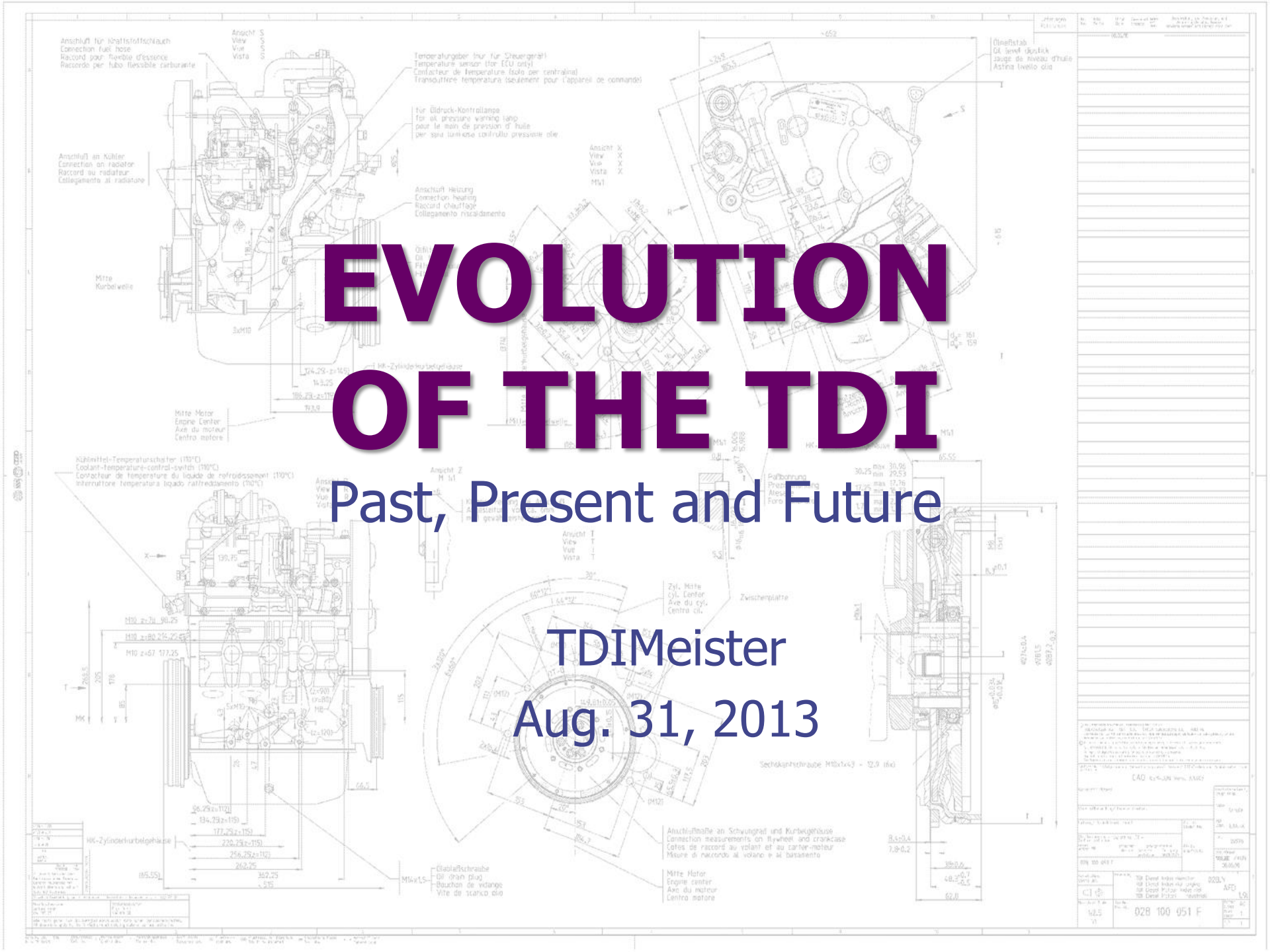


EVOLUTION OF THE TDI

Past, Present and Future

TDIMeister

Aug. 31, 2013

Contents

- Past
  - Some Diesel History
- Present
  - The EA288 TDI
- Future
  - Focus on Efficiency and Sustainability

Past – Some Diesel History

- March 18, 1858 – Rudolf Christian Karl Diesel, born in Paris to Bavarian parents
- 1880 – Completed engineering studies at Munich Polytechnic; upon graduation worked at Linde

Past – Some Diesel History

- 1893 – German patent granted; found a patron at the Augsburg Machine Works (later M.A.N.) to develop his invention
- 1893—1896 – Development of Diesel's engine marred by failures and setbacks

PATENT-URKUNDE

№ 67207

AUF GRUND DER ANGEHEFTETEN BESCHREIBUNG UND ZEICHNUNG IST DURCH BESCHLUSS DES KAISERLICHEN PATENTAMTES

an Rudolf Diesel, Ingenieur, in Berlin

EIN PATENT ERTHEILT WORDEN.

GEGENSTAND DES PATENTES IST:

GESETZ v. 7. APRIL 1891

Arbeitsverfahren und Ausführungsart für Verbrennungskraftmaschinen.

ANFANG DES PATENTES: 28. Februar 1892.

DIE RECHTE UND PFLICHTEN DES PATENTINHABERS SIND DURCH DAS PATENTGESETZ VOM 7. APRIL 1891 (REICHS-GESETZBLATT FÜR 1891 SEITE 79) BESTIMMT.

ZU URKUND DER ERTHEILUNG DES PATENTES IST DIESE AUSFERTIGUNG ERFOLGT.

Berlin, den 23. Februar 1893.

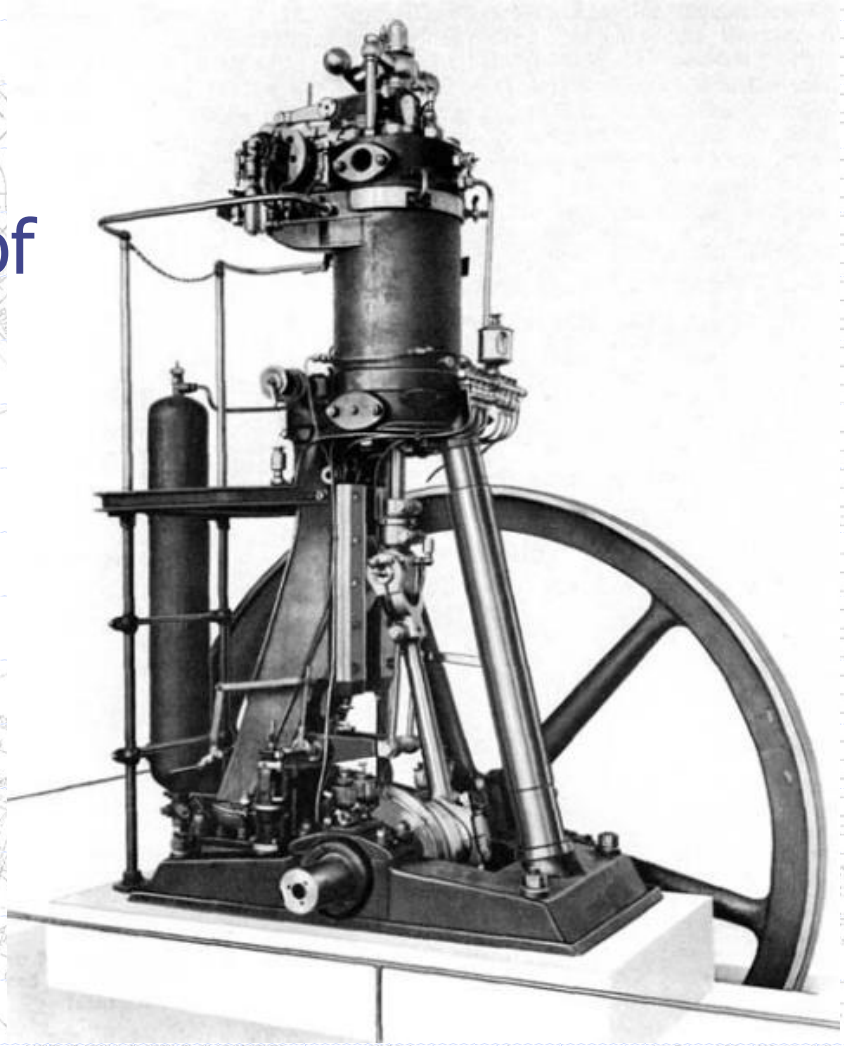
KAISERLICHES PATENTAMT.

