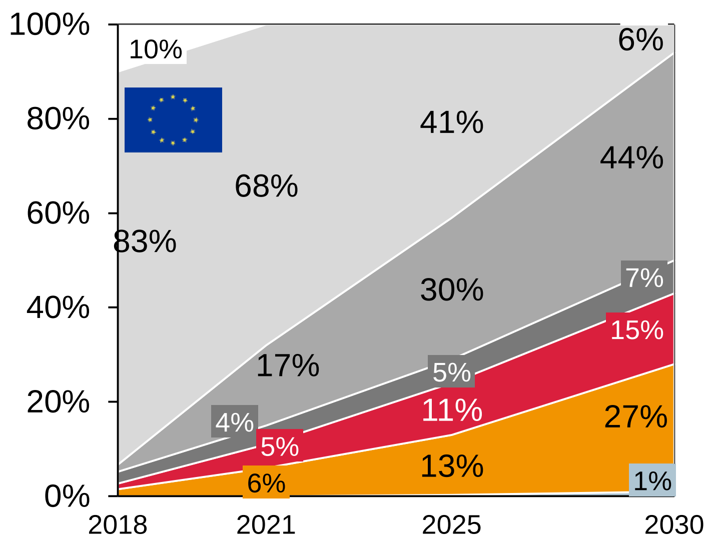


Passenger cars

NEDC = New European Driving Cycle; GHG = Greenhouse Gas
* EU: based on GHG reduction targets for transport sector by European Commission; US: 4% annual reduction assumed after 2025; China: convergence with EU targets expected
// CN figures are converted from l/km
Quelle: European Commission, ACEA, FEV

Significant BEV share increase to 2030 – major market for Battery electric vehicles is China followed by EU

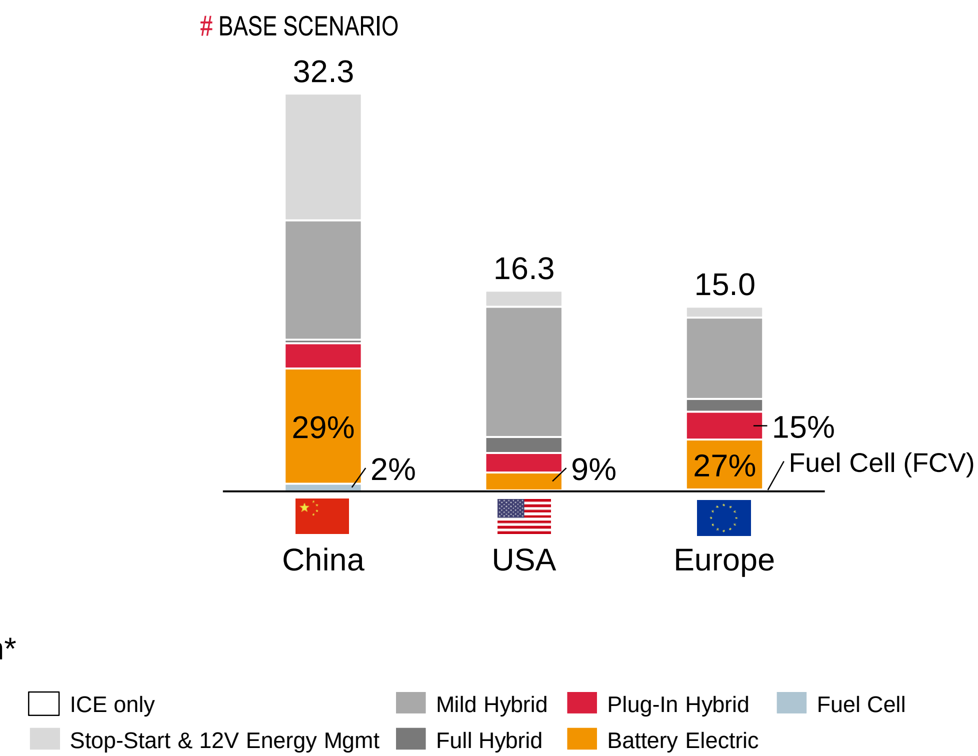
FEV Base Scenario



CO_2 fleet emission: | *95 g/km target expected to be violated by some OEMs* | <81 g/km* | <59 g/km*

Passenger Car powertrain electrification scenarios – Vehicle sales

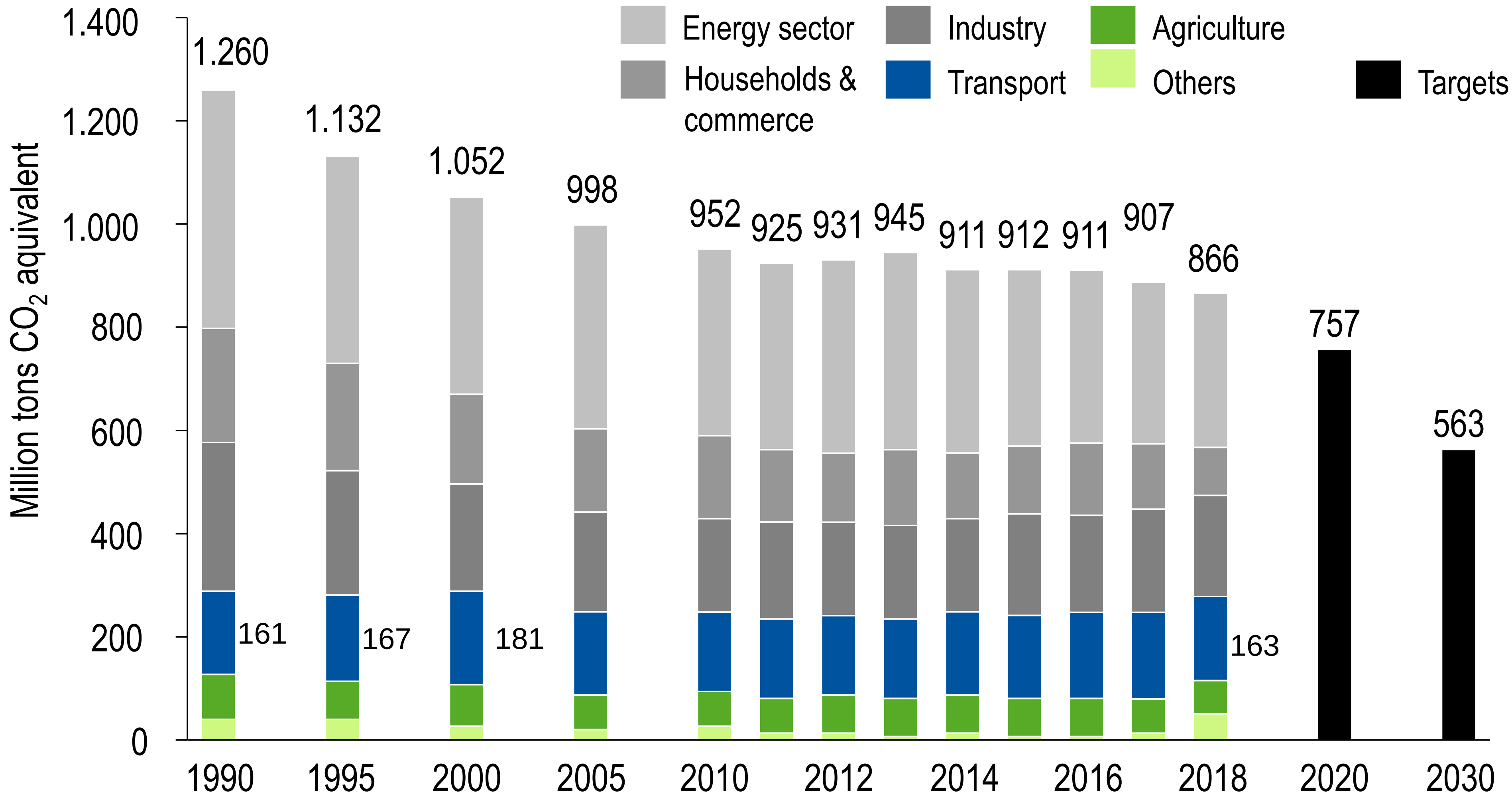
Pass. car powertrain type forecast 2030 in mio. units



*: normalized to NEDC

Source: FEV

Greenhouse gas emissions in Germany



Umweltbundesamt

Content of lecture

Classification of alternative propulsion systems

Classification by

Primary energy source
- fossil
- non-fossil

Energy conversion cycle/machine

Energy carrier
- chemical
- electrical/electrochemical
- mechanical

- Combinations of two or more classifications are possible.

Classification of alternative propulsion systems

by primary energy source:

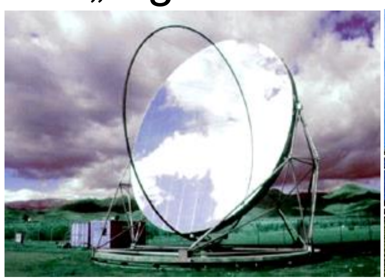
- fossil

Coal

Mineral oil

Natural gas

- „regenerative”:



Sun

Water

Wind

Biomass

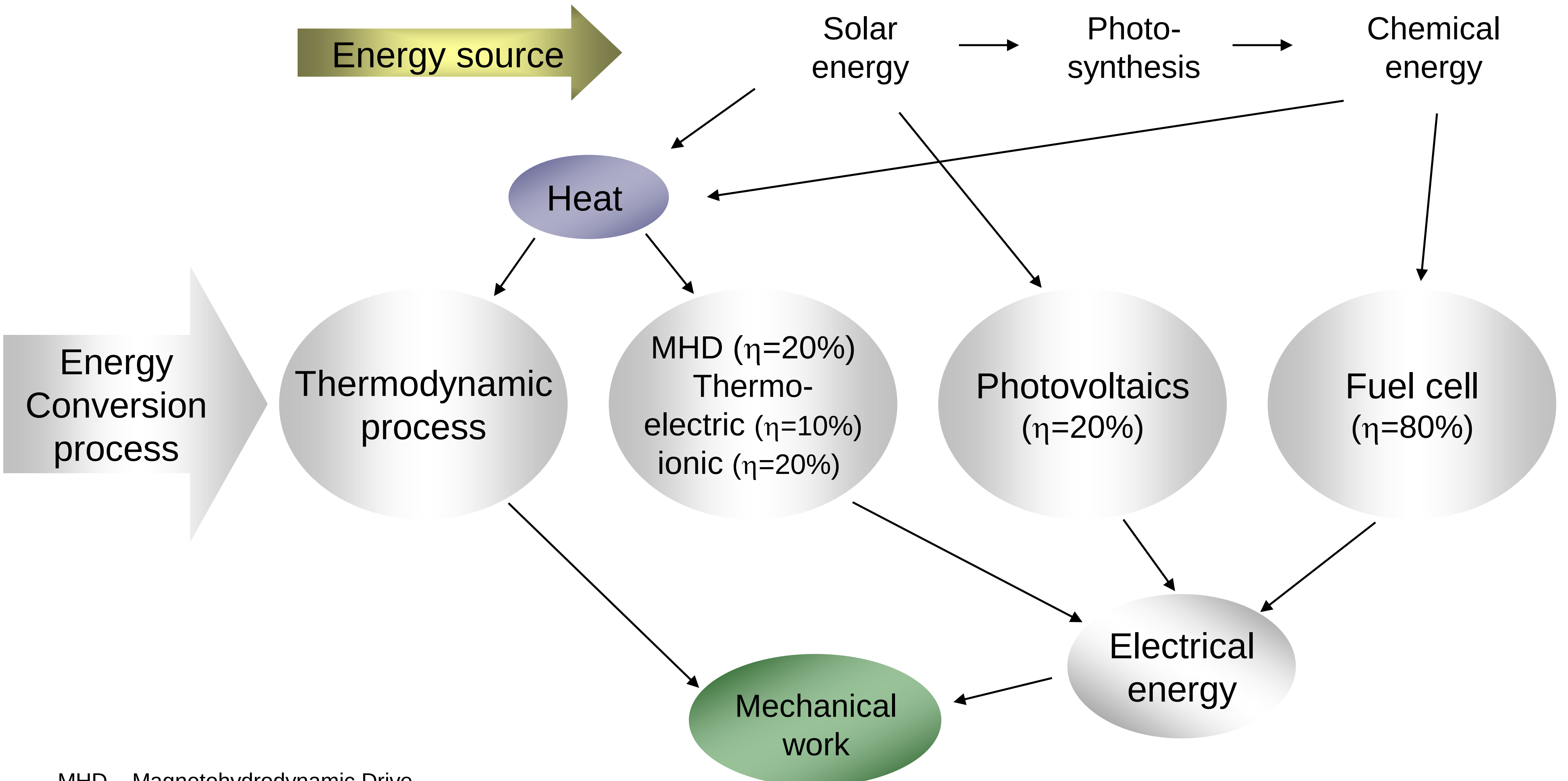
Geothermal

Classification of alternative propulsion systems

by form/ source of energy (closely related: energy storage):

