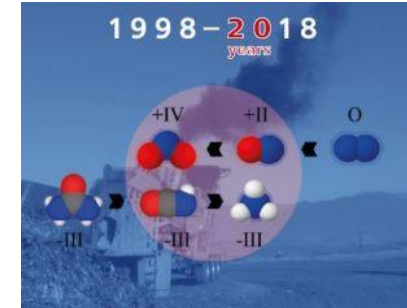


Combustion engines – today and in the future

Dr.-Ing. Uwe Wagner, KIT

9th VERT FORUM

Empa, Dübendorf, 15.03.2018



INSTITUT FÜR KOLBENMASCHINEN | Leiter Prof. Dr. sc. techn. Thomas Koch



Media Headlines

GESUNDHEIT WHO-UNTERSUCHUNG

Dieselabgase so krebserregend wie Asbest

Veröffentlicht am 13.06.2012 | Lesedauer: 2 Minuten



Frankfurter Allgemeine
 Feinstaub-Alarm
Dicke Luft in Stuttgart 
 Stuttgart will bessere Luft und eine größtenteils autofreie Innenstadt. Aber wie soll das in der Praxis funktionieren? [Mehr >](#) Von RÜDIGER SOLDT,
 STUTTGART
 01.05.2017, 20:09 Uhr | Wirtschaft

6. Januar 2017, 09:18 Uhr Studie

Süddeutsche Zeitung
 SZ.de Zeitung Magazin

Moderne Dieselaautos sind größere Dreckschleudern als Lastwagen

Szenario zur Verkehrswende: Greenpeace fordert Verbot für Autos mit Verbrenner ab 2025
 SPIEGEL ONLINE - 31.08.2017
SPIEGEL ONLINE



Dreckschleuder Diesel
 Pkw schmutziger als Lastwagen

Combustion engines – today and in the future

Agenda

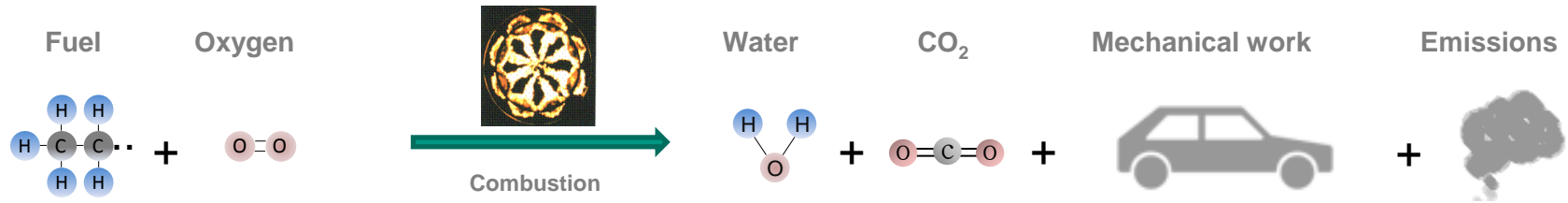
- Immission situation
- Emission regulation / RDE certification
- CO₂-challenge and e-fuels

Combustion engines – today and in the future

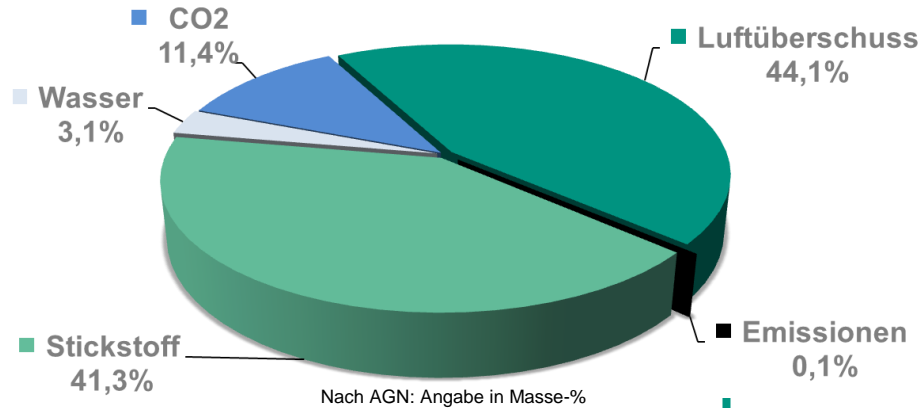
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Combustion engine and its emissions



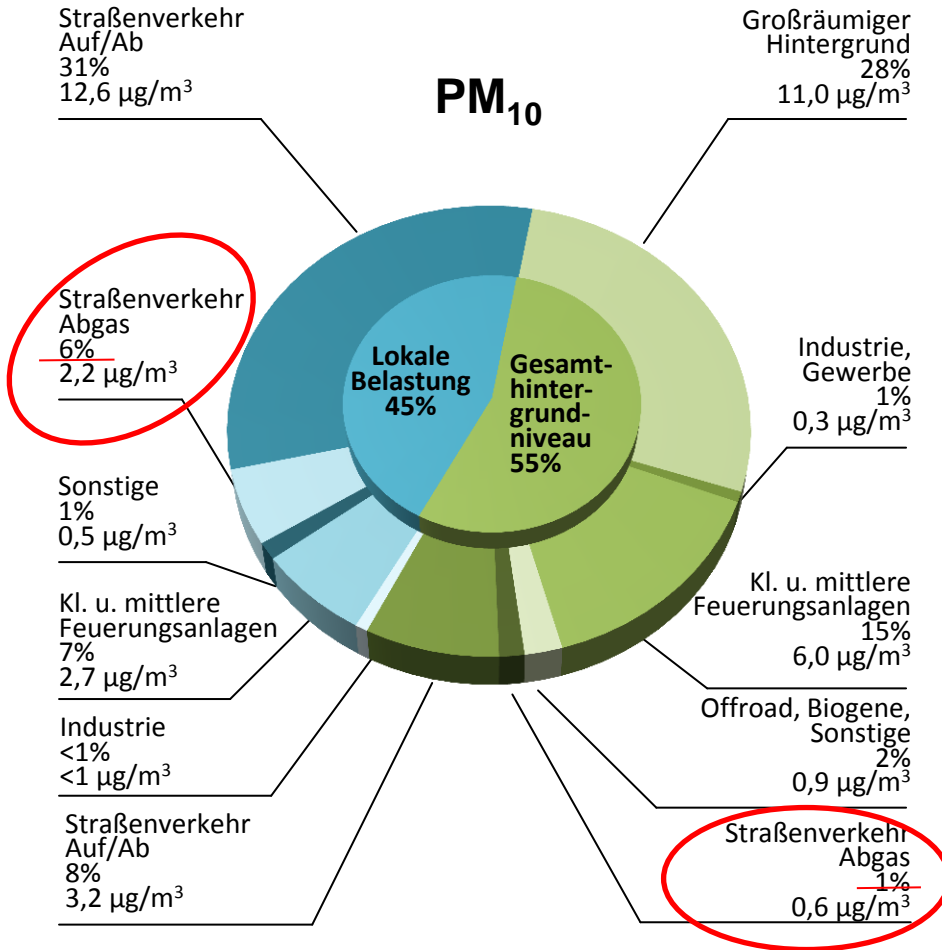
Exemplary composition of Diesel engine exhaust