Beglaubigt durch Klauß

Bureau-Vorsteher des Kaiserlichen Patentamtes.

Past – Some Diesel History

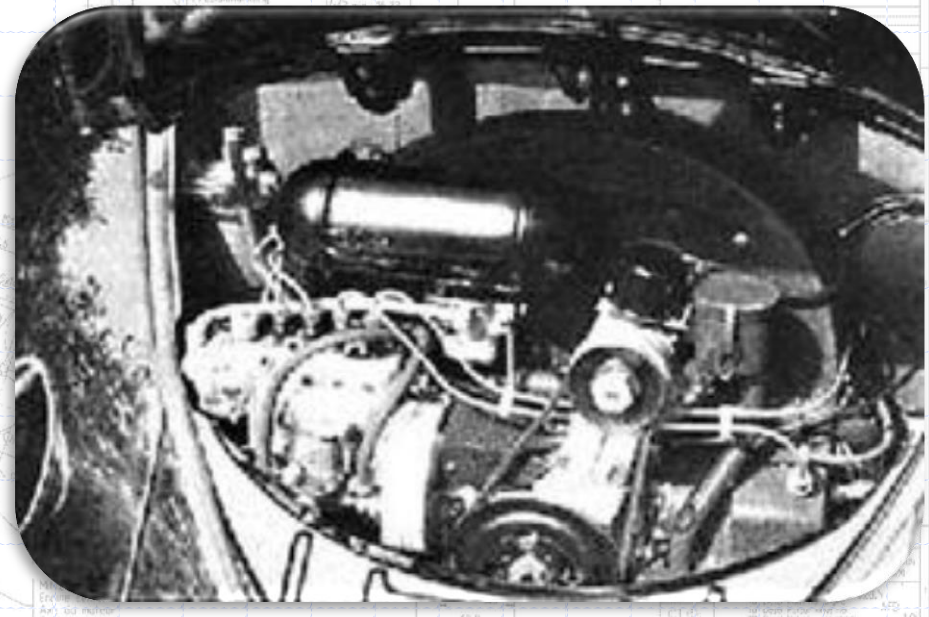
- Feb. 18 1897 – Breakthrough results of his engine: 17.8 PS @26.2% thermal efficiency from 19.8L displacement
- Sept. 29 1913 – Last seen alive retiring for the night aboard SS Dresden crossing the English Channel



Past – Some Diesel History

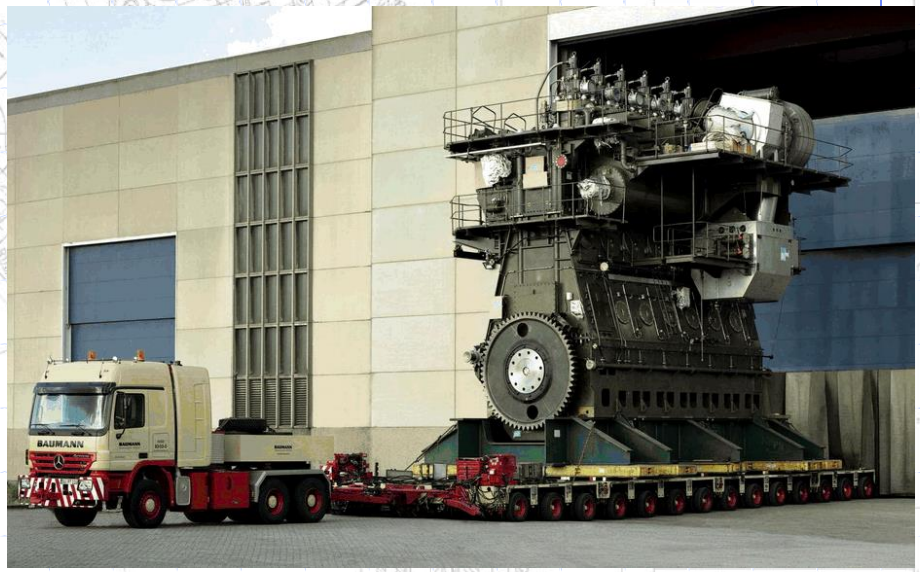
- 1903 – first Diesel marine vehicle ("Petit Pierre," France)
- 1923 – First Diesel truck (M.A.N.)
- 1929 – First Diesel car (Packard with Cummins engine)
- 1951 – First VW Diesel (air-cooled 1.3L boxer)

*Note: Astute viewers will note that the above is an Auburn, not the earlier Cummins-powered Packard prototype mentioned in the timeline. This is placed only for illustration.



Past – Some Diesel History

- 1982 – 2-stroke marine Diesels exceed 50% efficiency – newest engines >100,000 HP
- 1987 – First direct-injected Diesel car (Fiat Croma)
- 1989 – First TDI (Audi 100)



Past – Some Diesel History

- 1997 – First plug-in Diesel-electric hybrid car (Audi A4 duo III)
- 1997 – First common-rail Diesel car (Alfa Romeo 156)
- 1999 – First common-rail TDI (Audi 3.3 V8)

Past – Some Diesel History

- Progress in injection technology has enabled a dramatic increase in engine power capabilities