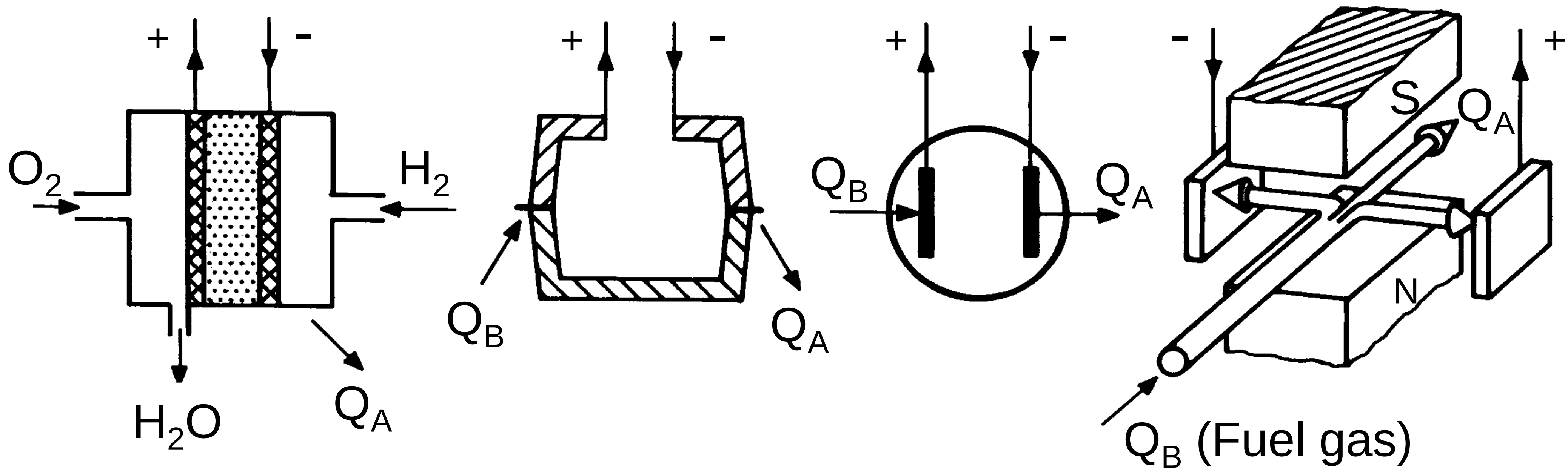
- - chemical (Otto, Diesel, natural gas, methanol, ethanol, hydrogen...)
  - Storage:
    - Liquid fuel tank
    - Pressure tank
    - Hydride storage
- electrical/electrochemical
  - Storage
    - Battery
    - Super capacitor
- mechanical (pneumatic, hydraulic, kinetic)
  - Storage
    - Pressure tank
    - Flywheel

Classification of alternative vehicle propulsion systems by energy conversion process



MHD – Magnetohydrodynamic Drive

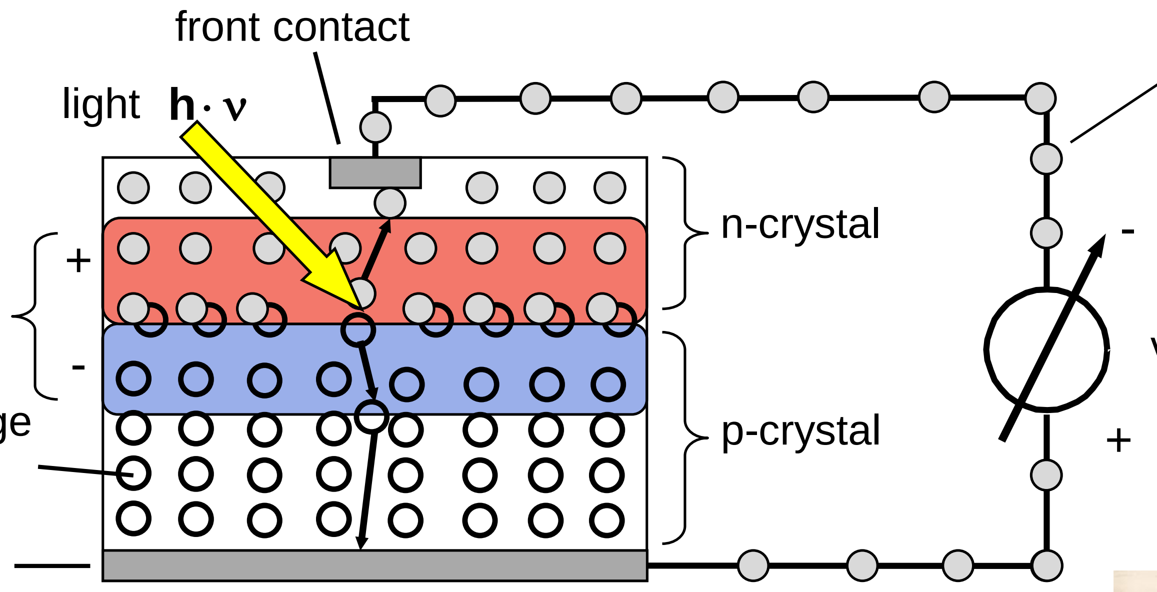
Principles for fuel energy conversion



Fuel-cell (electrochemical) | Thermo-electr. element | Thermionic element | magnetohydrodynamic converter

direct | via heat

Photovoltaic cell

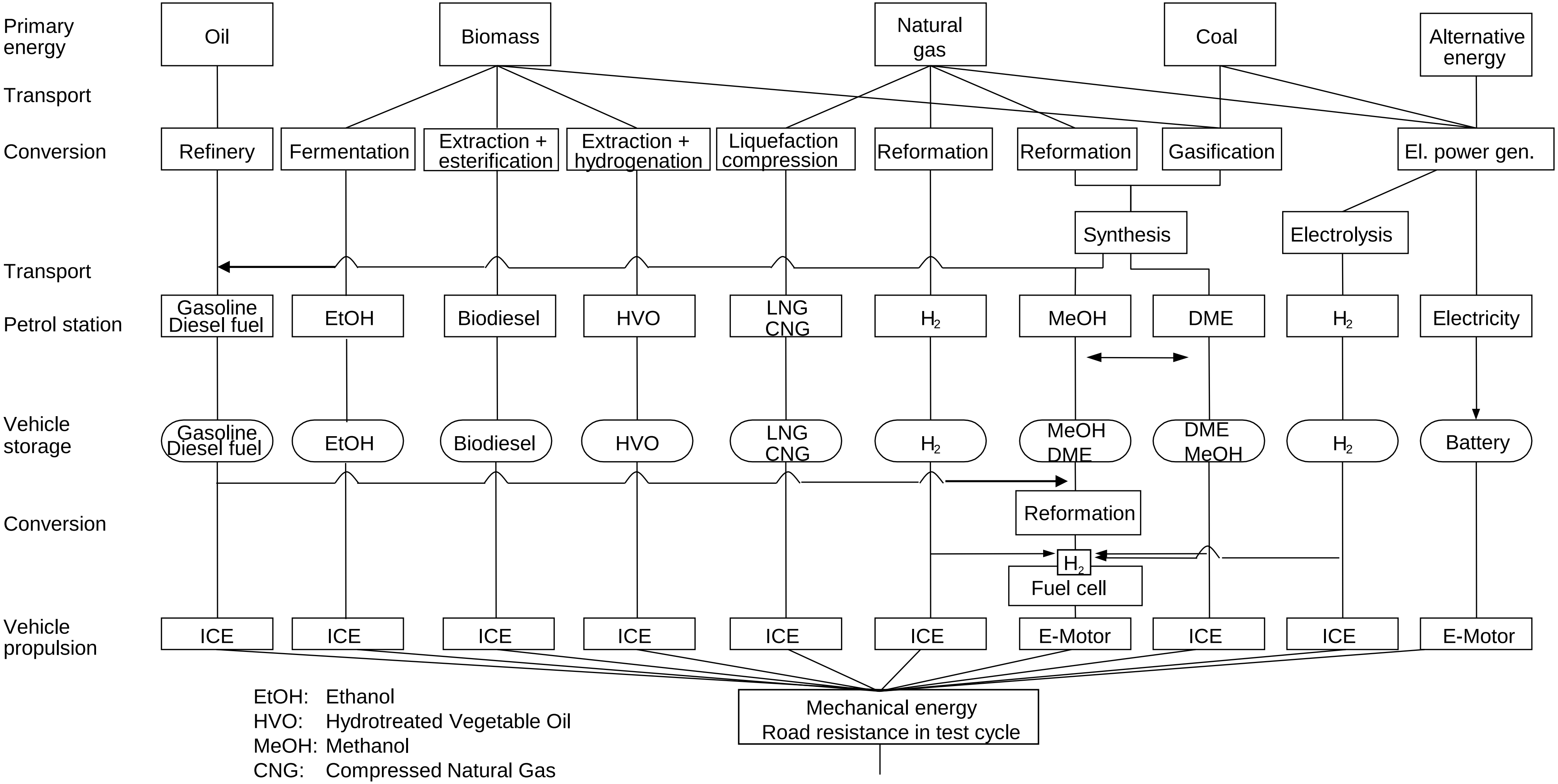


- At the p/n junction electrons diffuse into the p-crystal and holes into the n-crystal, whereby an area with less free charge carrier is generated (space charge area).
- Light enters the space charge area and produces free charge carrier (electrons/holes).
- Due to the electrical field, the charge carrier are separated and conducted to the contacts.
- A usable current is generated.

Solar car Aachen

20 kg lithium ion cell
4m² PV area
135 V wheel hub motor (1.4 kW)
Weight = 200 kg
V_{Max} = 135 km/h

Well-to-Wheel
New energy sources and propulsion systems for road traffic



EtOH: Ethanol
HVO: Hydrotreated Vegetable Oil
MeOH: Methanol
CNG: Compressed Natural Gas
LNG: Liquid Natural Gas
DME: Dimethyl ether

Quelle: IEV, Forschungszentrum Jülich 01.97, VKA

Content of lecture

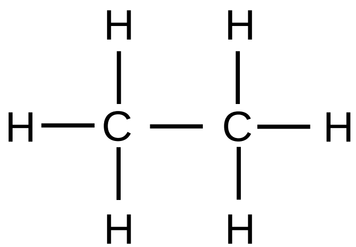
Properties of chemical energy sources

- Energy carriers
  - chemical
  - electrical / electrochemical
  - mechanical
- This chapter focuses on chemical energy sources
  (storage density is much higher compared to other energy sources)
- Chemical energy sources
  - Almost only hydrocarbons (C, H, O, (N), S)
  - Requirements of energy carriers are lower for external combustion than for internal combustion

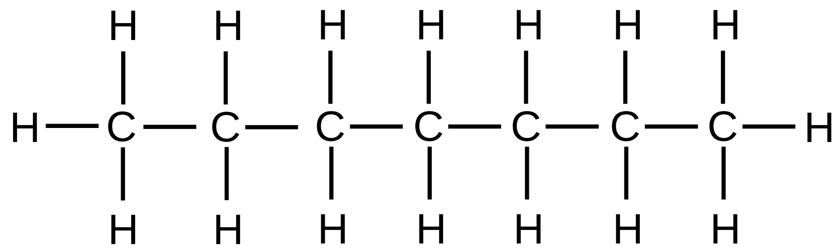
Hydrocarbon chain

Paraffin (Alkane) C_nH_{2n+2}

Normal Paraffins:

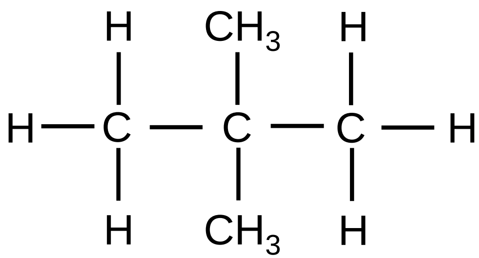


Ethane

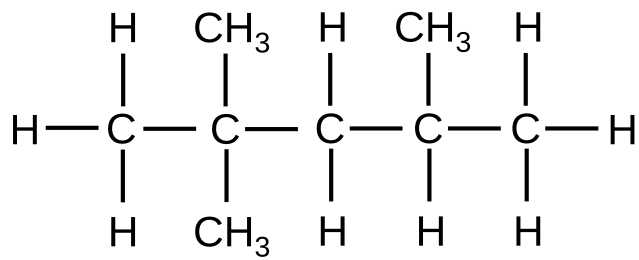


n-Heptane

Isoparaffins:



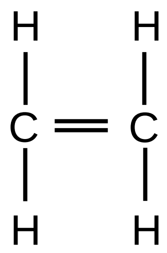
2,2 Dimethylpropane (Isopentane)



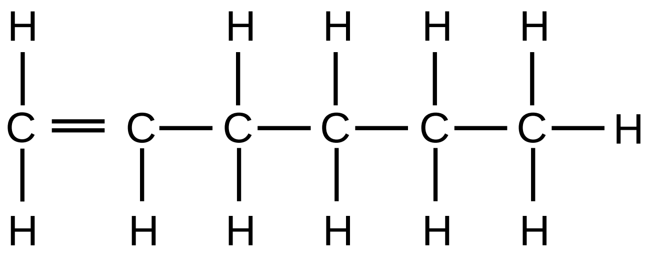
2,2,4 Trimethylpentane (Isooctane)