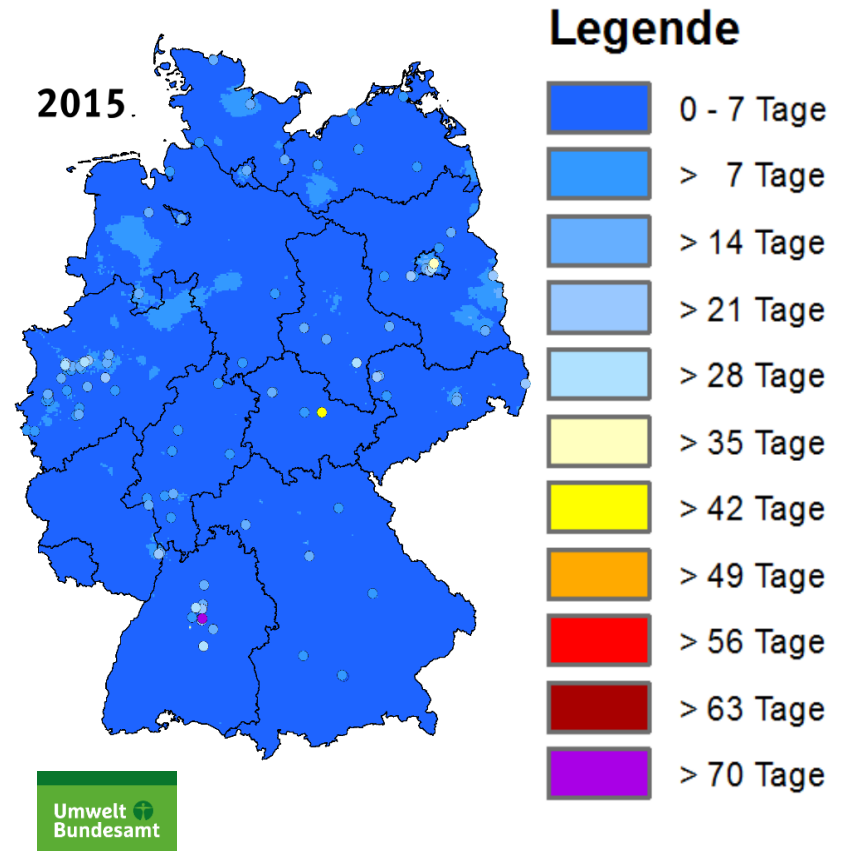
Unwanted immissions

Carbon monoxide	CO	Today not critical anymore	<input checked="" type="checkbox"/>
Unburned hydrocarbons	HC	Today not critical anymore	<input checked="" type="checkbox"/>
Sulfur oxide	SO _x	Today not critical anymore	<input checked="" type="checkbox"/>
Particulates	PM	Particulate matter	?
Nitrogen oxide	NO _x	Nitrogen oxide (mainly NO+NO ₂)	?

PM₁₀-situation



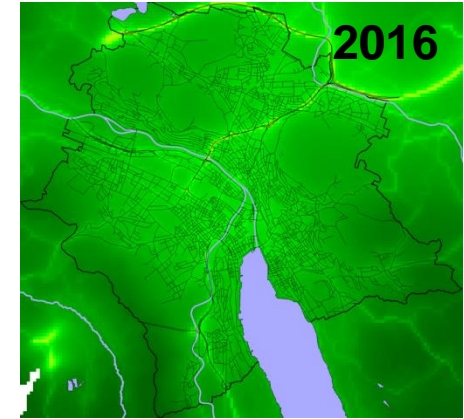
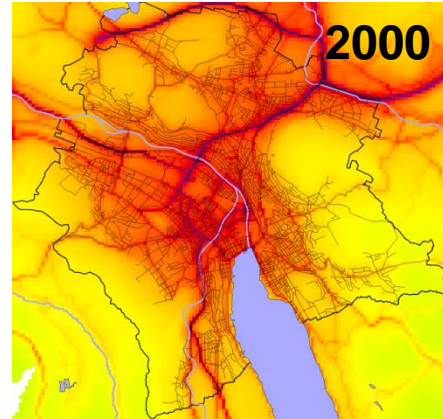
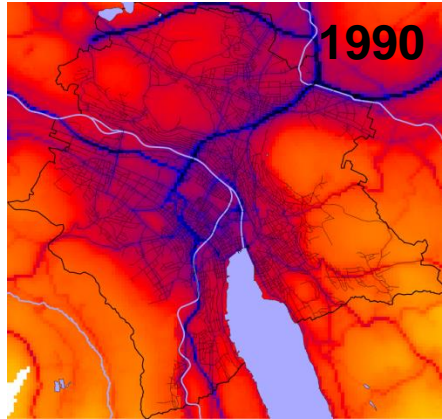
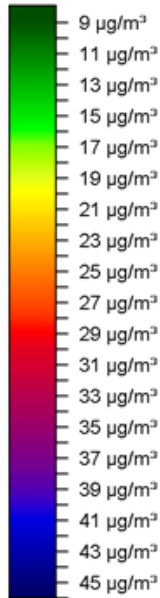
PM₁₀-daily average
of excess days of 50µg/m³
(limit 35 d/a)