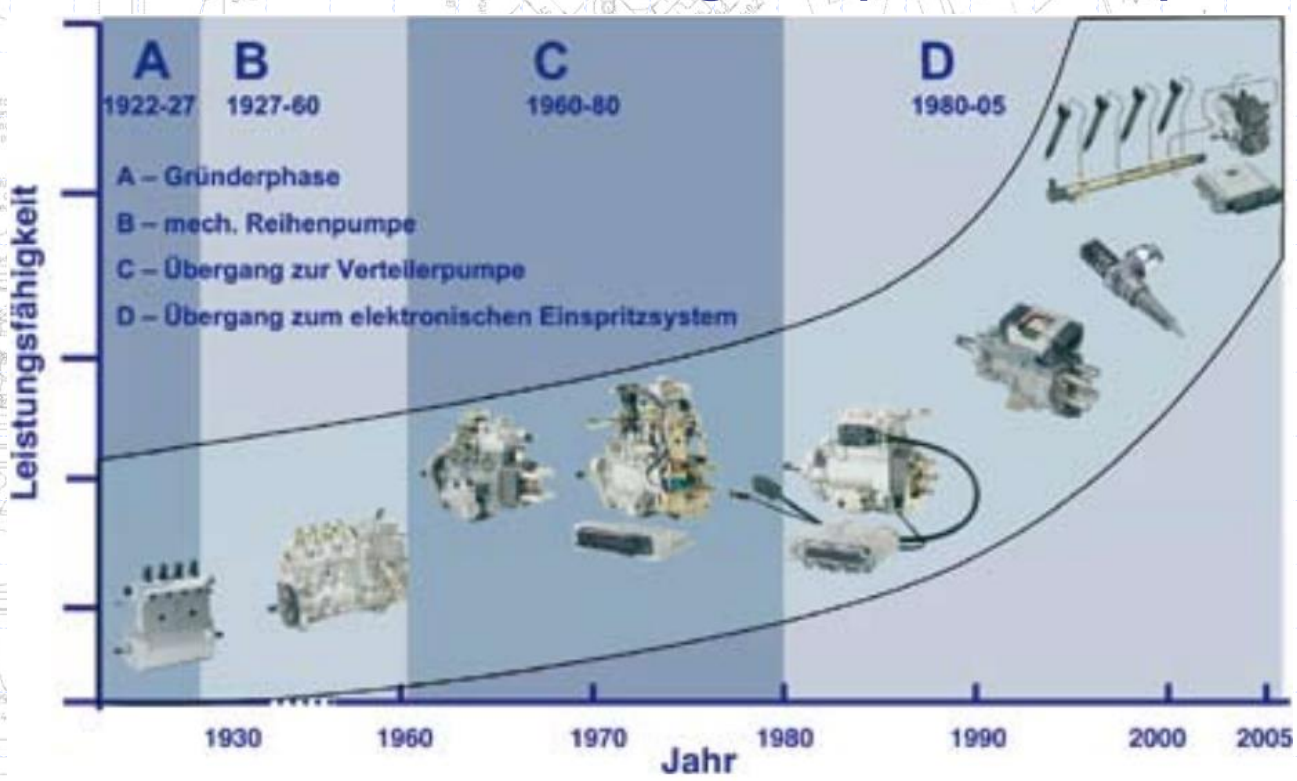


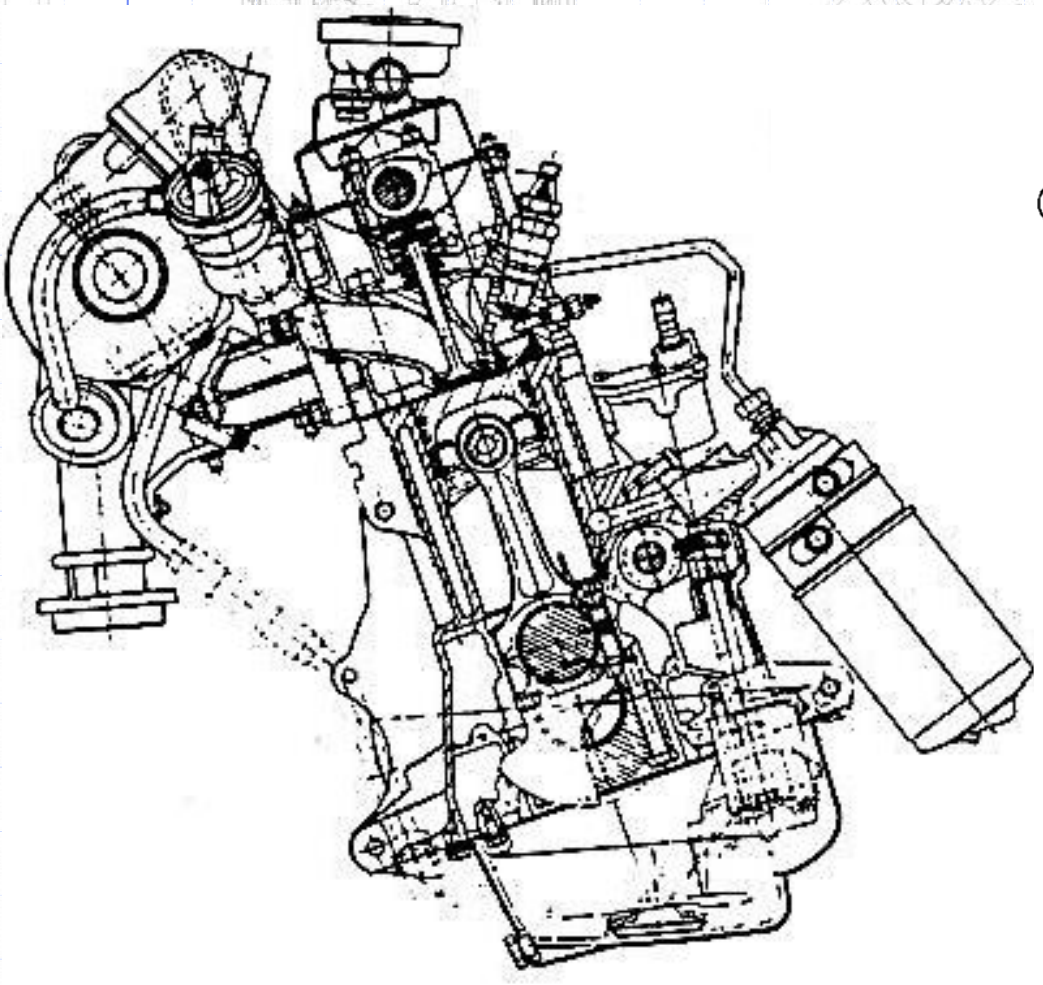
Bild 1: Entwicklung der Dieseleinspritztechnik

Figure 1: Development of Diesel fuel injection technology

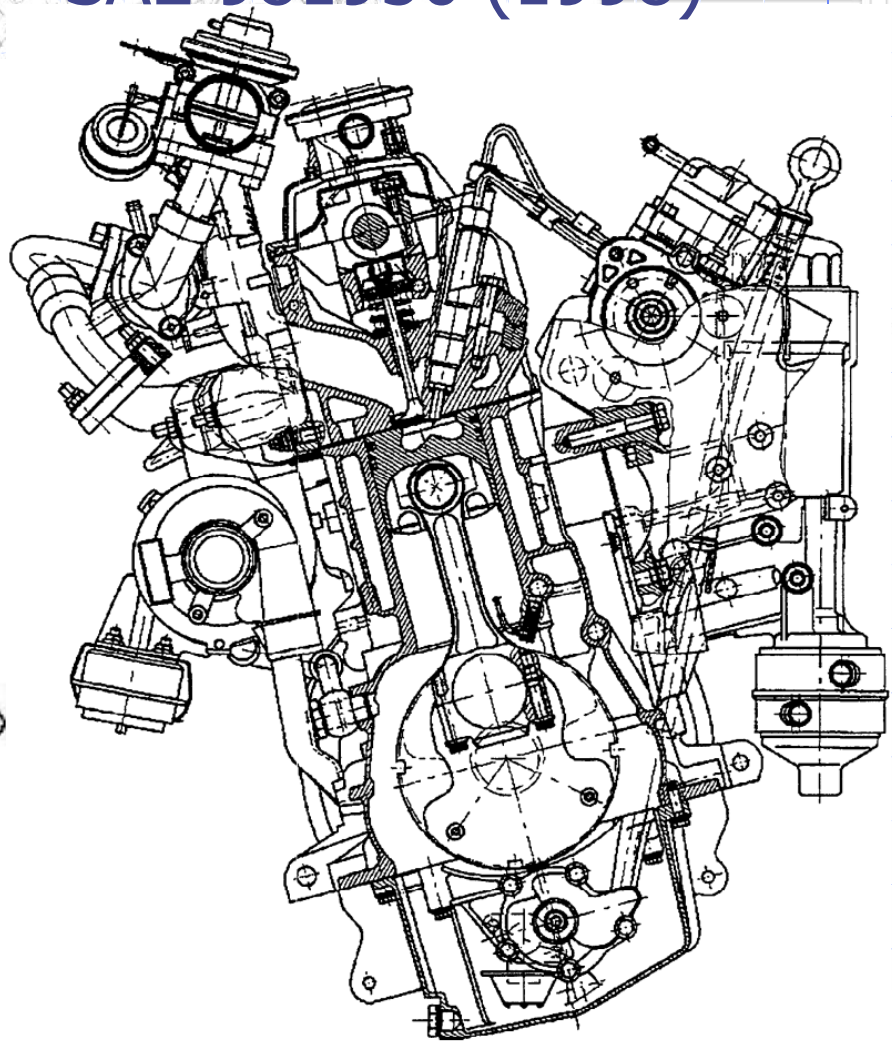
Source: [5]

Past – Some Diesel History

SAE 820441 (1982) [1]