Hydrocarbon chain

Olefins

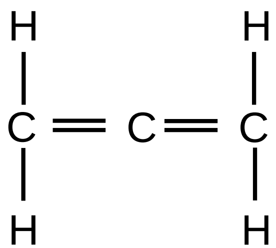


Ethylene

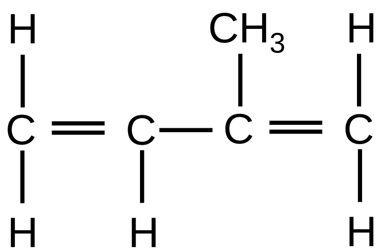


1-Hexen

Diolefins (Alkadienes)



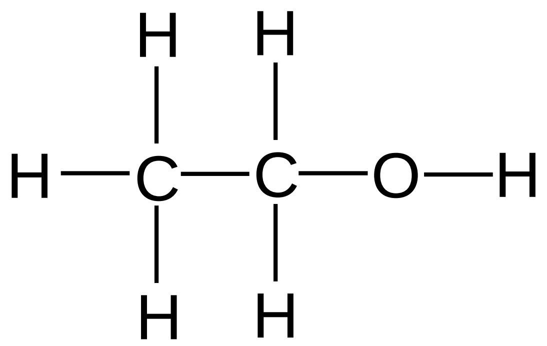
Propadiene (Allene)



2-Methyl-1,3 Butadiene (Isoprene)

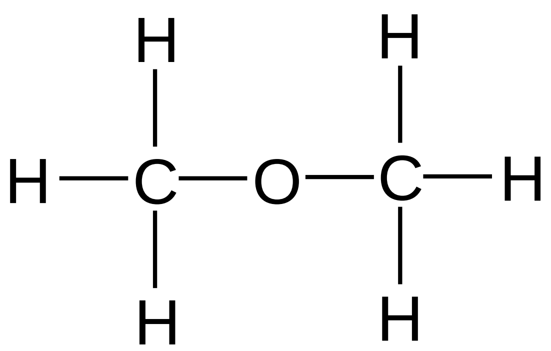
Hydrocarbon chain

Alcohols



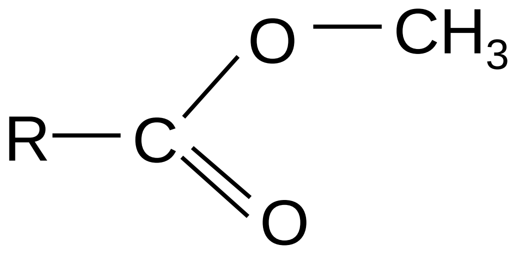
Ethanol

Ether



Dimethyl Ether

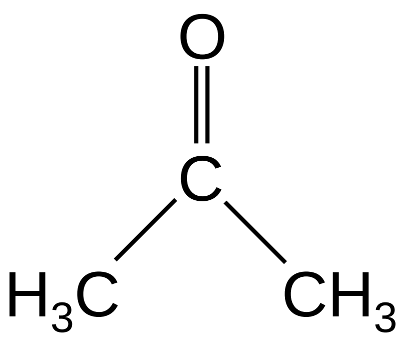
Ester



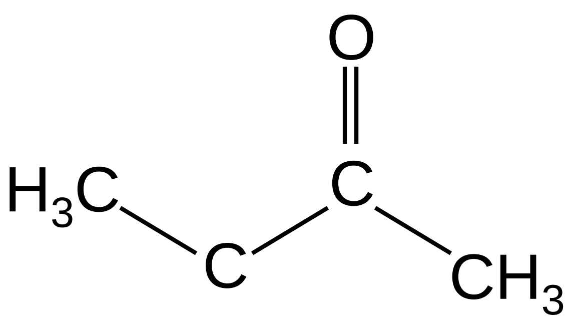
Fatty Acid Methyl Ester

Hydrocarbon chain

Ketones



Acetone

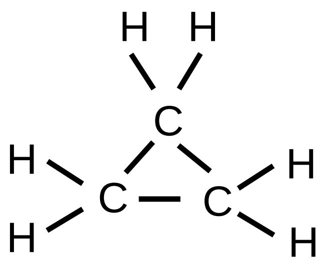


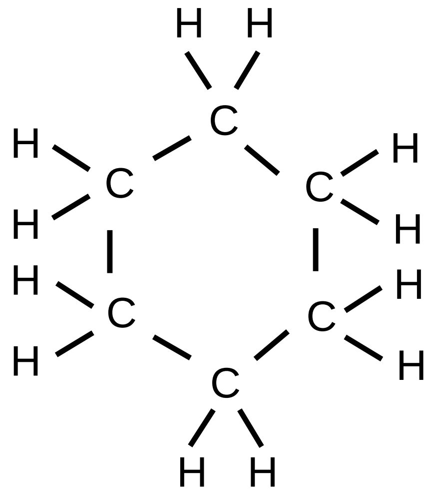
Butanone

Cyclohydrocarbons

Naphthenes (Cycloalkenes)

Cyclopropane

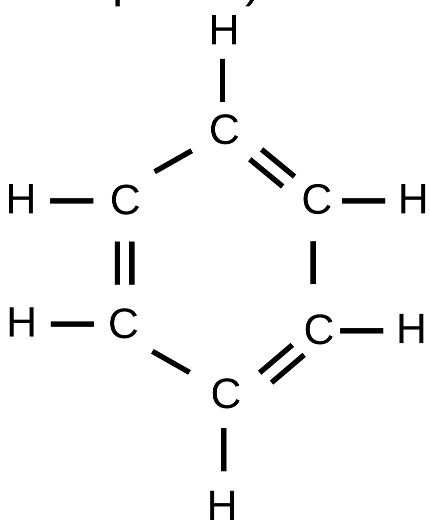


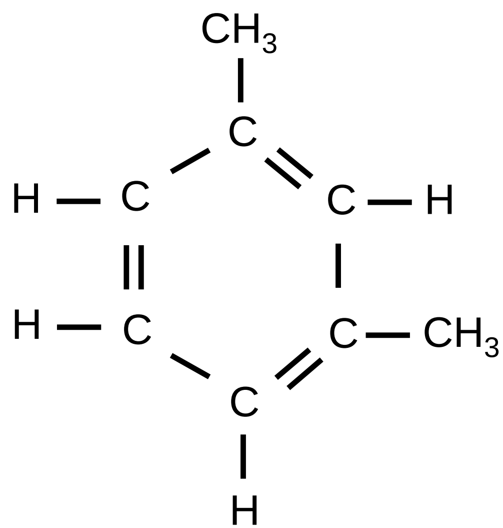


Cyclohexane

Benzene (aromatic compound)

Benzene (C_6H_6)



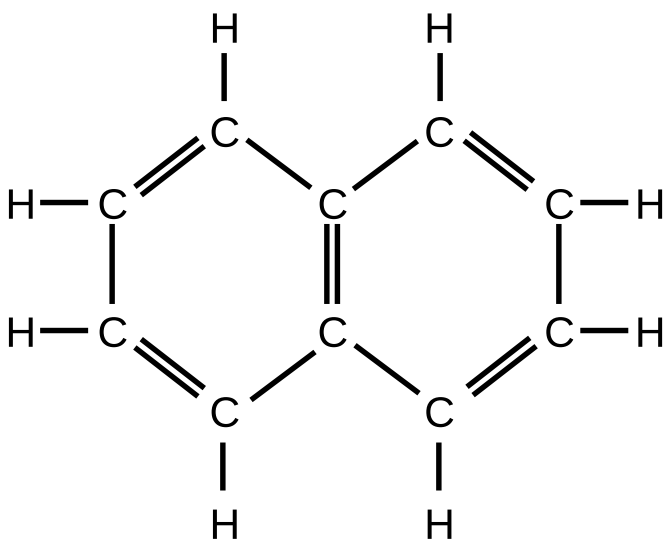


1,3 Dimethylbenzene
(*m-Xylene*)