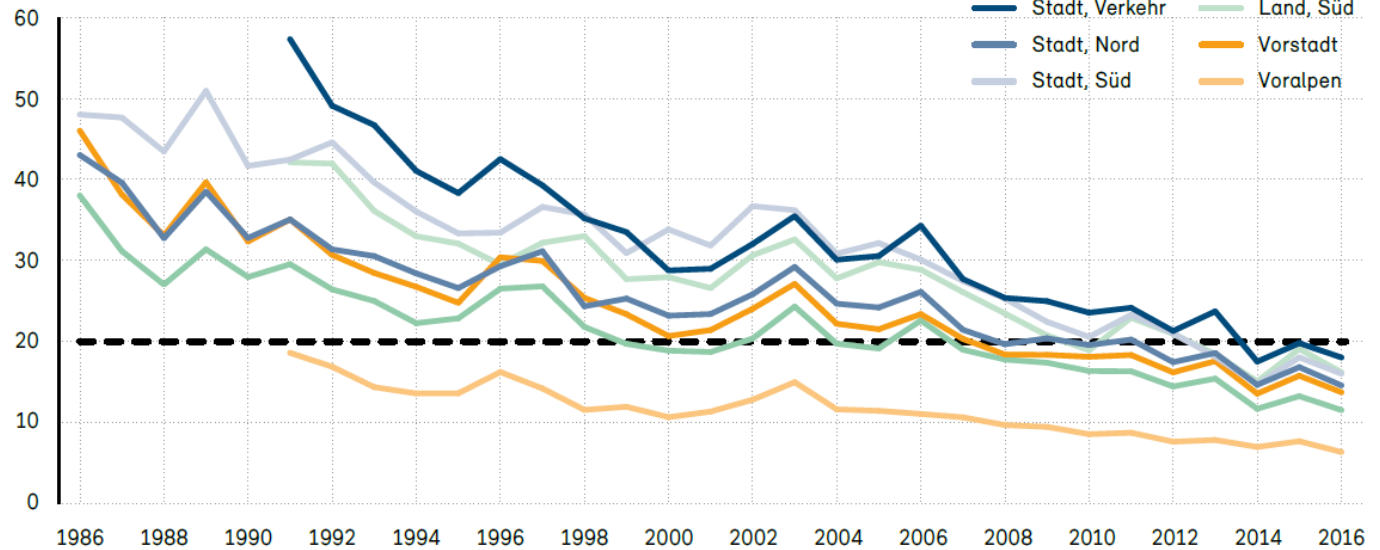
Quelle: Christoph Erdmenger; Ministerium für Transport und Infrastruktur Baden Württemberg; IFKM/KIT – NO_x Conference, Heidelberg, 01.2016

The contribution of engine tailpipe exhaust to PM immissions is very small!

PM₁₀-situation over time

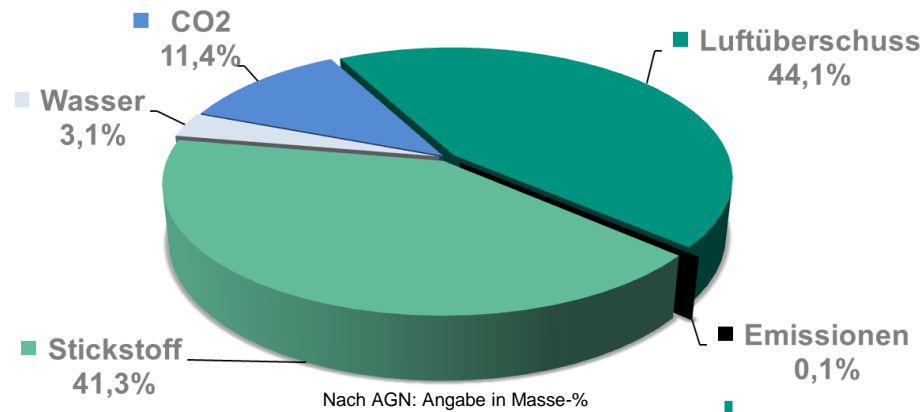


Feinstaub PM10 in µg/m³



Quelle: [1] www.stadt-zuerich.ch/gud/de/index/umwelt_energie/luftqualitaet/messdaten/schadstoffkarten.html; Abruf 28.02.2018, Gesundheits- und Umweltdepartement, Stadt Zürich
 [2] BAFU (Hrsg.) 2017: Luftqualität 2016. Messresultate des Nationalen Beobachtungsnetzes für Luftfremdstoffe (NABEL). Bundesamt für Umwelt, Bern. Umwelt-Zustand Nr. 1723

Exemplary composition of Diesel engine exhaust



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Emission formation: NO_x

What is NO_x?

- NO_x: collective term for various nitrogen oxides
- Relevant for combustion engines: almost exclusively NO and NO₂

Formula	Name
N ₄ O	Nitrosylazide
N ₂ O	Nitrous oxide
N ₄ O ₂	Nitryl azide
NO	Nitrogen monoxide
N ₂ O ₃	Dinitrogen trioxide
N ₄ O ₆	Trinitramide
NO₂	Nitrogen dioxide
N ₂ O ₄	Dinitrogen tetroxide
N ₂ O ₅	Dinitrogen pentoxide

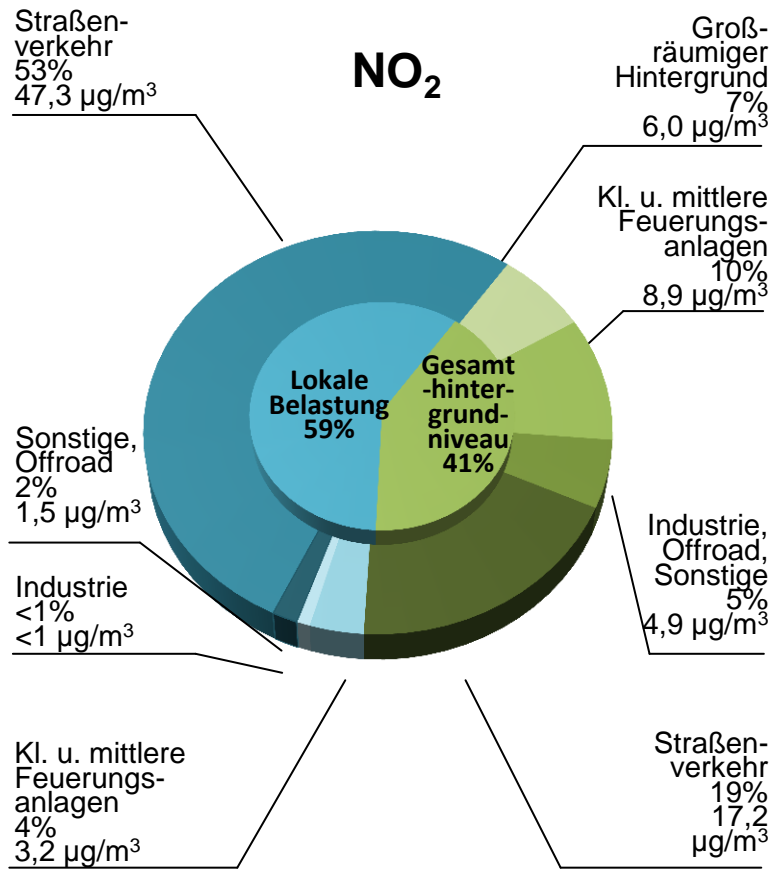
→ Relevant as engine **emission**
Formed mostly during combustion