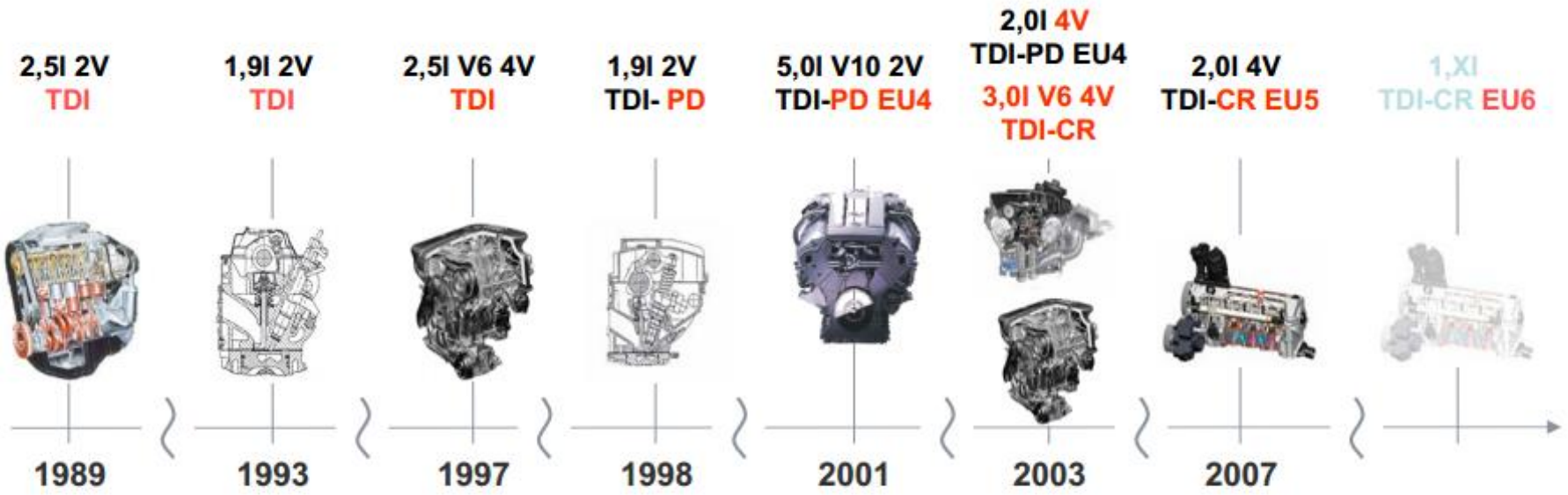
SAE 981950 (1998) [2]



VW Diesel Engine Program

Source: [3]

TDI Technology of Volkswagen



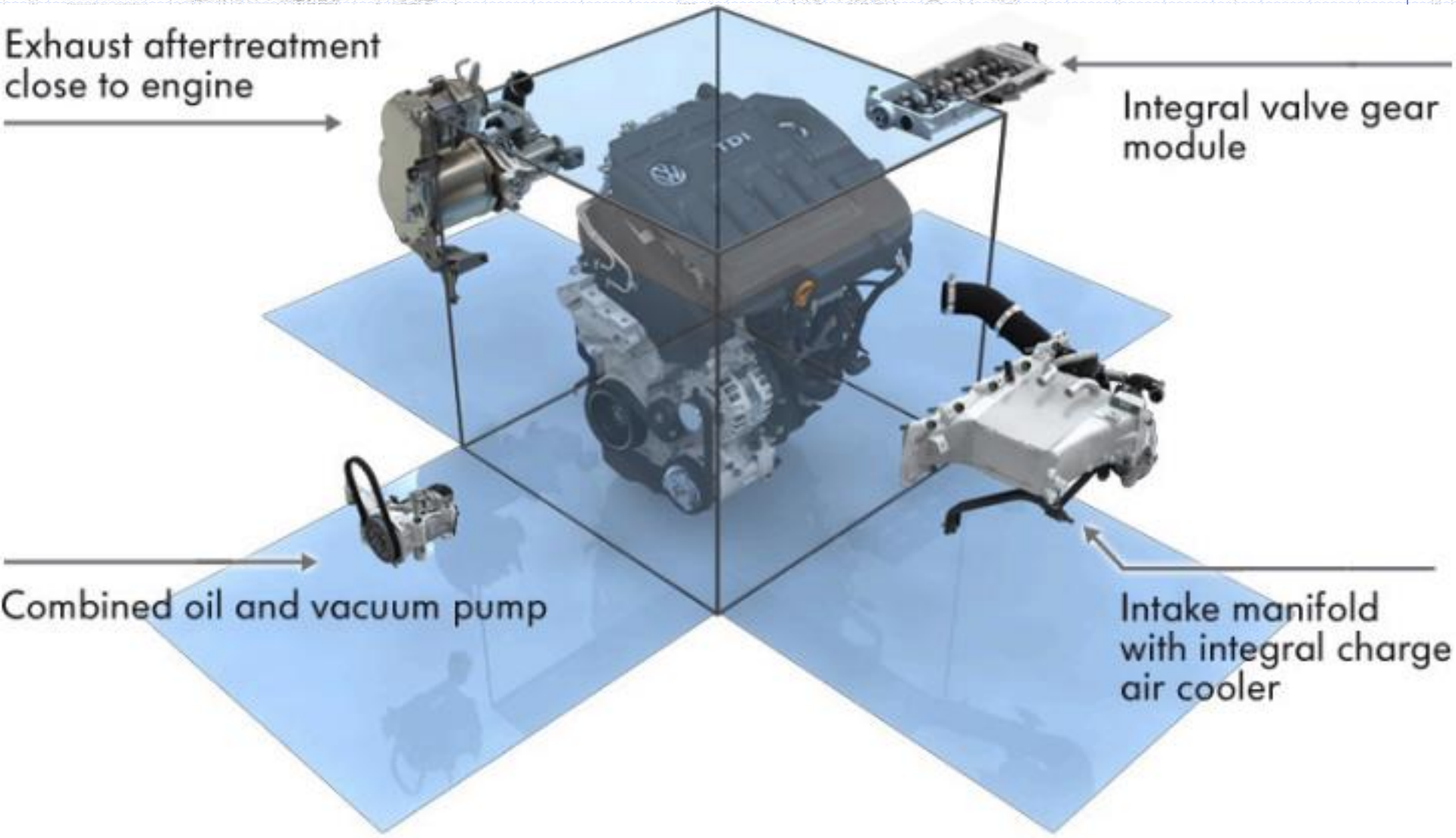
Source: [4]

Present – the EA288 TDI

- Evolution of VW Group 4-cylinder TDI family
- Designed for maximum modularity – MDB
- Common base engine with changeable sub-modules
  - Exhaust aftertreatment
  - Turbocharging
  - 1.6/2.0L

Sources: [7], [11]

Present – the EA288 TDI



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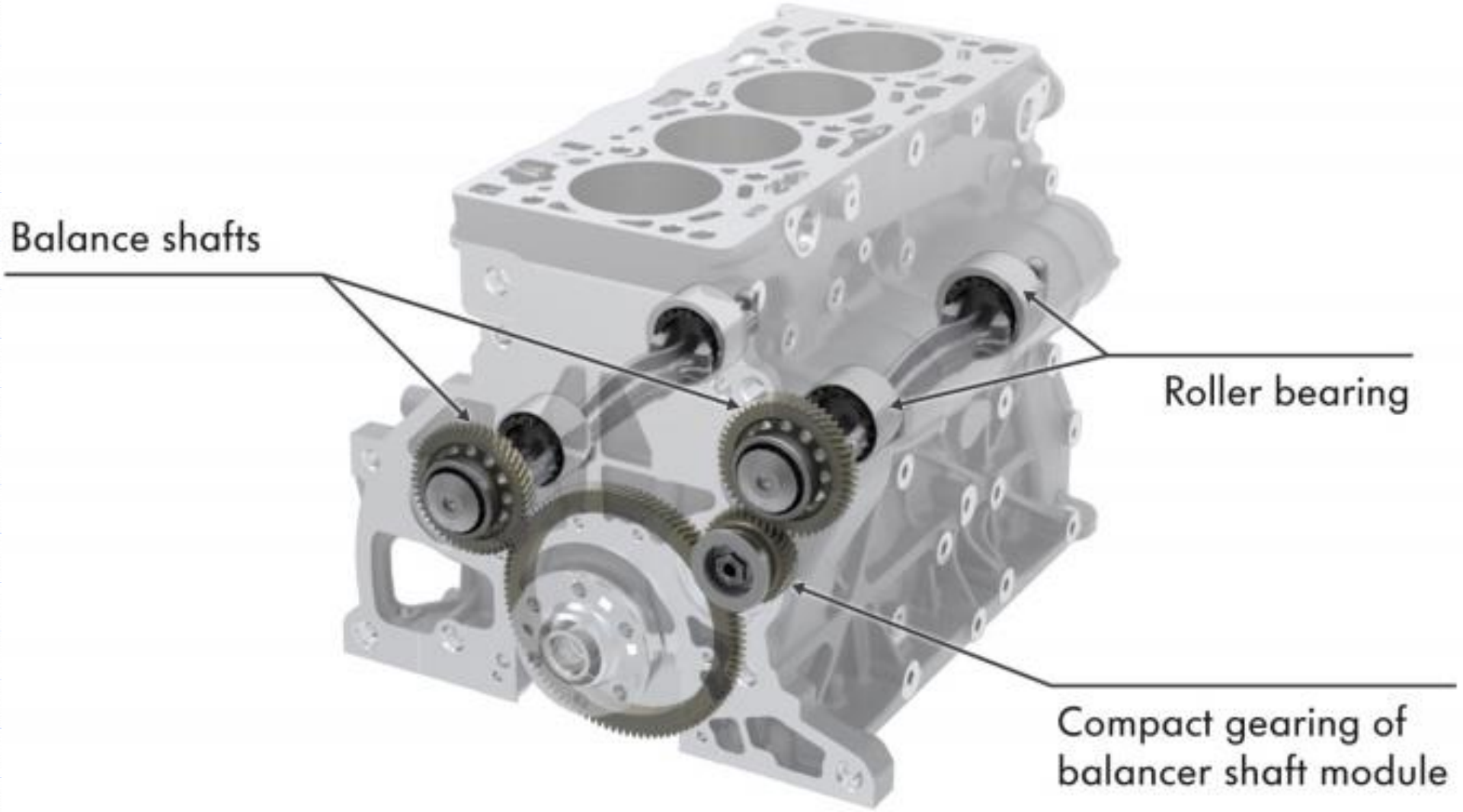