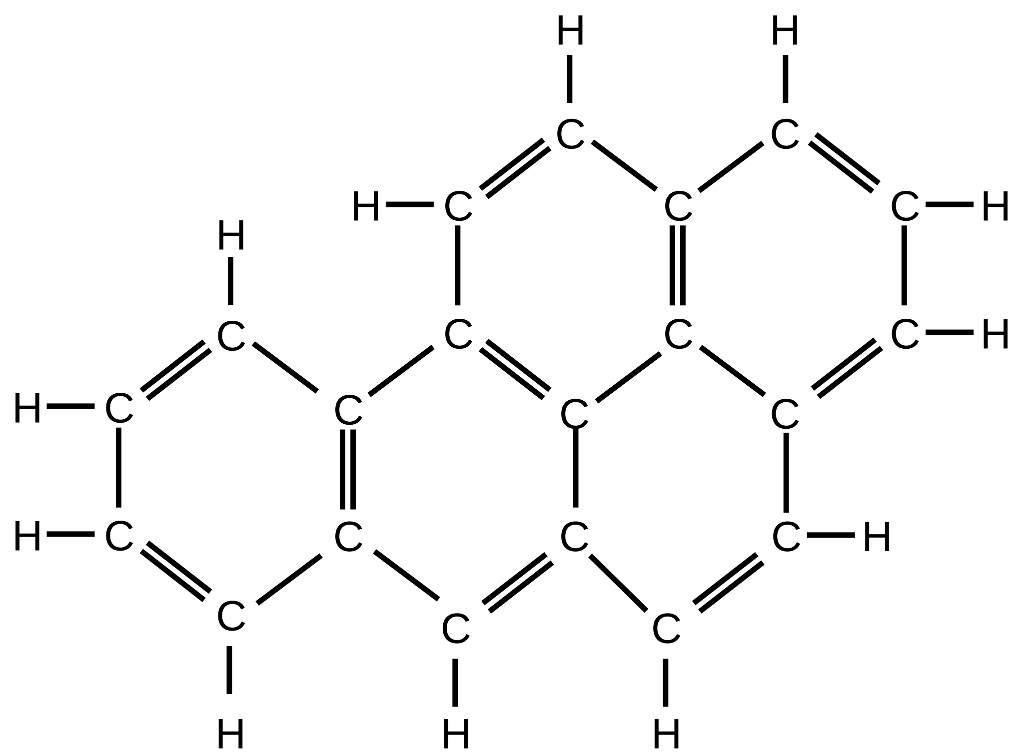
Polycyclic hydrocarbons

polycyclic compound

naphthalene



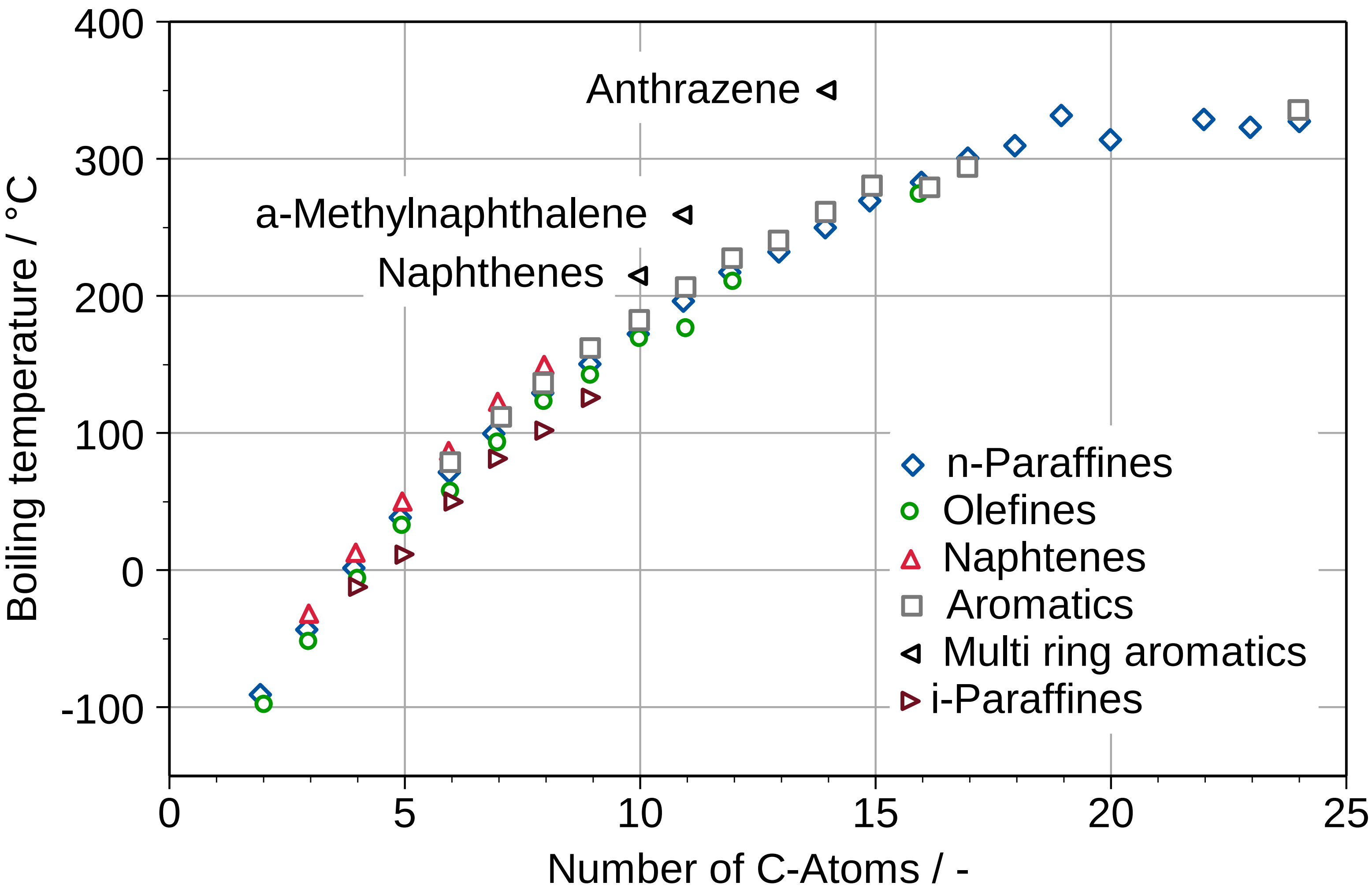
Benzo [a] pyrene



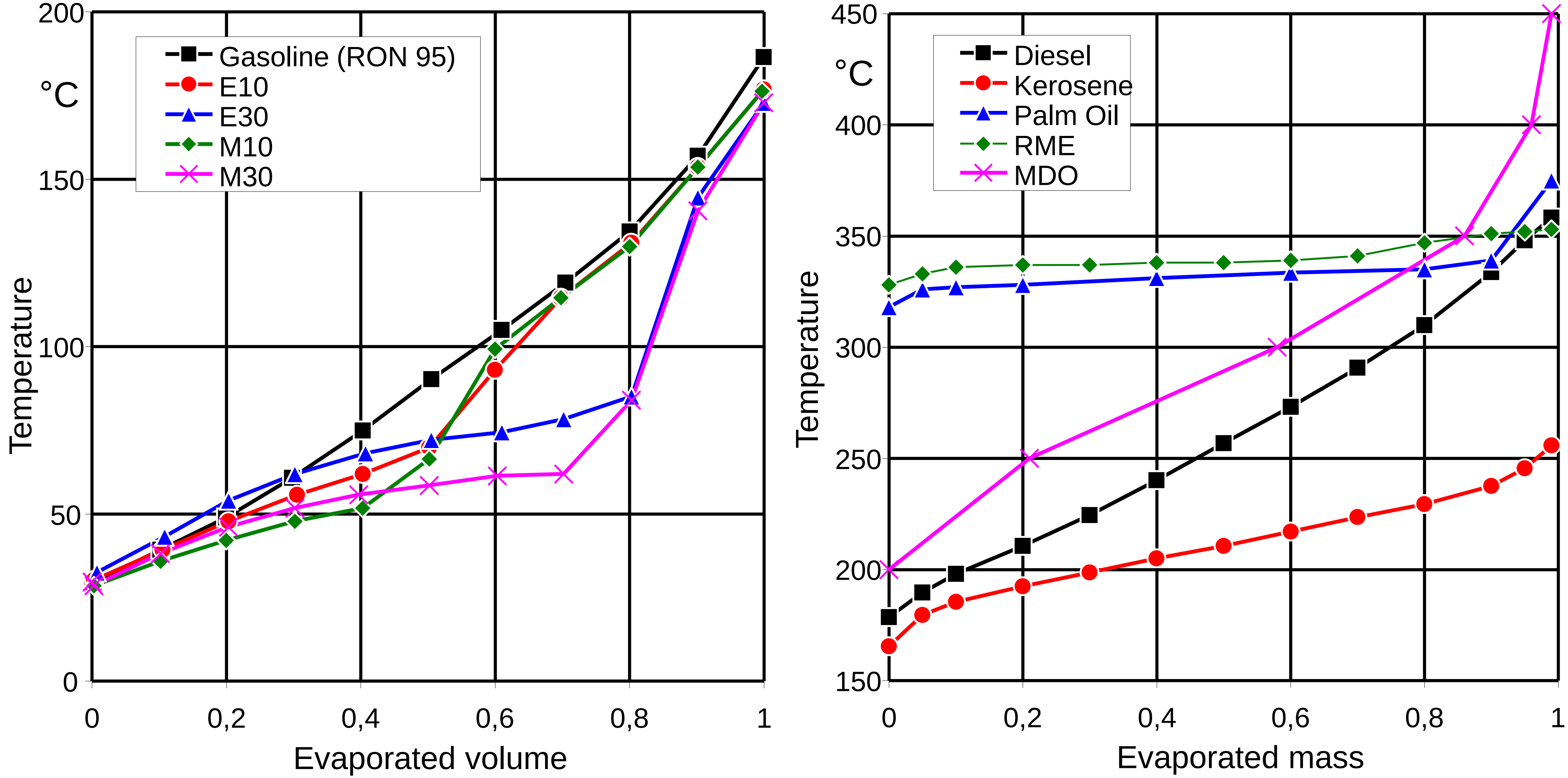
Chemical energy carriers: Main properties and relevance for vehicle propulsion

- Boiling temperature:
  - Increases with long chained molecules and is of importance for mixture formation.
  - Fuel mixtures have boiling curve
- Heat of vaporization / Vapor pressure:
  - Indicates amount of heat required for fuel vaporization; a high vaporization heat causes a high mixture cooling, thus naturally aspirated SI-engines with an exterior mixture formation will have a better cylinder charge
- Calorific value:
  - H_u, kJ/kg: Mass of stored fuel
- Stoichiometric air requirement L_{St}:
  - Indicates amount of air required for stoichiometric combustion: $L_{St} = m_{LSt}/m_B$
- Energy specific carbon content:
  - c/H_u: CO_2-Emission based on fuel energy
    - H_2 emits no CO_2
    - CH_4 has a CO_2 advantage compared to gasoline of about 20 %
- Density / State of aggregation:
  - Density increases with number of C, higher density → less tank volume
- Volume specific calorific value → tank volume

Boiling Temperature of HC Compounds



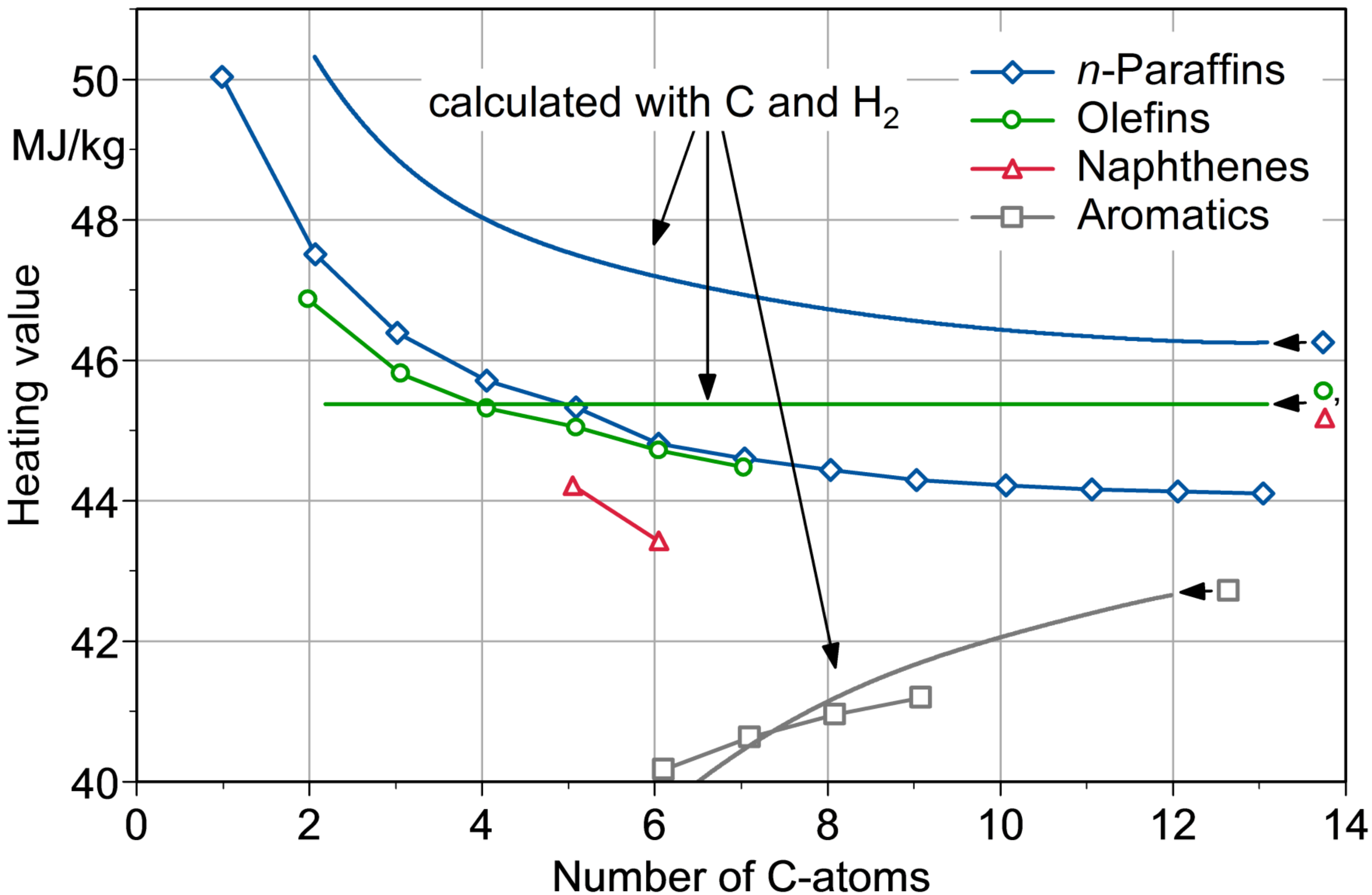
Boiling Curves of Alternative Fuels



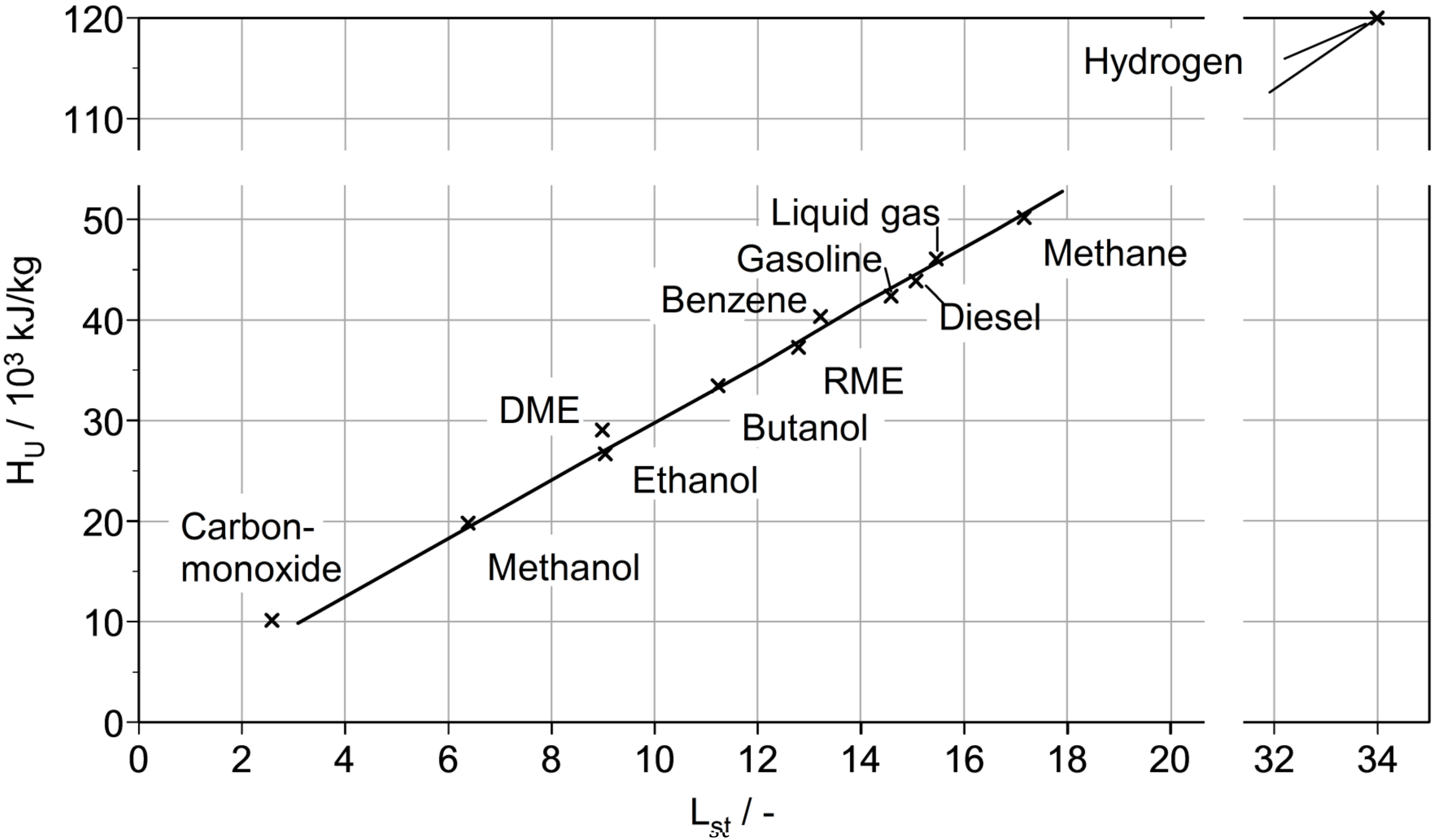
MDO – Marine Diesel Oil

Quelle: AAN & PetrochemCarless; Diss. Grabe, 2002; Takasaki et al, M.E.S.J., Vol. 27, No.1; SAE 2007-01-0472