→ Relevant as **immission**

reacts with
O₂ to NO₂

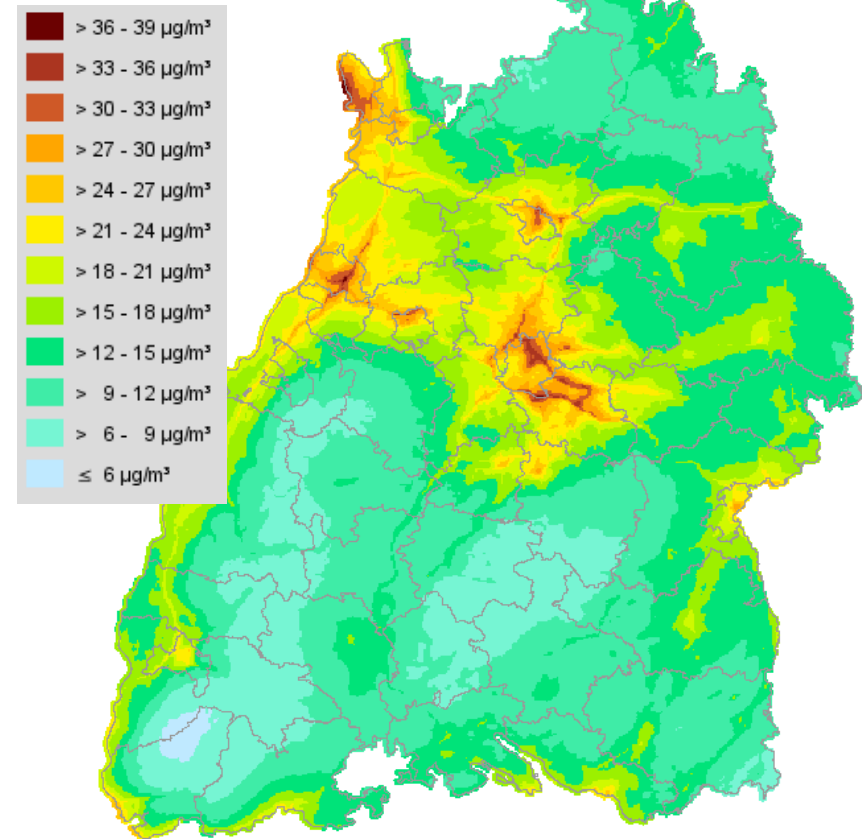
NO is formed in the presence of oxygen and high temperatures (>2000 K).

NO₂-sources and NO₂-distribution



Quelle: Christoph Erdmenger; Ministerium für Transport und Infrastruktur Baden Württemberg; IFKM/KIT – NO_x Conference, Heidelberg, 01.2016

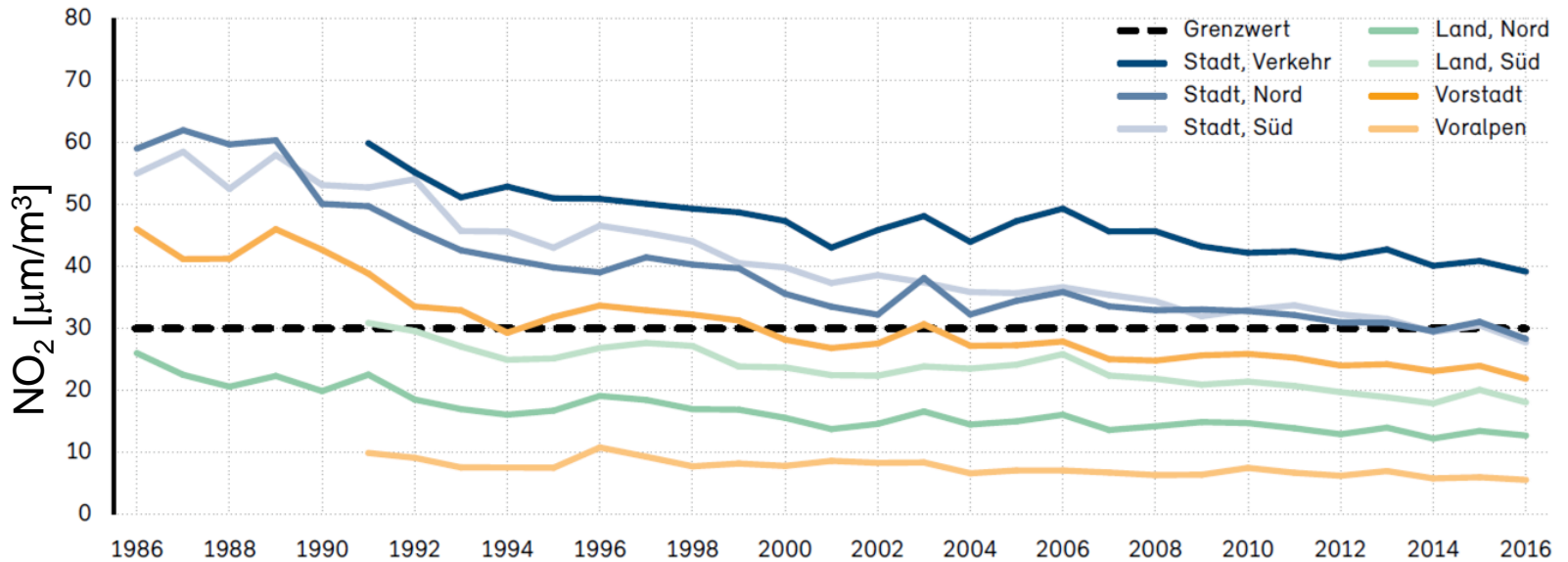
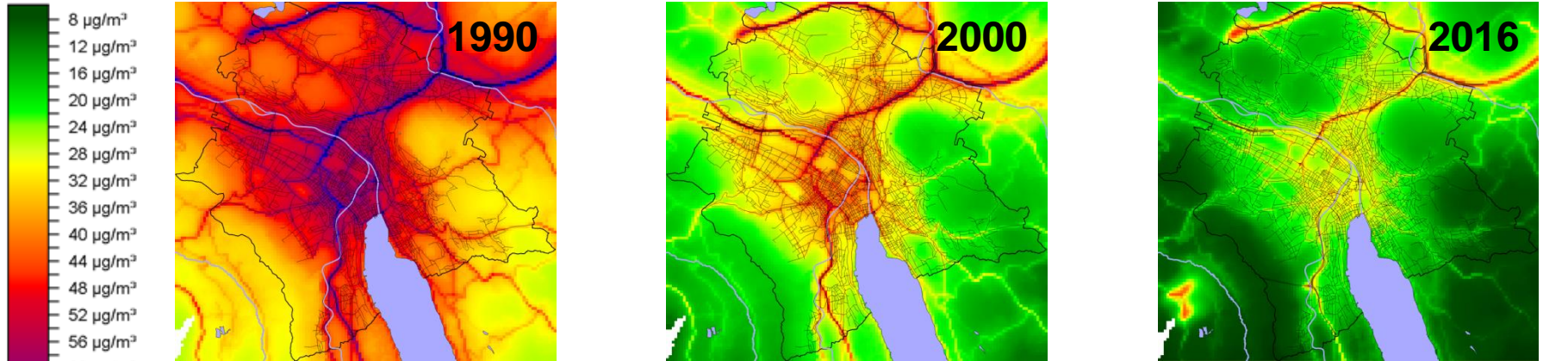
Yearly average 2010