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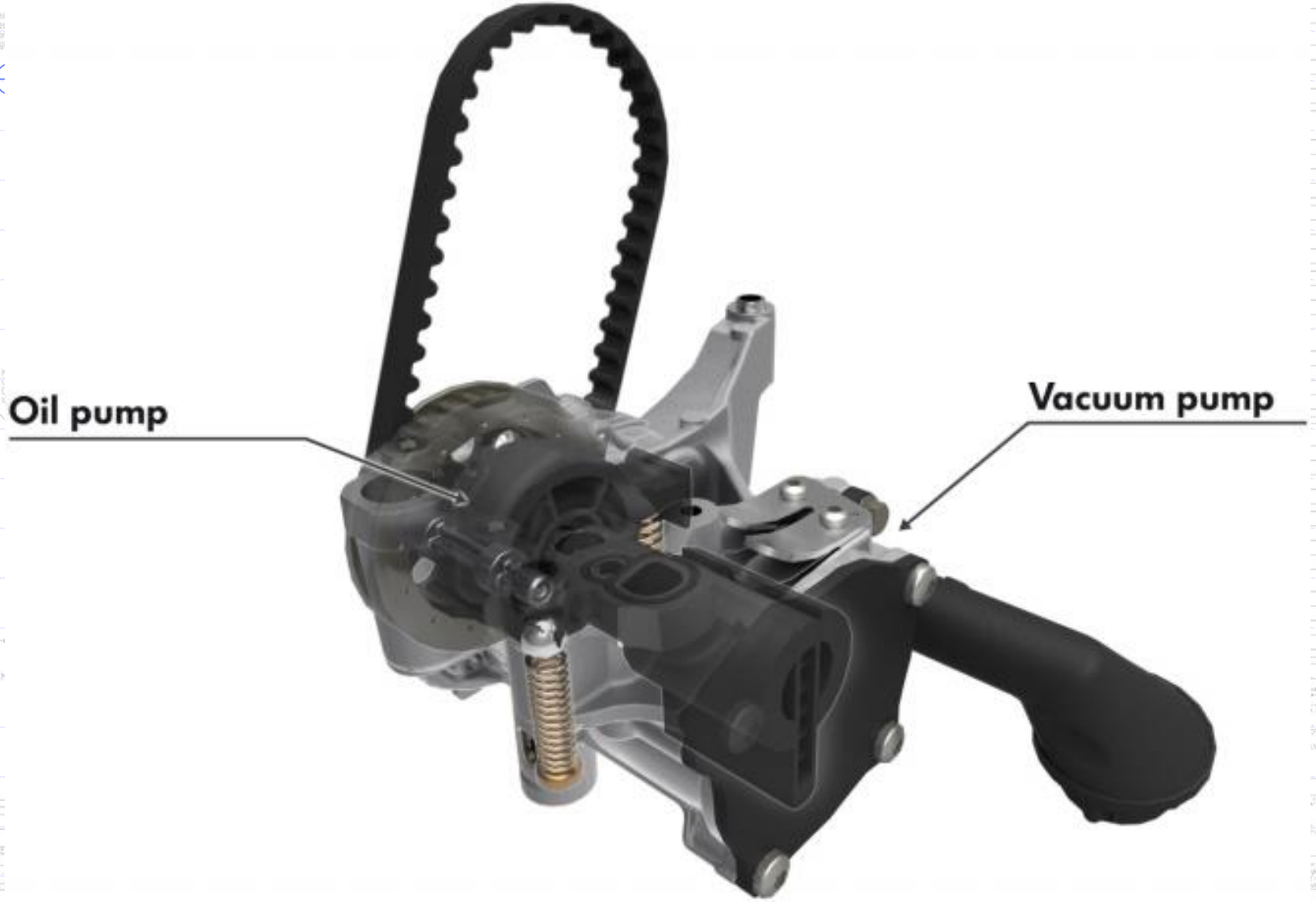

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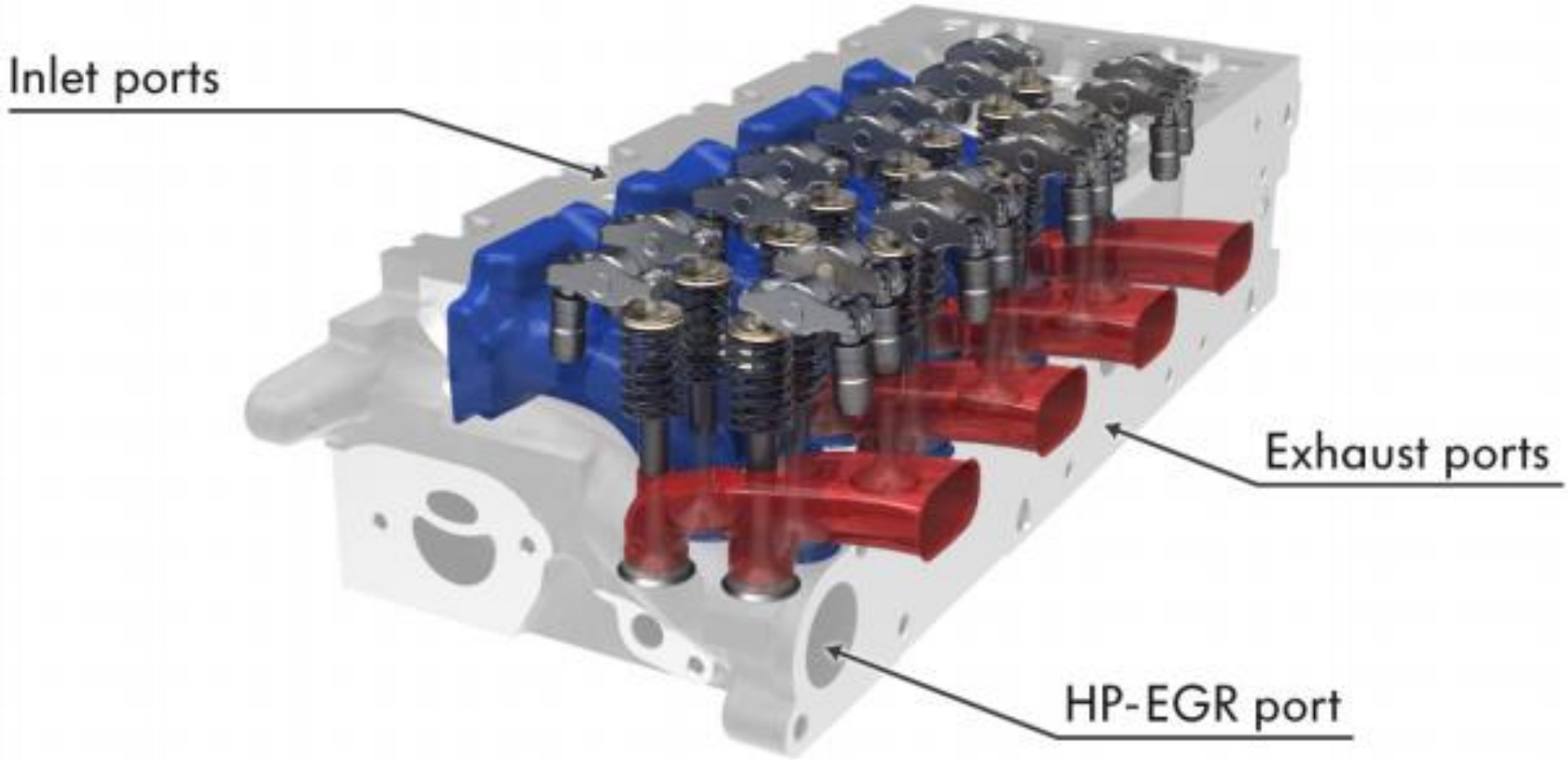