Heating value of HC compounds

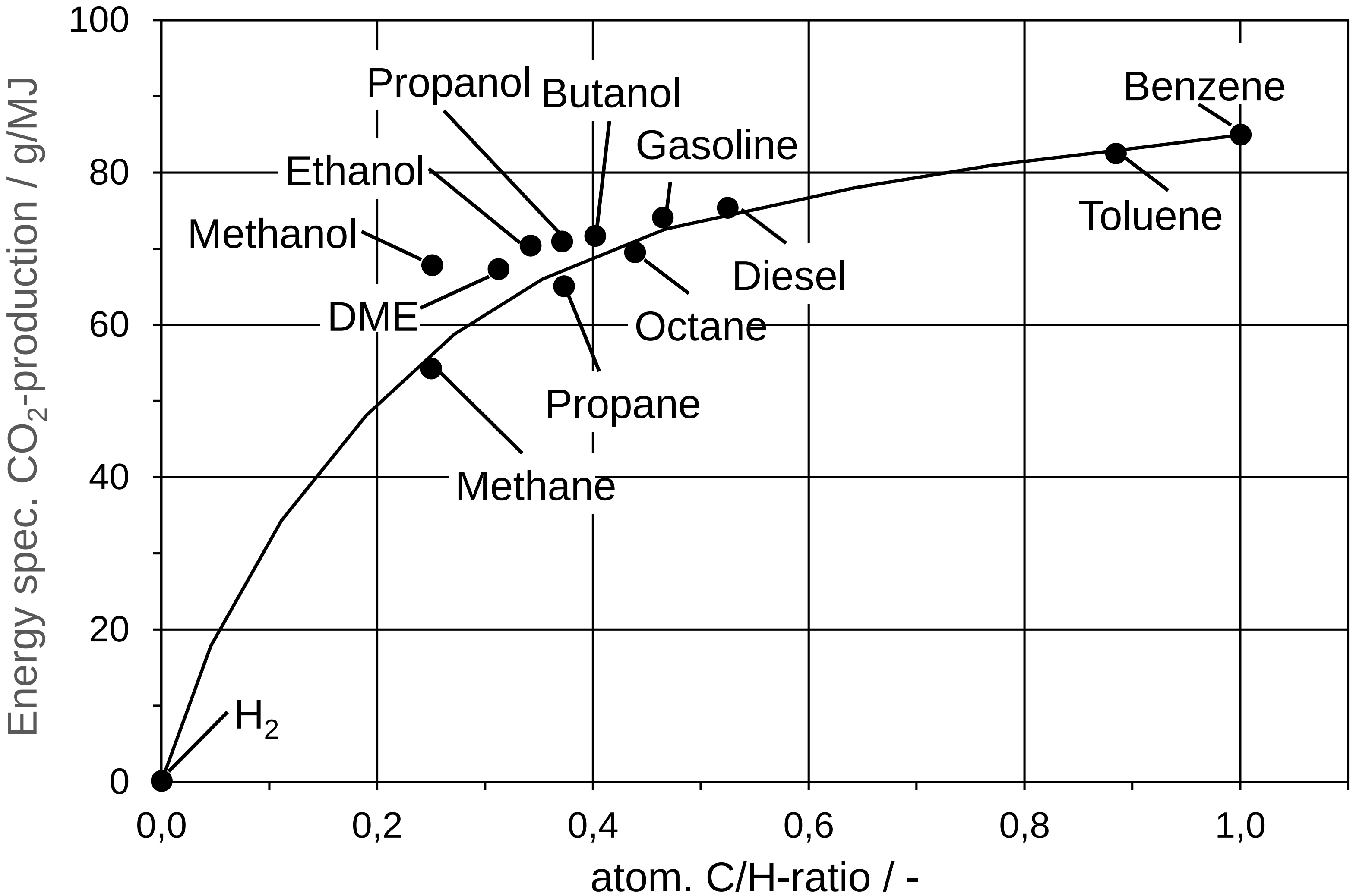


Features of chemical energy sources

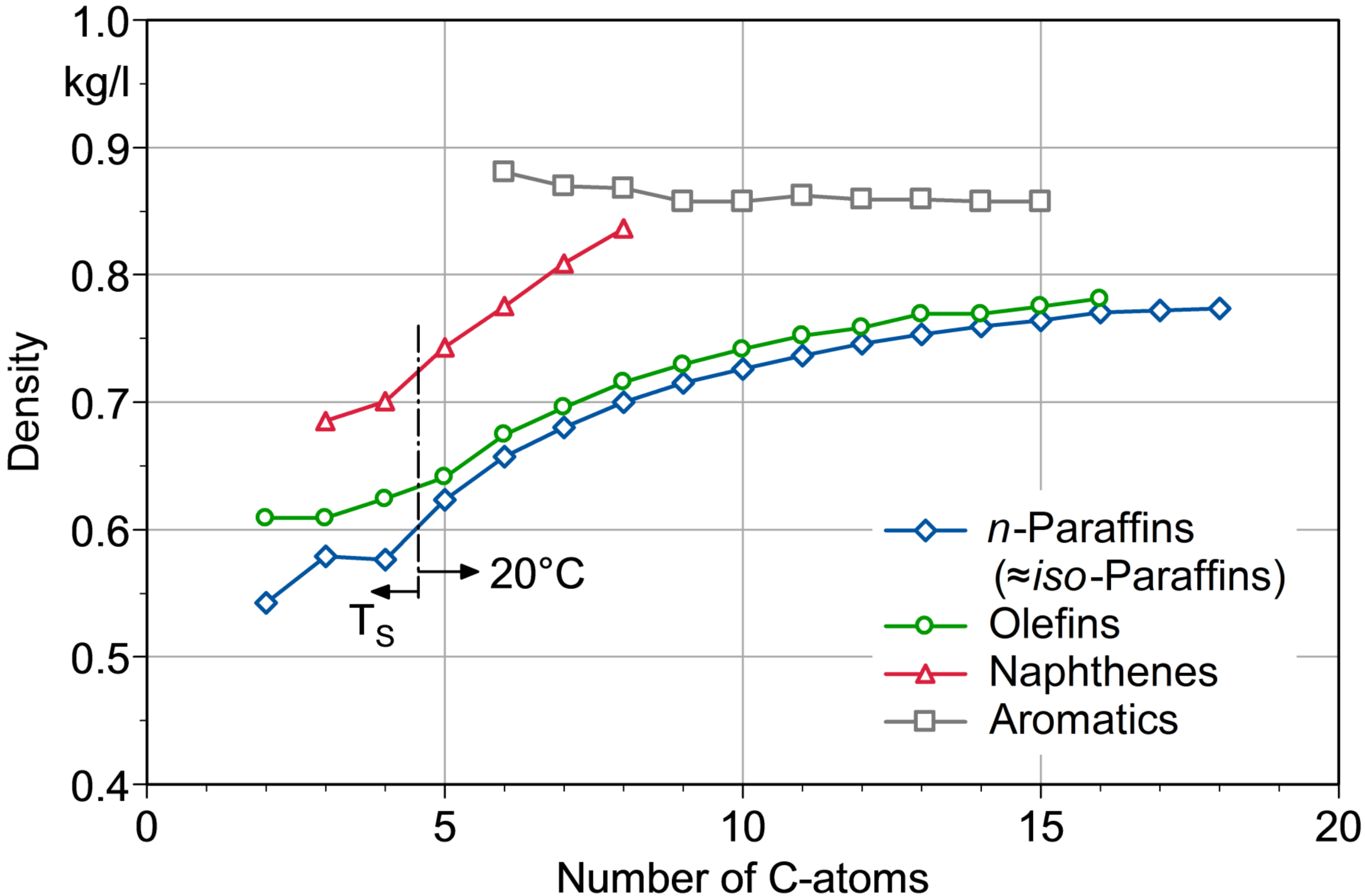


Lecture notes: ICEF 5.1, ICE1 2.4, AVPS 2.2
E 4309 ICEF, ICE1, AVPS

Energy specific CO_2 emissions of fuels



Density of HC Compounds



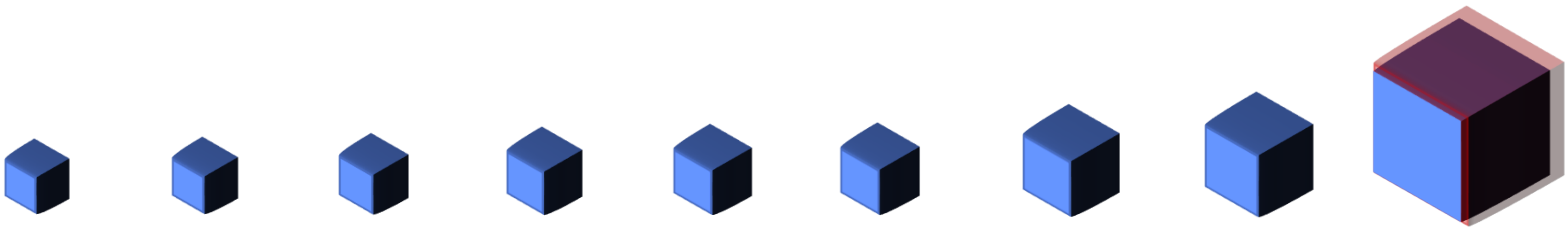
Main properties and significance for vehicle propulsion

- Volume-related calorific value
  - Tank volume
- Ignitability / Antiknock property:
  - Octane number ON (n-Heptane / iso-Oktane)
    - antiknock property (Otto cycle) RON > 95 (Eurosuper, EN)
  - Cetane number CN (a-Methylnaphtalin / Cetane)
    - ignition performance (Diesel cycle) CN > 51 (Diesel, EN)
  - Methane number MN (Hydrogen / Methane)
    - antiknock property for gaseous fuels (range up to ON > 100, ON of Methane approx. 140)
- Soot formation:
  - decreases with oxygen content
- Burning velocity, Ignition limits:
  - high burning velocity
  - wide ignition limits

  → advantageous for homogeneous lean operation (low NO_X combustion with high efficiency)

Size of storage systems for identical vehicle range

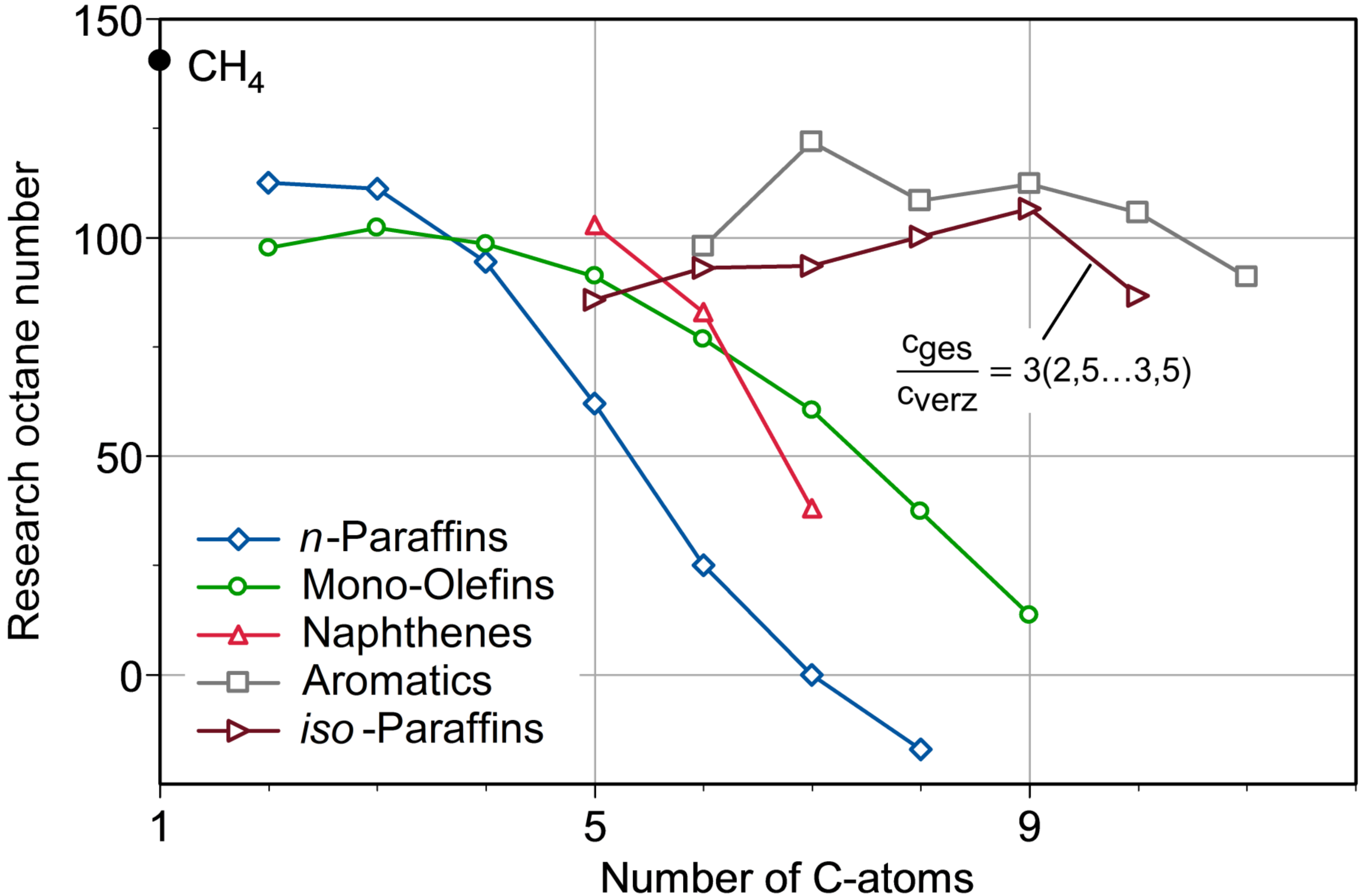
Mass and volume for identical range (1000 km):
(* including storage system)