Quelle: LUBW <http://www4.lubw.baden-wuerttemberg.de/servlet/is/242644/>

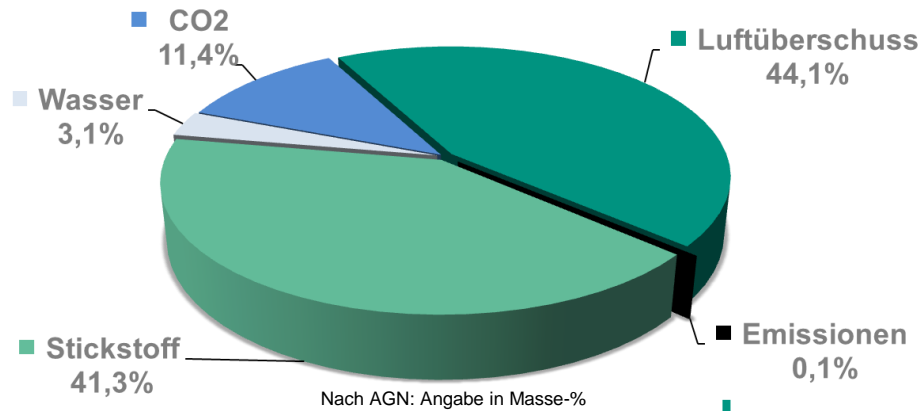
Close to roads, NO₂ immission limits are partly exceeded!

NO₂-immission situation over time



Quelle: [1] www.stadt-zuerich.ch/gud/de/index/umwelt_energie/luftqualitaet/messdaten/schadstoffkarten.html; Abruf 28.02.2018, Gesundheits- und Umweltdepartement, Stadt Zürich
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Combustion engines – today and in the future

Agenda

- Immission situation
- Emission regulation / RDE certification
- CO₂-challenge and e-fuels

Emission regulation, driving cycles and emission limits

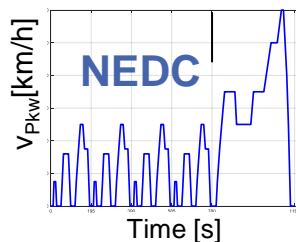
EURO 1-6a/b



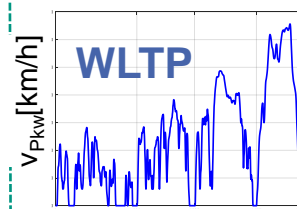
RDE (Real Driving Emissions)



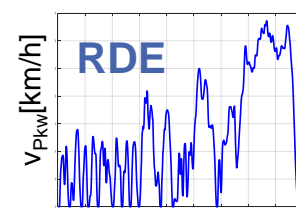
Quelle: LUBW



Time ~20 min
Distance ~11 km
 $v_{max} = 120$ km/h



Time [s] ~ 30 min
Distance ~23 km
 $v_{max} = 131$ km/h

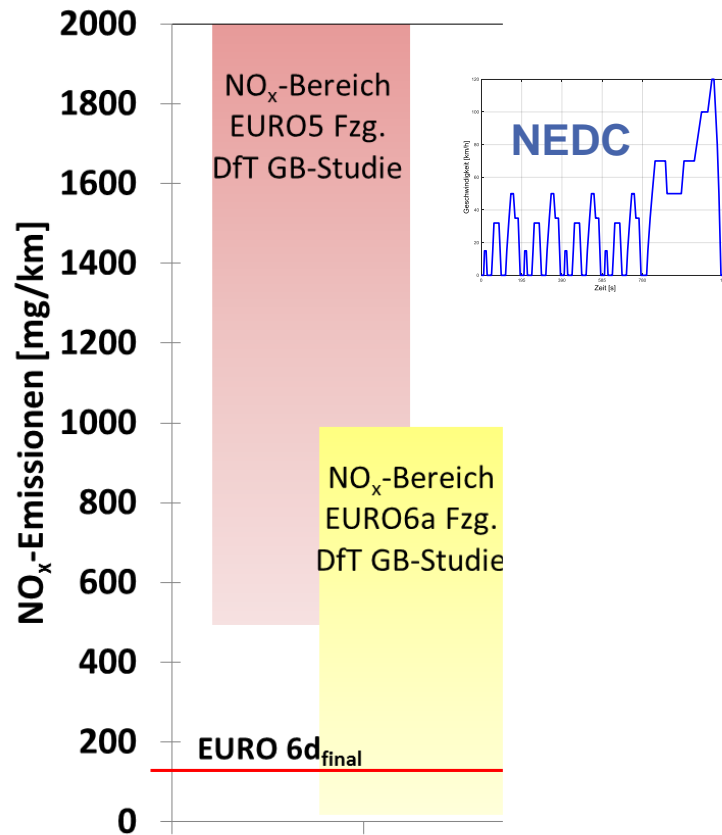


Time [s] >90 min
Distance >48 km

Year	1992	1996	2000	2005	2009	2014	2017	2021
Standard	EURO 1	EURO 2	EURO 3	EURO 4	EURO 5	EURO 6	EURO 6d _{Temp}	EURO 6d _{final}
PM10 [g/km]	0,14	0,10	0,05	0,025	0,005	0,0045	0,0045	0,0045
NO _x [g/km]	0,97*	0,7*	0,5	0,25	0,18	0,08	0,08	0,08
	* HC+ NO _x							

In the last 20 years, target emissions were decreased considerably. Starting with **EURO 6d_{Temp} (2017)**, NO_x emission limits are also prescribed during driving.