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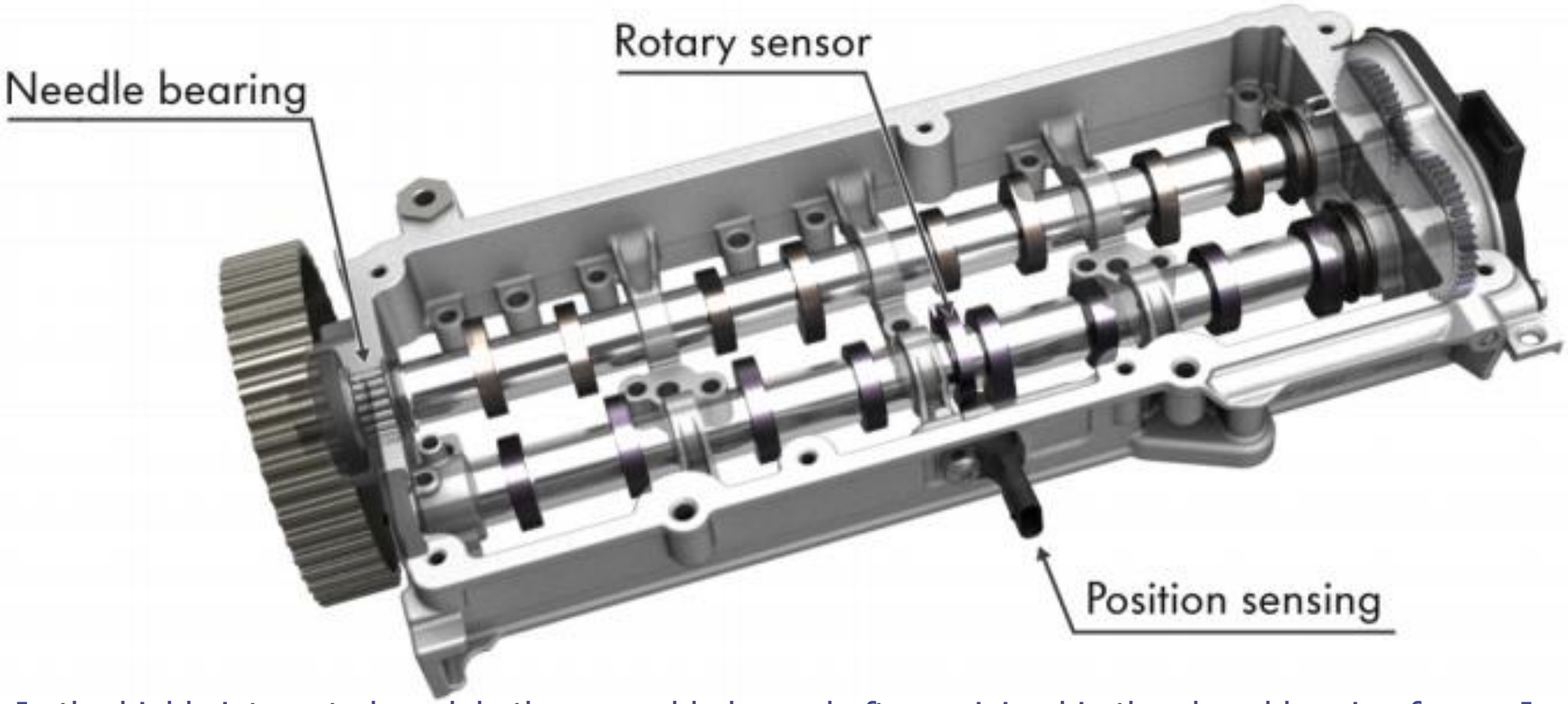
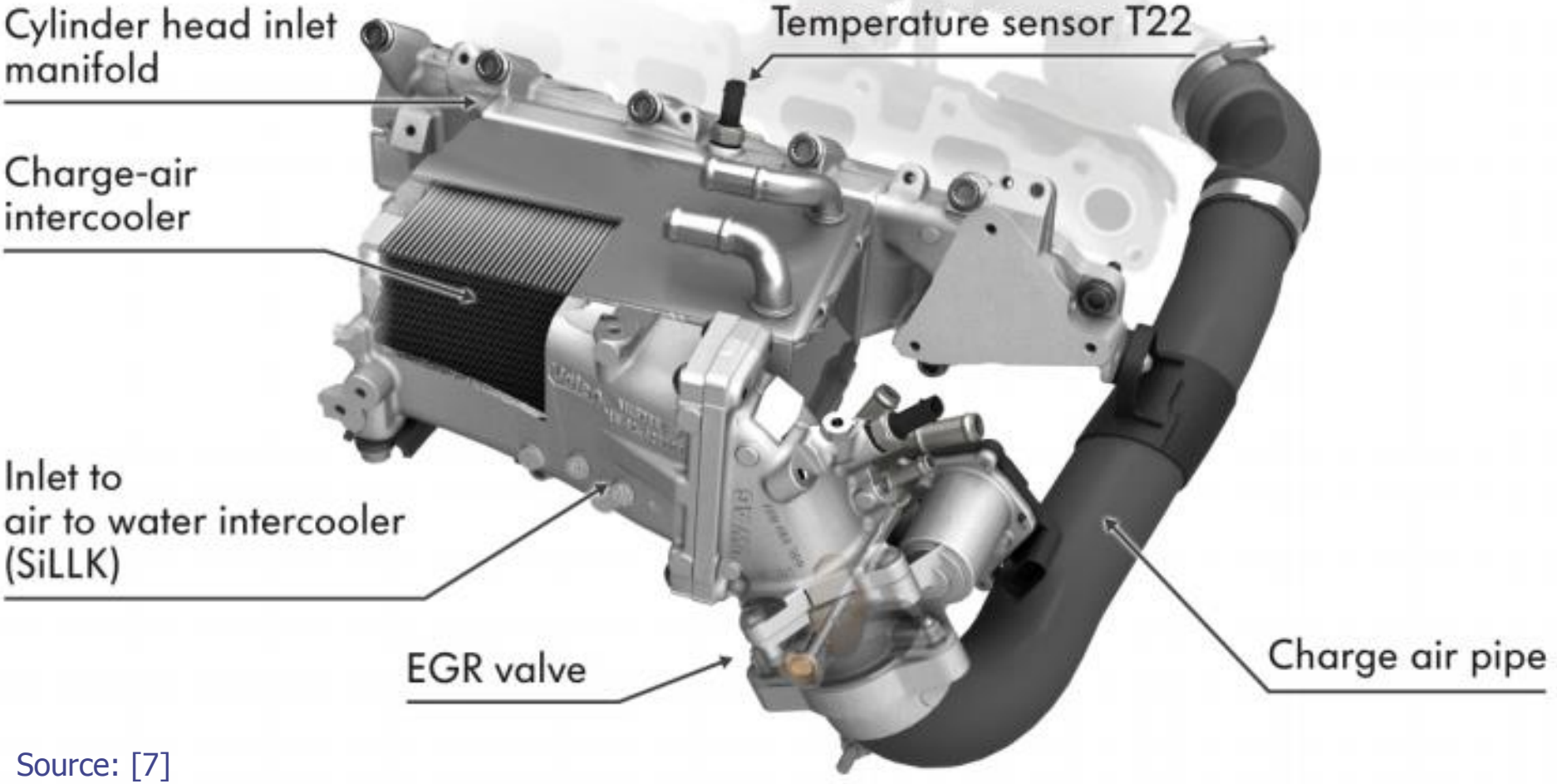