	Diesel	RME	Gasoline (Petrol)	LPG	Ethanol	DME	Hydrogen liquid for PEM (H_2 700bar)	Natural Gas (CNG 200 bar)	Battery Li-Ion
	54 kg*	61 kg*	65 kg*	72 kg*	95 kg*	93 kg*	140 kg*	164 kg*	943 kg*
	39 kg	45 kg	45 kg	41 kg	68 kg	58 kg	8 kg	37 kg	736 kg
	47 l	51 l	60 l	77 l	86 l	89 l	165 l	231 l	1023 l 1314 l*
Energy consumption NEDC in MJ / 100 km :	166	166	191	190	181	166	95	184	53

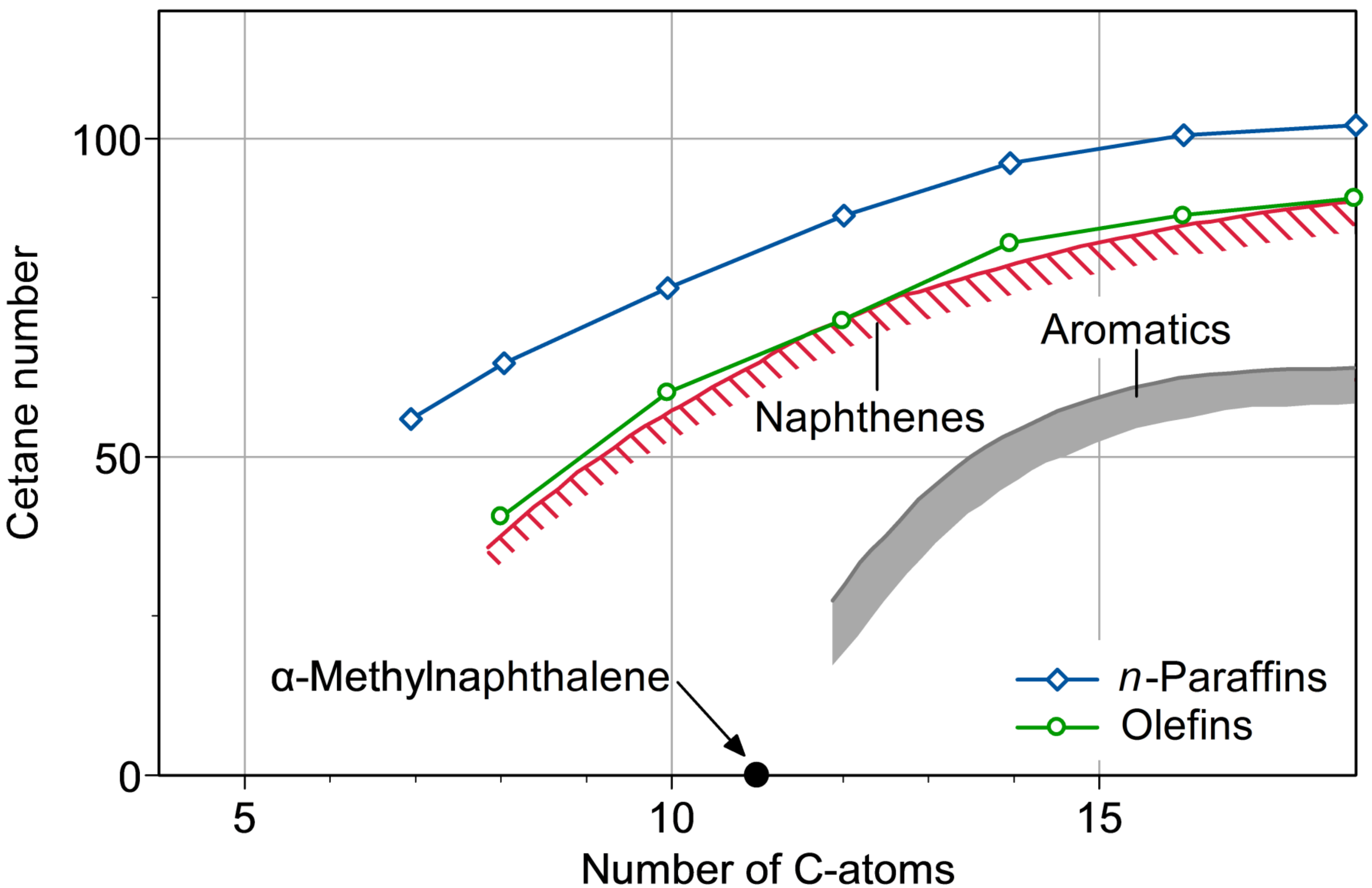
DME – dimethyl ether
RME – rapeseed methyl ester
LPG – liquefied Petroleum Gas
PEM – polymer electrolyte fuel cells

RON of HC Compounds

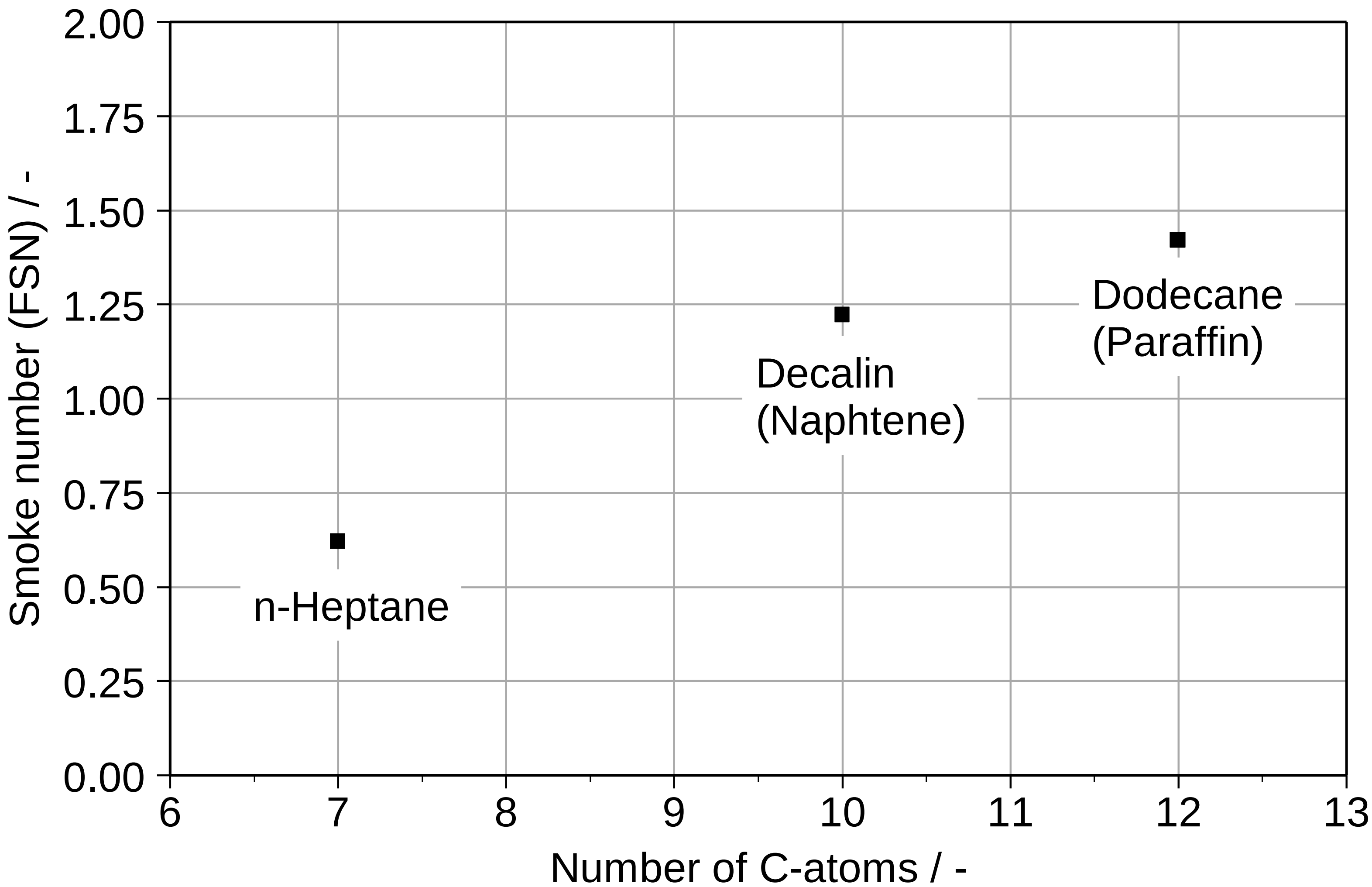


Lecture notes: ICE1 2.1
E 4312 ICE1

Cetane Number of HC compounds



Influence of different fuels on soot emissions



1-Cylinder Diesel

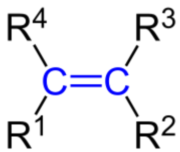
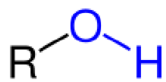
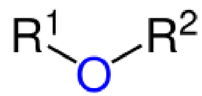
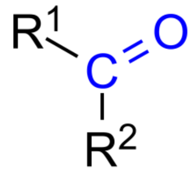
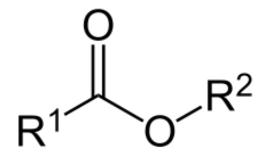
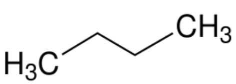
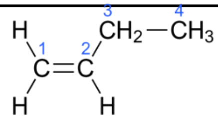
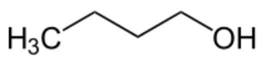
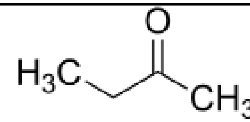
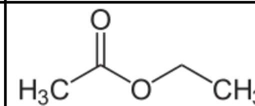
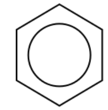
$V_{\mathrm{H}} = 400\ cm^3$

Engine Load:

$n = 2280\ min^{-1}$

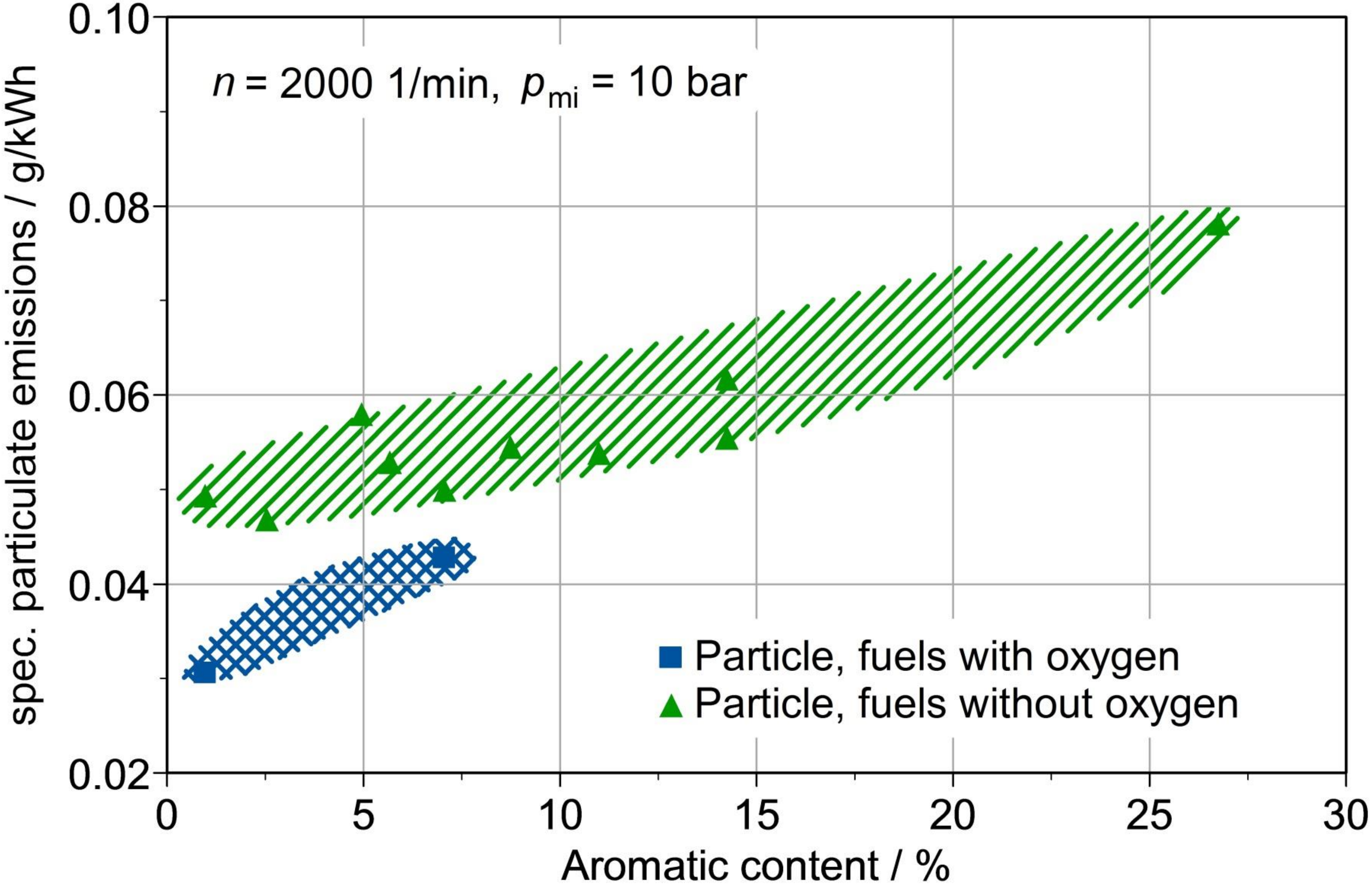
$p_{\mathrm{mi}} = 4{,}4\ bar$

Influence of the molecular structure of fuels on the tendency to soot formation

Alkanes	Alkenes	Alcohols	Ethers	Ketones	Esters	Aromatics
						Cyclic, C-C double bond
Butane C_4H_{10}	Butene C_4H_8	Butanol $C_4H_{10}O$	Diethyl ether $C_4H_{10}O$	Butanone C_4H_8O	Ehyl acetate $C_4H_8O_2$	Benzene C_6H_6
						