NO_x real driving emissions



Quelle: Vehicle Emissions Testing Programme, Department for Transport, UK 2016

The NEDC NO_x emission limits of 180 mg/km (EURO 5) and 80 mg/km (EURO 6a/b) are exceeded notably during real driving.

Test drives with RDE vehicles (EURO 6_{d, temp})



AUDI Q7 3.0l V6

- Max. power 200 kW
- Exhaust gas treatment DOC and SDPF
- High-pressure EGR



BWM 730d 3.0l R6

- Max. power 195 kW
- Exhaust gas treatment DOC-NSK, DPF and SCR
- High- and low-pressure EGR



Mercedes-Benz E220d 2.0l R4

- Max. power 143 kW
- Exhaust gas treatment DOC and SDPF
- High- and low-pressure EGR



Volkswagen Tiguan 2.0l R4

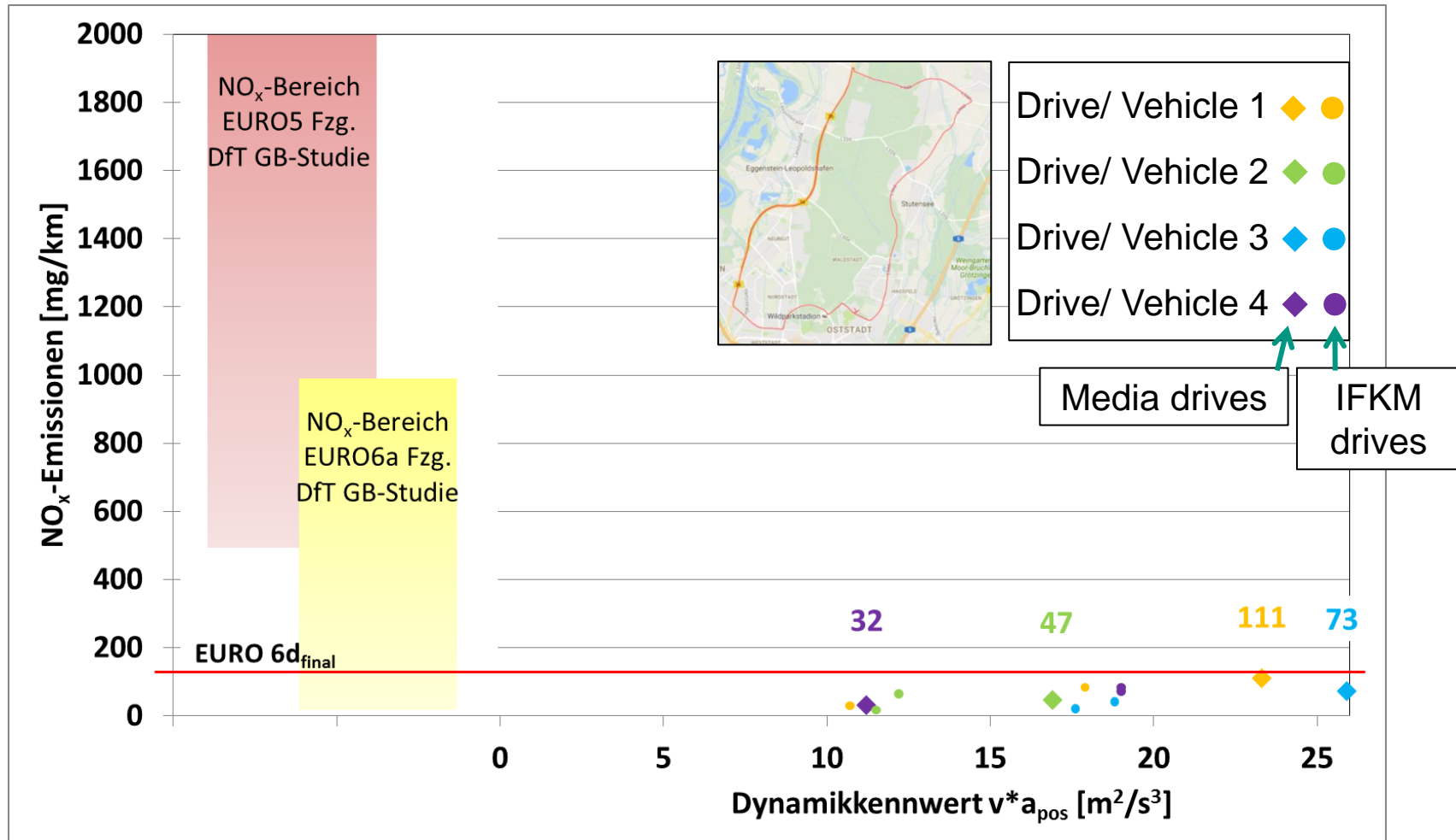
- Max. power 140 kW
- Exhaust gas treatment DOC und SDPF
- High- and low-pressure EGR