In the highly integrated module the assembled camshafts are joined in the closed bearing frame. In this technique the machined bearing frame is mounted in a fixture and the ground and heated cams together with the rotary sensor are held in position by a holder in the bearing frame. Then the camshaft pipes, pre-fitted with their end-fittings and pre-chilled, are fed through the bearing points in the frame and through the heated cams. Once the cams have cooled and the pipes have heated up, ***the two camshafts are inseparably assembled in the IVM***.

Source: [7]

Present – the EA288 TDI



Source: [7]

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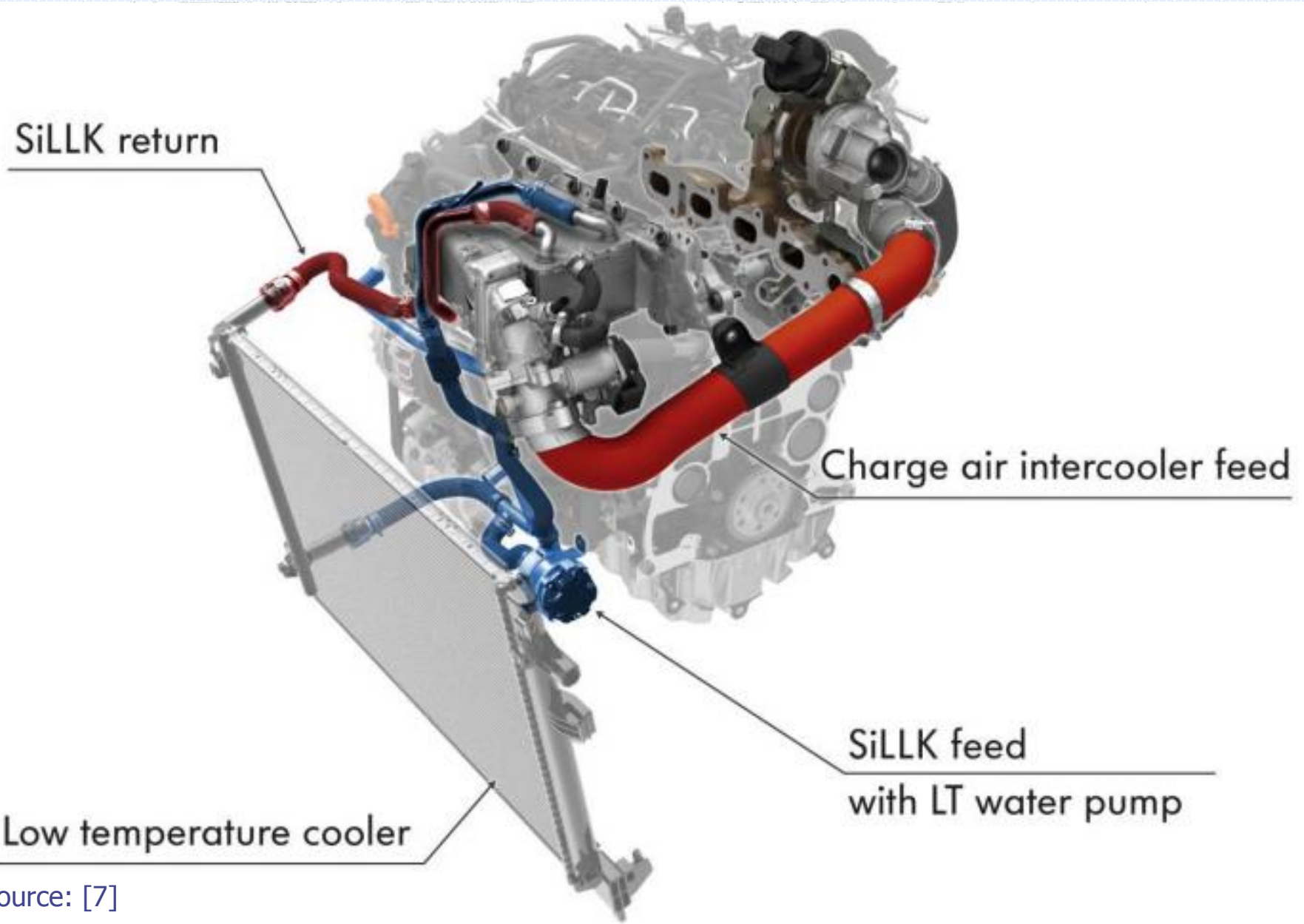

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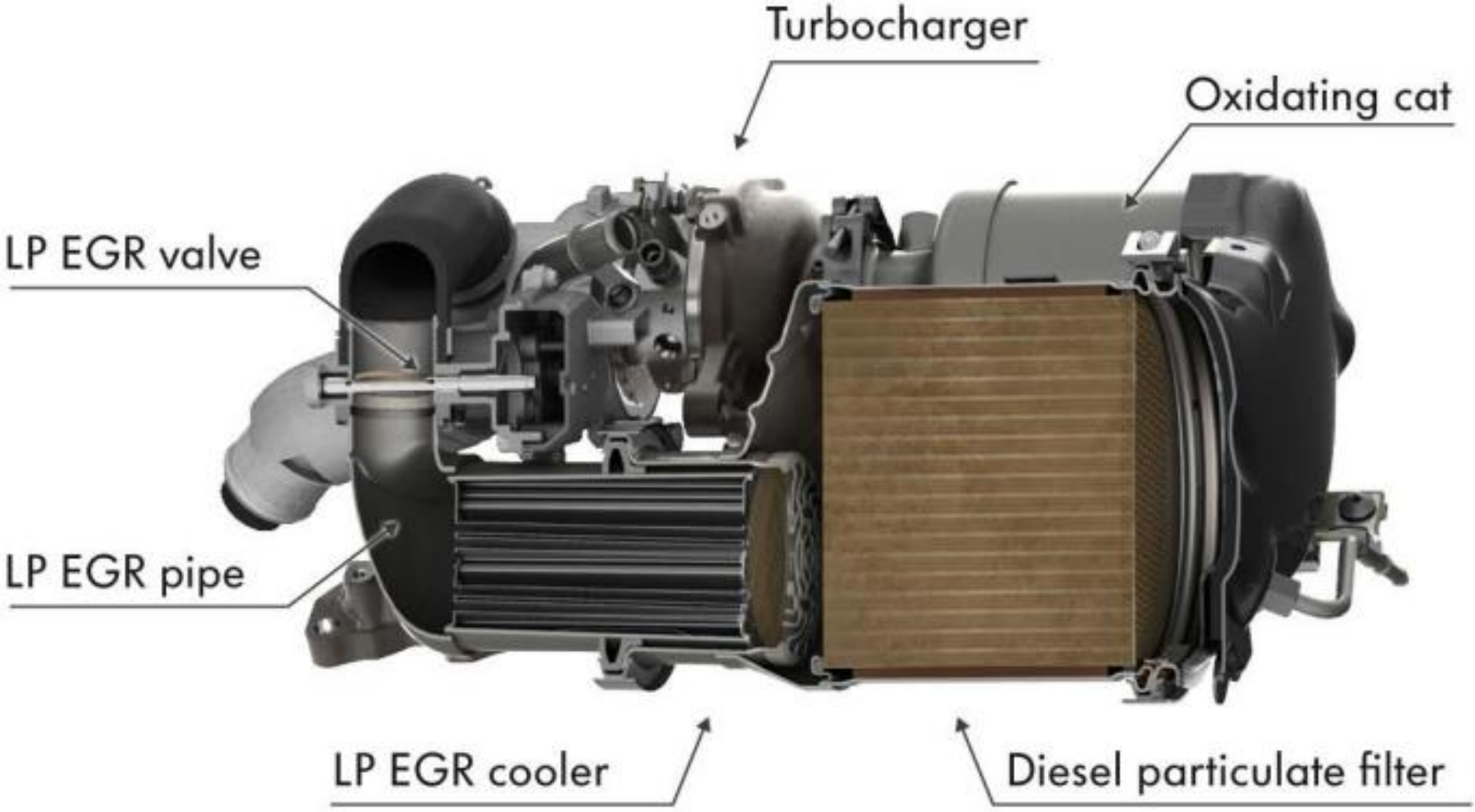