Moderate sooting tendency	High sooting tendency due to C-C double bond	Low sooting tendency due to oxygen in functional group				Very high sooting tendency, because soot precursor

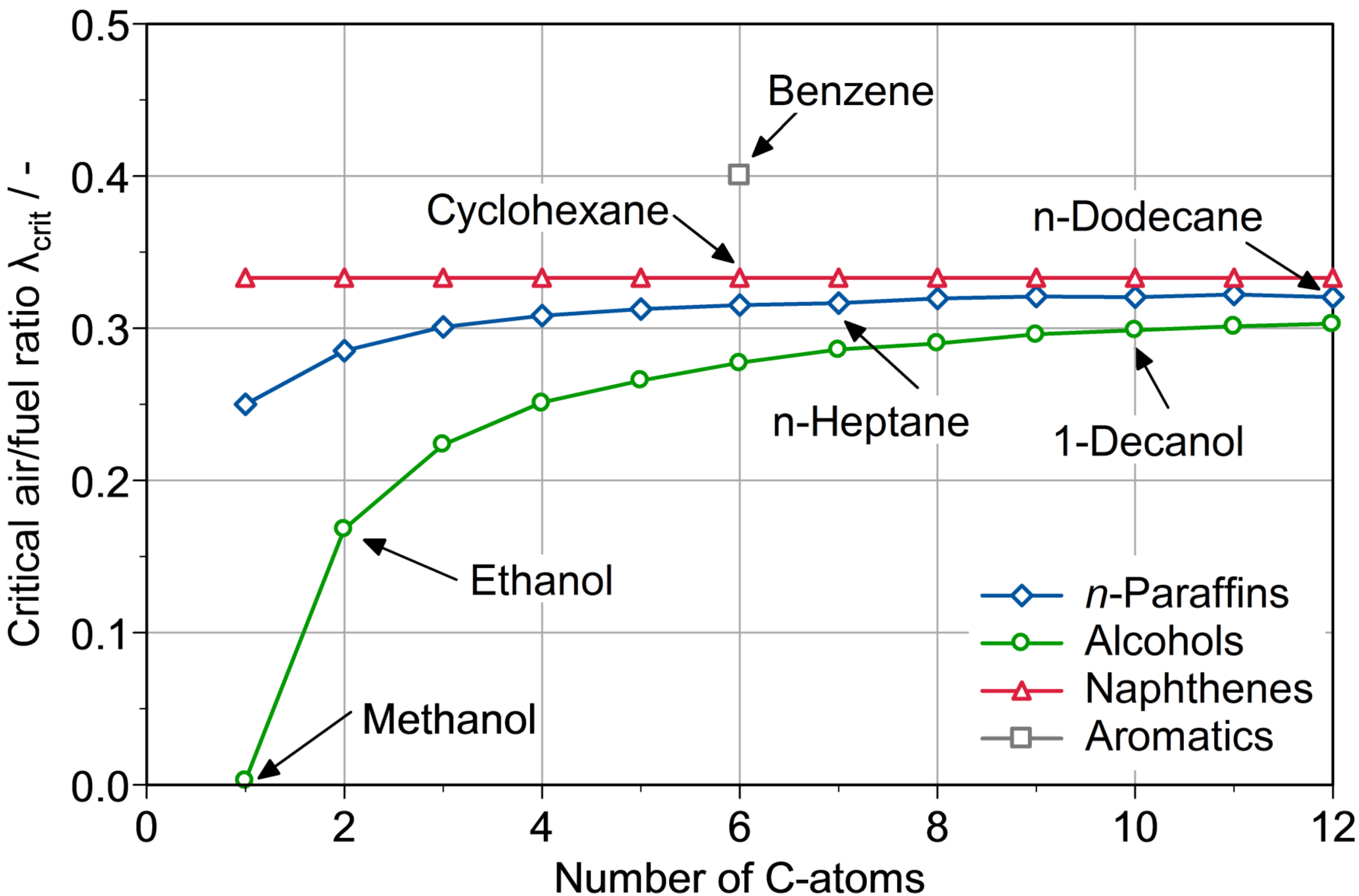
R = organic residual

Influence of different fuels on particulate emissions

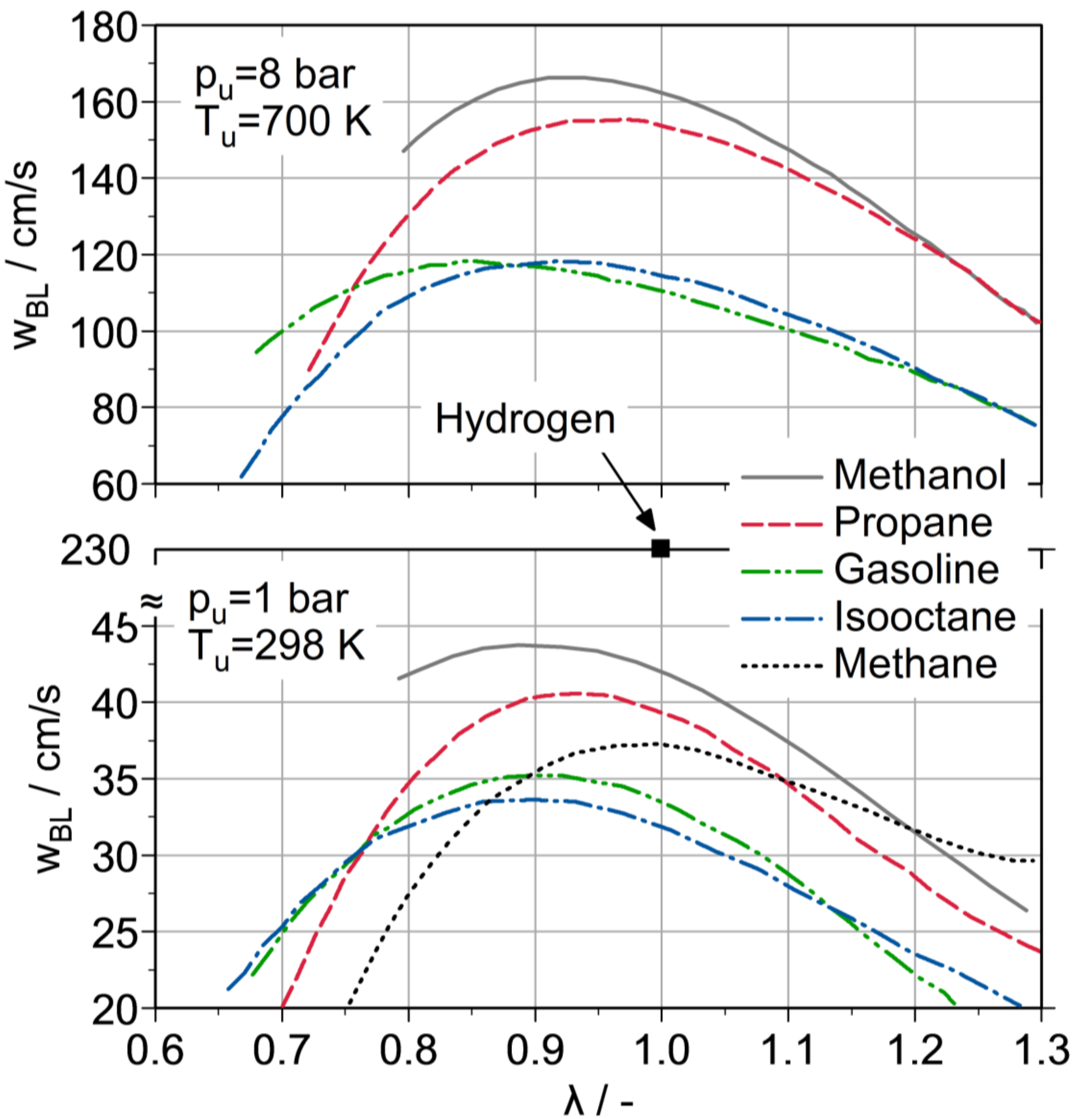


Source: Dissertation Pungs, VKA 2001

Critical Air-Fuel Ratio λ_{crit}



Laminar burning velocity w_{BL} for different fuels



Source: Metghalchi, Keck

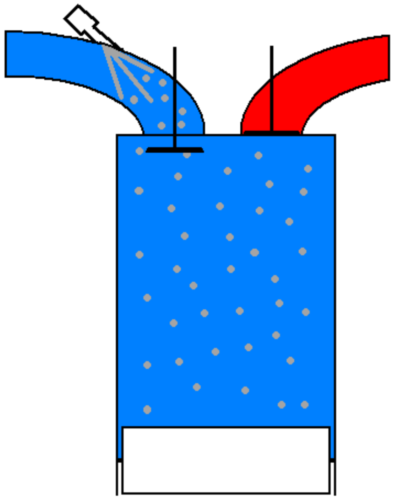
Engine ignition limits for different fuels (selection)

Fuel	Ignition limits
Gasoline	$0.4 < \lambda < 1.4$ (1.7)
Hydrogen	$0.15 < \lambda < 10.5$
Natural gas (CNG)	$0.7 < \lambda < 2.1$
Methanol	$0.34 < \lambda < 2.0$
Ethanol	$0.3 < \lambda < 2.1$
LPG	$0.4 < \lambda < 1.7$

Chemical energy sources: Main properties and significance for vehicle propulsion

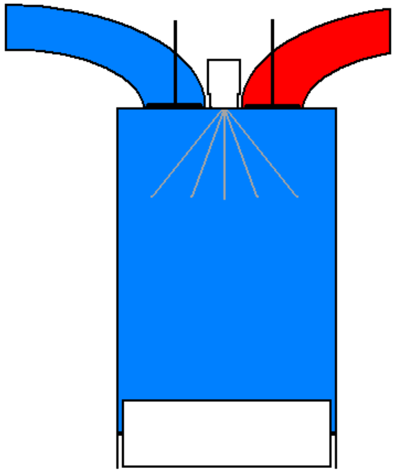
- **Mixture calorific value:** Important for internal combustion, indicates displacement based engine power.