Compact, highly integrated and EGT close to the motor



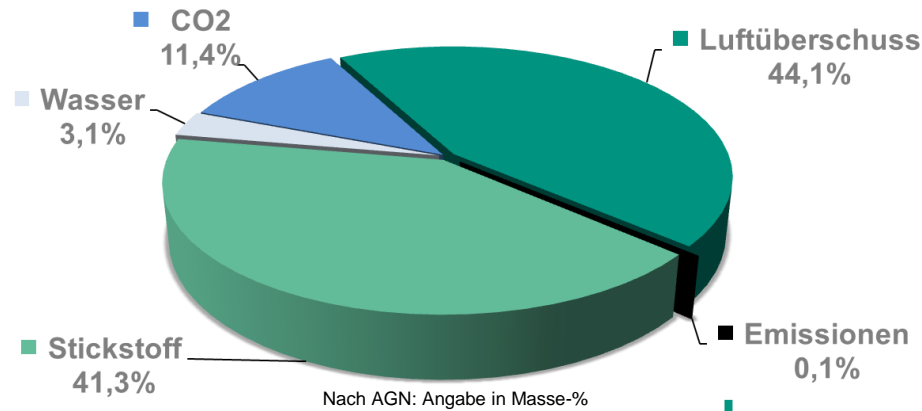
Quelle: Daimler AG, 2017

Vehicle emissions NO_x in real driving (RDE)



On the road, NO_x emissions are notably below the limits. (Acceptable values are 168mg/km for RDE EURO 6d_{temp} and 120mg/km for EURO 6d_{final})

Exemplary composition of Diesel engine exhaust



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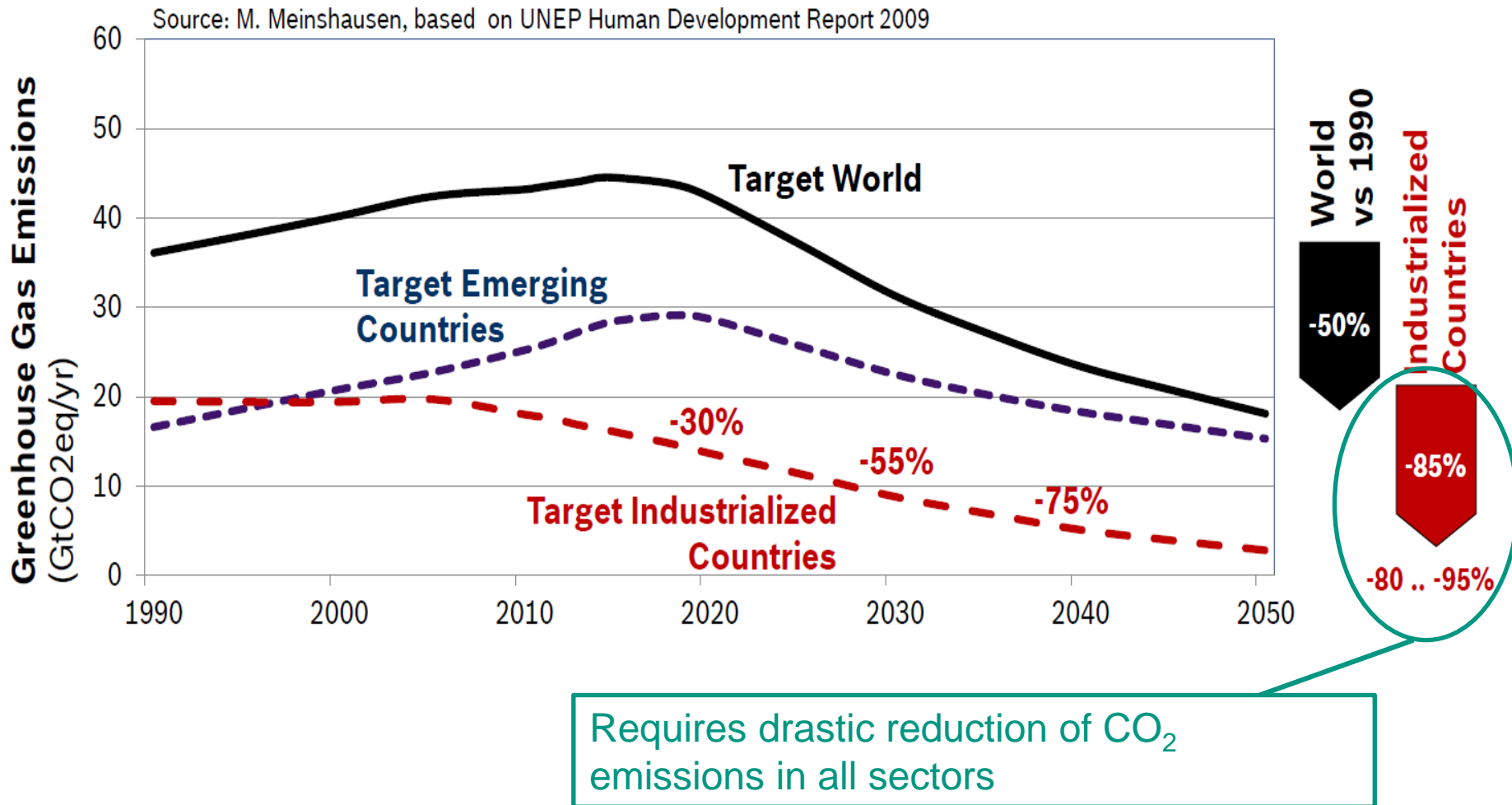