external mixture formation



$$H_G = \frac{m_B * H_u}{V_G} = \frac{\rho_G * H_u}{\lambda * L_{St} + 1}$$

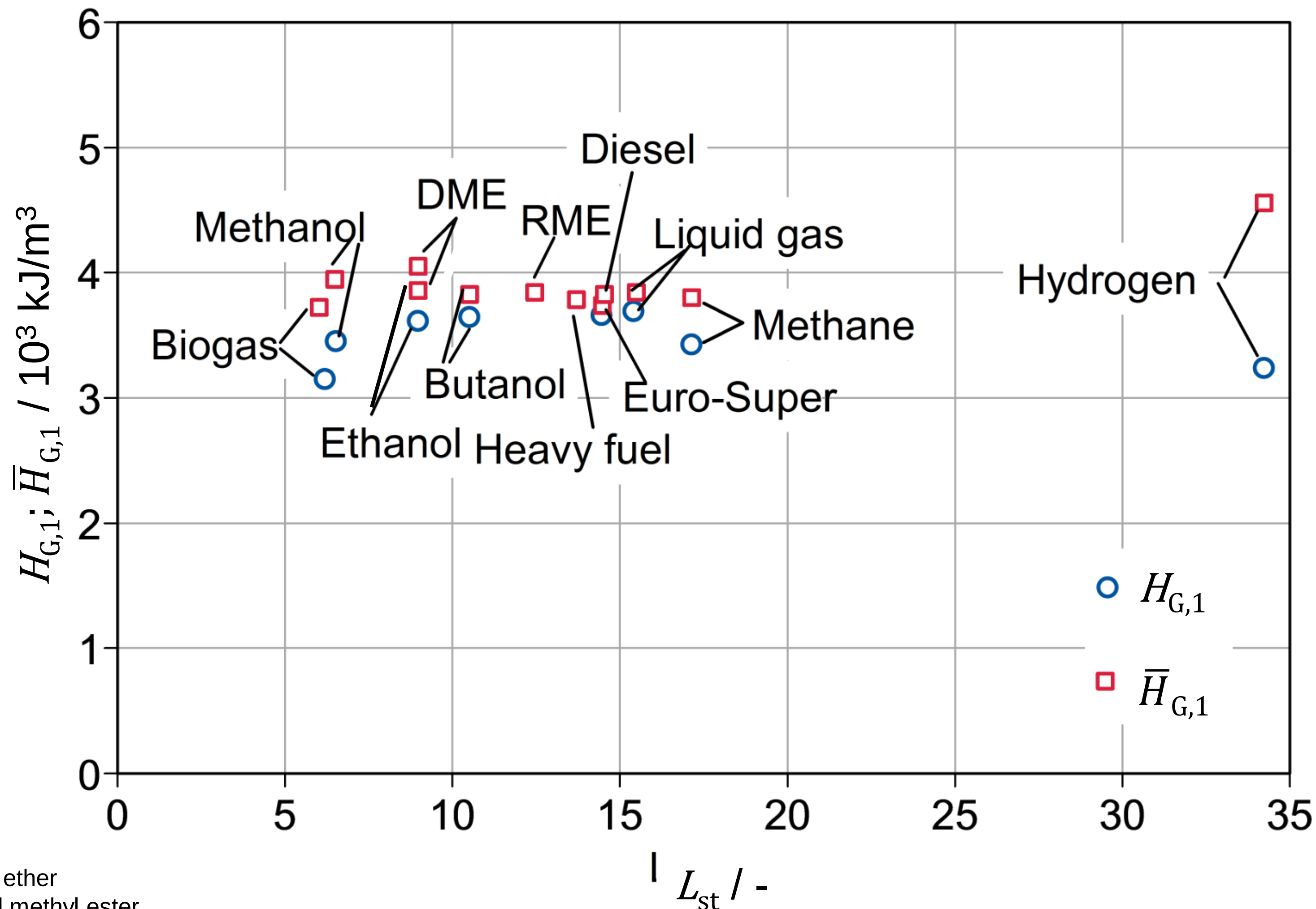
internal mixture formation



$$\overline{H}_G = \frac{m_B * H_u}{V_L} = \frac{\rho_L * H_u}{\lambda * L_{St}}$$

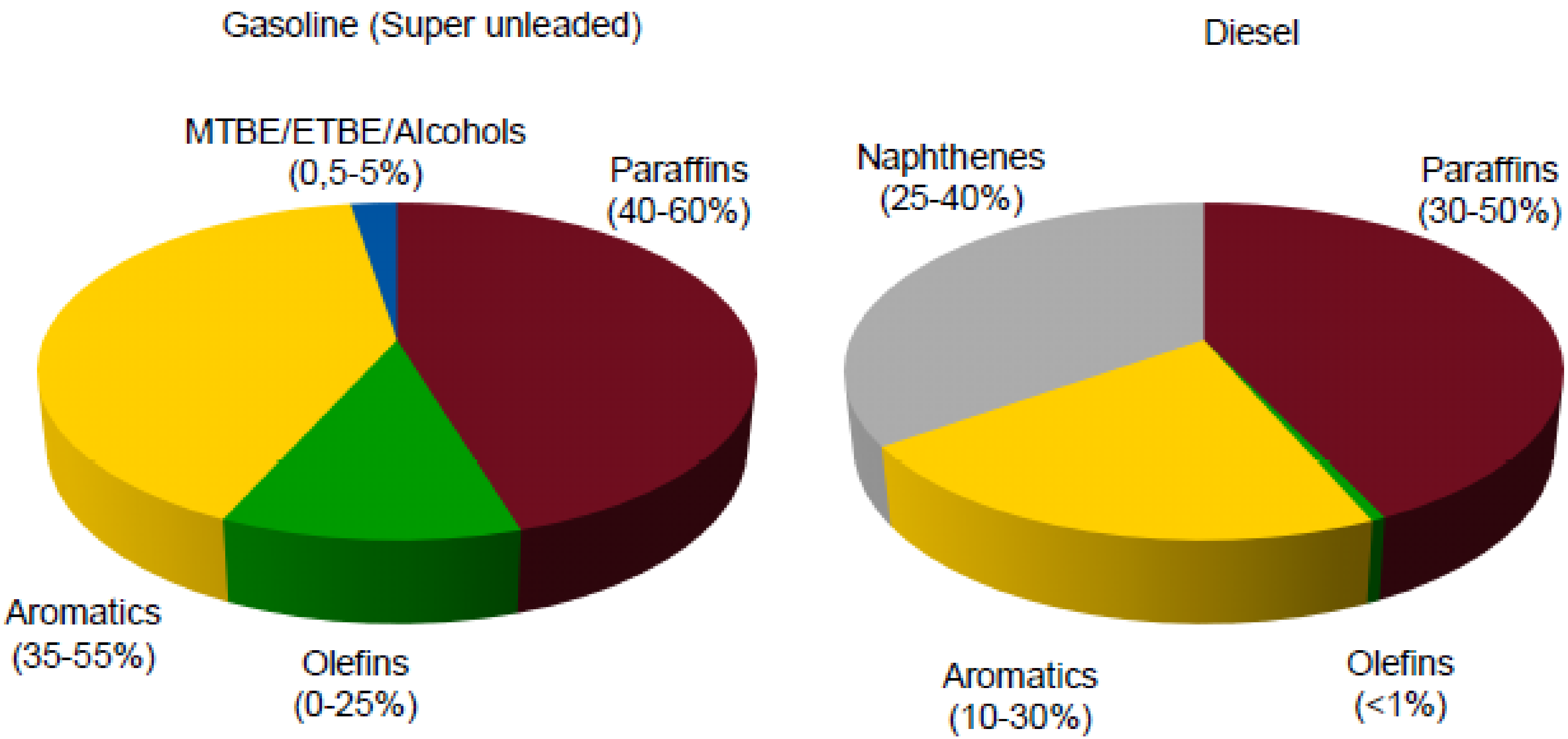
- **Viscosity:** Suitability for high pressure injection (lubrication)

Chemical energy carriers and characteristics



DME – dimethyl ether
RME – Rapseed methyl ester

Chemical energy carriers and characteristics



Source: ARAL, 2010

Characteristic values of gasoline fuel

- Components C_4 to C_{12}
- h; c: 0,14; 0,84
- n_H / n_C = 2,12
- Mean molar mass $M_B \approx$ 98 kg/kmol
- Flash point ≈ - 40 °C (<-20 °C)
- Hazard category A I
- Permittivity ≈ 2,0
- Heating value ≈ 42000 kJ/kg
- Density (15°C) ≈ 0,760 kg/l
- Heat of evaporation ≈ 420 kJ/kg
- Adiab. cooling (λ = 1) 20 °C
- Kinem. viscosity (20°C) ≈ 0,7 cSt
- Heating value of mixture H_{G1} (20°C) 3670 kJ/m³
- Stoichiom. air demand $L_{St} \approx$ 14,5 kg/kg
- Ignition limits in air ≈ 1,0 to 8 Vol. %
- Ignition limits in engine $\lambda \approx$ 0,4 to 1,4
- Ignition temperature 220 ...300 ...450 °C

Characteristics of Diesel fuel

- $h : c$ = 0,137 : 0,863
- n_H / n_C ≈ 1,90
- Mean molar mass M_B ≈ 190 kg / kmol
- Boiling temperature ≈ 170-350°C
- Electrical conductivity < 10^{-15} S/cm
- Heating value H_u ≈ 42800 kJ/kg
- Volumetric heating value ≈ 35950 kJ/l
- Density ≈ 0,840 kg/l
- Aromatic content ≈ 26 Vol -%
- Evaporation heat ≈ 300 kJ/kg
- Mixture heating value H_{G1} ≈ 3790 kJ/m^3
- Stoichiometric air demand L_{st} ≈ 14,6
- Ignition temperature ≈ 230 °C

Fuel properties I

	Unit	Euro-Super	Diesel	Crude-oil	Methanol	Ethanol	RME	LPG[1)]	Methane	Biogas[2)]	Hydrogen	DME
H_u	MJ/kg MJ/l [4)]	42 31.7	42.8 35.6	40.3 39.5	19.7 15.5	26.8 21.2	37.2 32.8	45.33 23.64	50.0 0.036	20.0 0.021	120 8.52	28.4 18.74
$H_{G,1}$ [3)] $H_{G,1}$	MJ/m^3 MJ/m^3	3.67 3.74	 3.79	 3.78	3.44 3.92	3.60 3.85	 3.85	3.66 3.76	3.40 3.76	3.15 3.71	3.19 4.54	3.81 4.08
Ignition limit λ	-	0.4 1.4	0.48 1.35	0.5 1.35	0.34 2.0	0.3 2.1		0.4 1.7	0.7 2.1	0.7 2.3	0.5 10.5	
λ_{crit}	-	0.33	0.34	0.36	0	0.17	0.32	0.30	0.25	-	0	0.17
RON MON	-	95 85			114.4 94.6	111.4 94.0		94.5	140			
MN	-							28	100	125	0	
CN	-		min 51	20…45			54…58					55…60
EN	-	228	590				14214	589				

1) Liquefied Petroleum Gas (typical winter fuel in EU: 70 Mass % Propane, 30 Mass % Butanes)
2) Gas mixture of 60 % methane, 35 % CO_2, additional quantities of steam and hydrogensulfide
3) p = 1.013 bar; T = 273 K 4) T = 20°C

Fuel properties II

	Unit	Euro-Super	Diesel	Crude-oil	Methanol	Ethanol	RME	LPG[1)]	Methane	Biogas[2)]	Hydrogen	DME
h *c* *o* *s*	- - - -	0.14 0.84 0.02 0	0.14 0.86 0 0	0.11 0.86 0 0.03	0.12 0.38 0.5 0	0.13 0.52 0.35 0	0.12 0.77 0.11 0	0.18 0.82 0 0	0.25 0.75 0 0	0.09 0.44 0.47 0	1 0 0 0	0.13 0.52 0.35 0
M	kg/kmol	98	190	198	32	46	296	48	16	27	2	46
Boiling point	°C	30… 190	170… 350	175… >450	65	78	180… 360	-39	-162	-128	-253	-24.9
Evapo-ration heat 3)	kJ/kg	420	300		1097	839		325	509		450	410
Vapor pressure 4)	bar	0.45… 0.9			0.37	0.21		10				
Density 3)	f kg/m^3 g	725- 780	820- 860	950 -1010	795	793	880	540 2.06	424 0.72	 1.20	71 0.09	660
L_{St}	kg/kg	14.5	14.6	13.8	6.5	9.0	12.5	15.6	17.2	6.1	34.2	9.0

1) Liquefied Petroleum Gas (typical winter fuel in EU: 70 Mass % Propane, 30 Mass % Butanes)
2) Gas mixture of 60 % methane, 35 % CO_2, additional quantities of steam and hydrogensulfide
3) p = 1.013 bar and the appropriated boiling temperature 4) T = 40 °C

Assessment criteria for alternative fuels

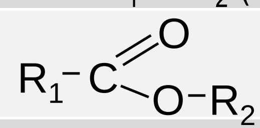
Availability of Primary Energy	Conversion to Drive Energy	Distribution of infrastructures	Vehicle Technology	Customer Benefit	Environmental Compatibility
- Amount - Range - Security of supply - Produktions-technik - Possibility of usage by other consumers	- Usage of existing facilities - Required new systems - Possibility of usage by other consumers	- Usage of existing systems - Required new facilities - Possibility of usage by other consumers	- Principal suitability - Required new facilities - Usage of existing facilities - Improvement of efficiency	- Refueling time - Action radius - Payload - Mileage - Comfort - Economy - Emotional acceptance	- Global (Global warming) - Regional (Smog) - Local (Toxicity, noise, Property damage)

Security / costs / total energy and ecological balance / avoidance of environmental costs / economic impact / cost-benefit analysis / technology advantage for industry

↓

"Social benefit" for alternative fuel X

Alternative fuels

Atom	Name	Formula	Note
H	Hydrogen	H_2	LH_2/GH_2
C,H	Methane	CH_4	Natural gas (CNG, LNG)
C,H	Liquefied petroleum gas	C_3H_8, C_4H_{10}	Propane, Butane (main component LPG)
C,H,O	Methanol	CH_3OH	R-OH (Alcohol)
C,H,O	Ethanol	C_2H_5OH	R-OH (Alcohol)
C,H,O	Butanol	C_4H_9OH	R-OH (Alcohol)
C,H,O	Dimethylether	CH_3OCH_3	CH_3 (Methyl) R_1-O-R_2 (Ether)
C,H,O	Vegetable oil methyl ester		 (Ester)
C,H,O	Mixtures (e.g. biogas)	CH_4+CO_2	