Combustion engines – today and in the future

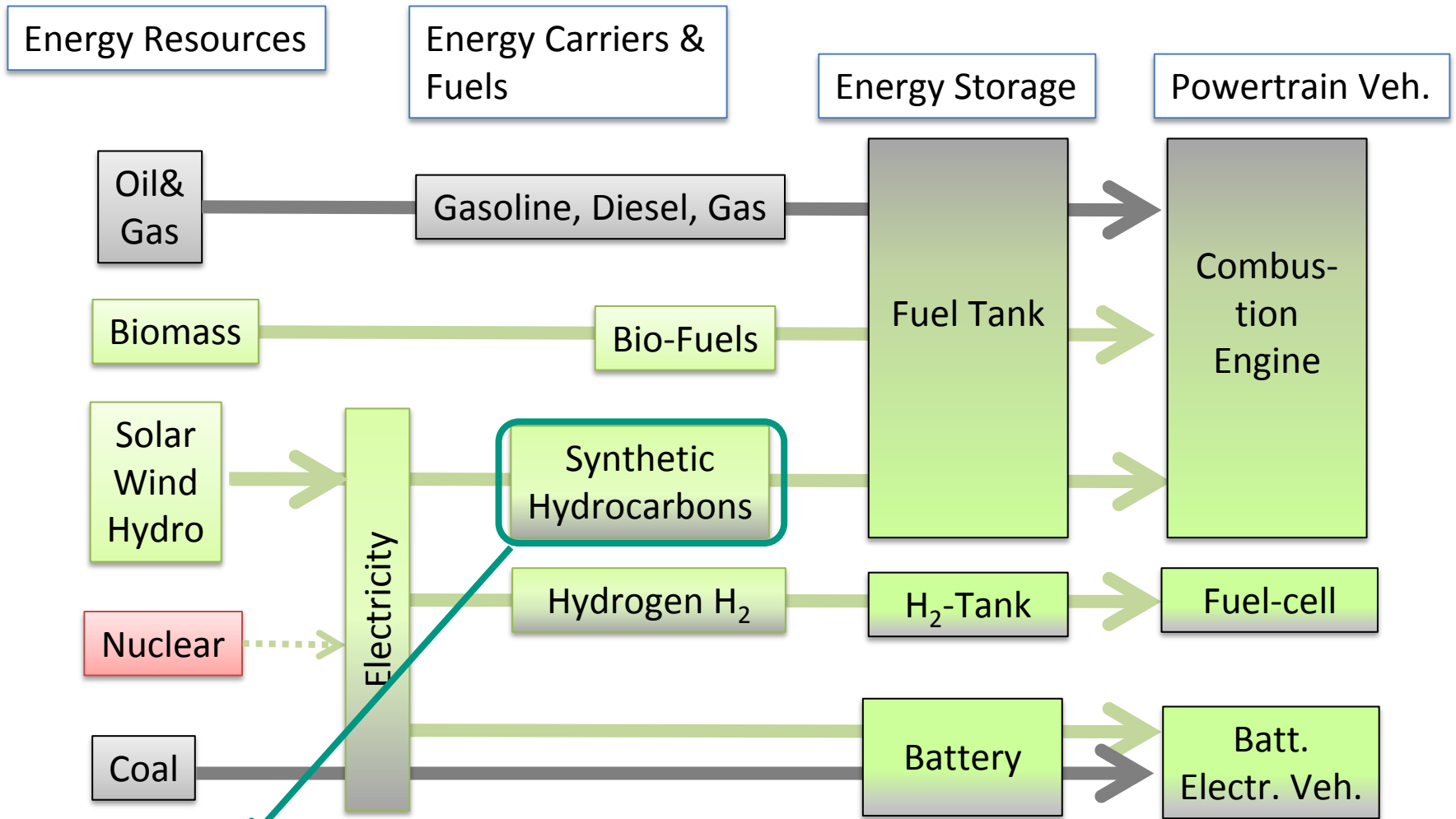
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GHG reduction: Temperature increase <2°C Agreement of the UN Climate Summit 2009 in Copenhagen



Energy Pathways for Mobility Applications

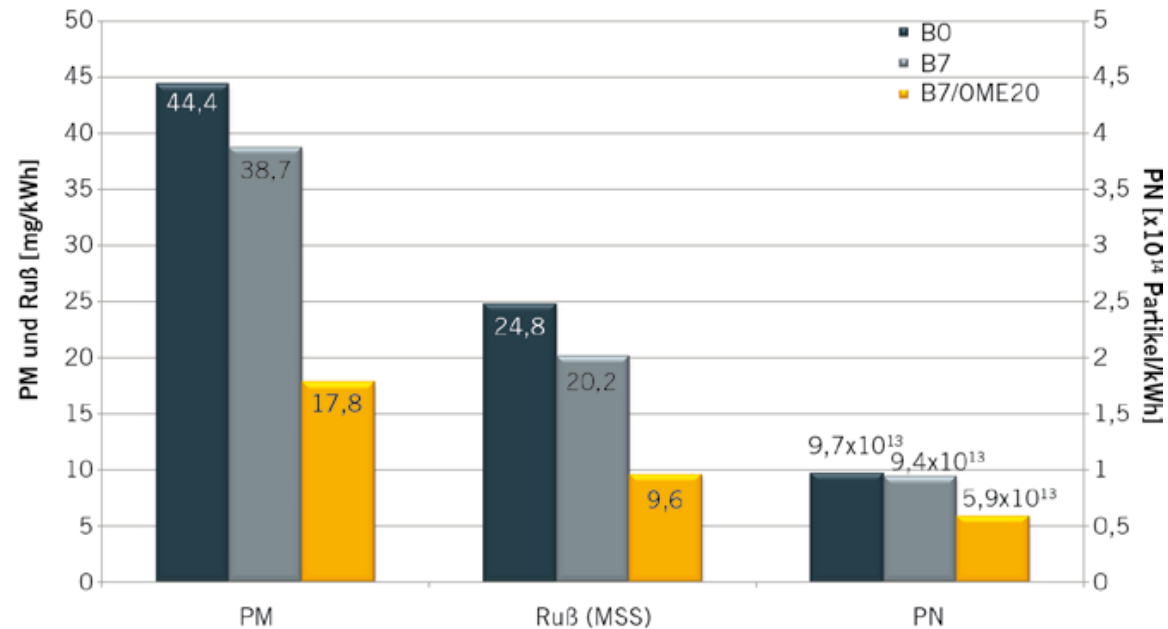


eFuels from renewable energy resources, e.g. eOxygenates,...

Advantages of O₂-containing Fuels in Combustion



Quelle: Homepage Profilregion Mobilitätssysteme Karlsruhe



Quelle: Lump et al., „OXYMETHYLENETHER ALS DIESELKRAFTSTOFFZUSÄTZE DER ZUKUNFT“, MTZ 03|2011

Example OME (Oxymethylenether): similar properties like Diesel fuel, miscibility, significantly reduced soot formation

Combustion engines – today and in the future

Summary

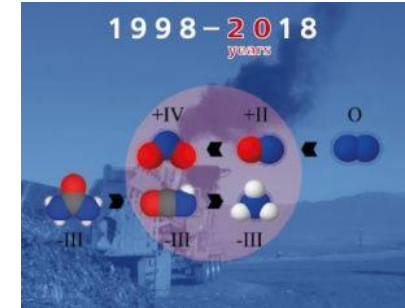
- Emission issues from combustion engines are solved
 - Fleet penetration has to take place
 - engine exhaust related immission issues are solved
- With EURO6d and RDE strongly needed regulations are in power
- Contribution of combustion engines for climate protection possible and necessary (not all applications purely e-driven possible)

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Empa, Dübendorf, 15.03.2018



INSTITUT FÜR KOLBENMASCHINEN | Leiter Prof. Dr. sc. techn. Thomas Koch



Thank you for your attention.