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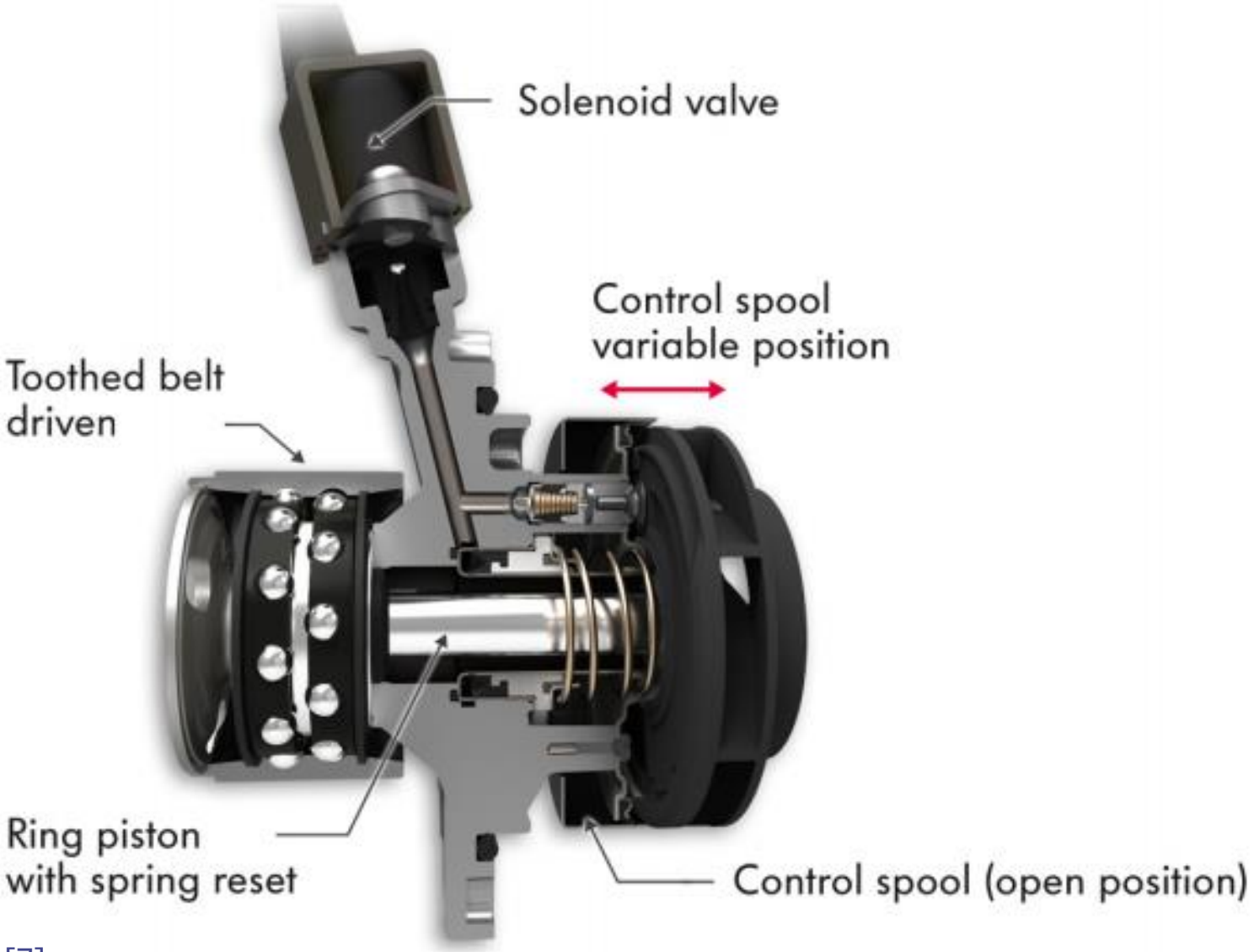

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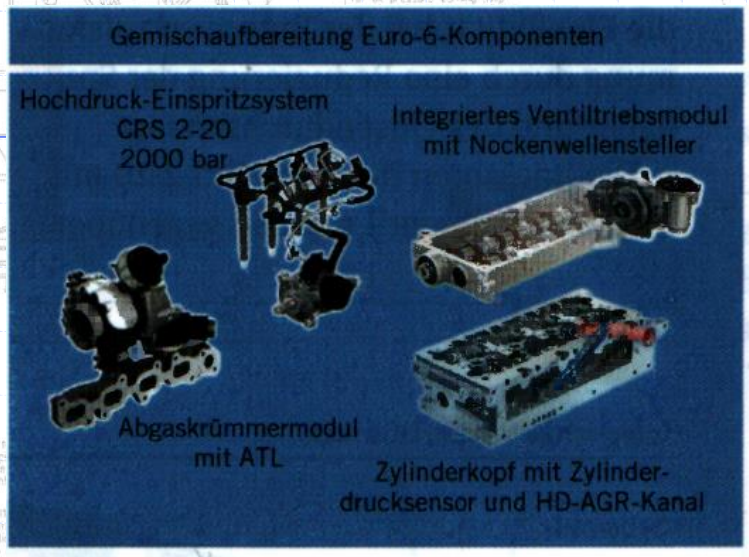
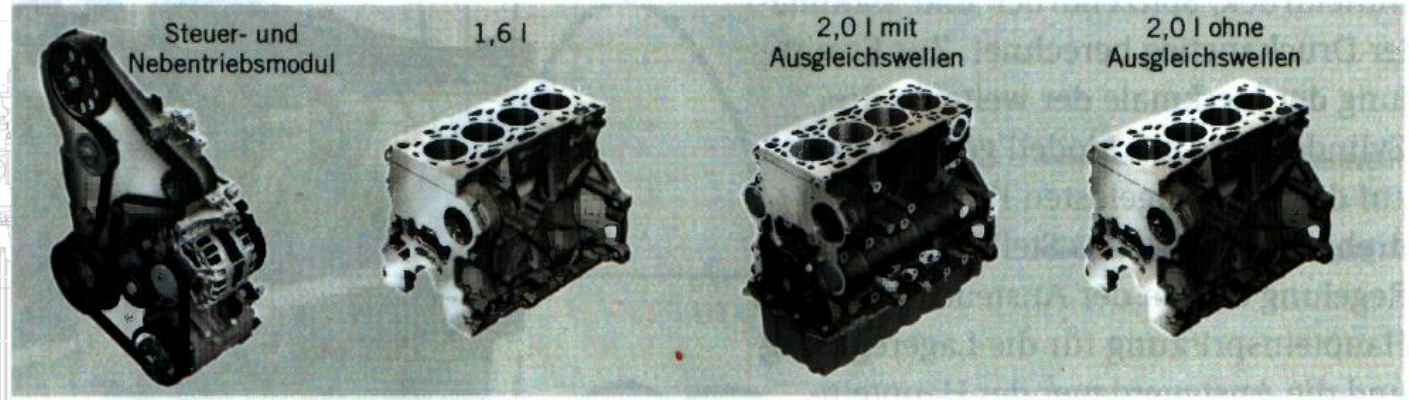
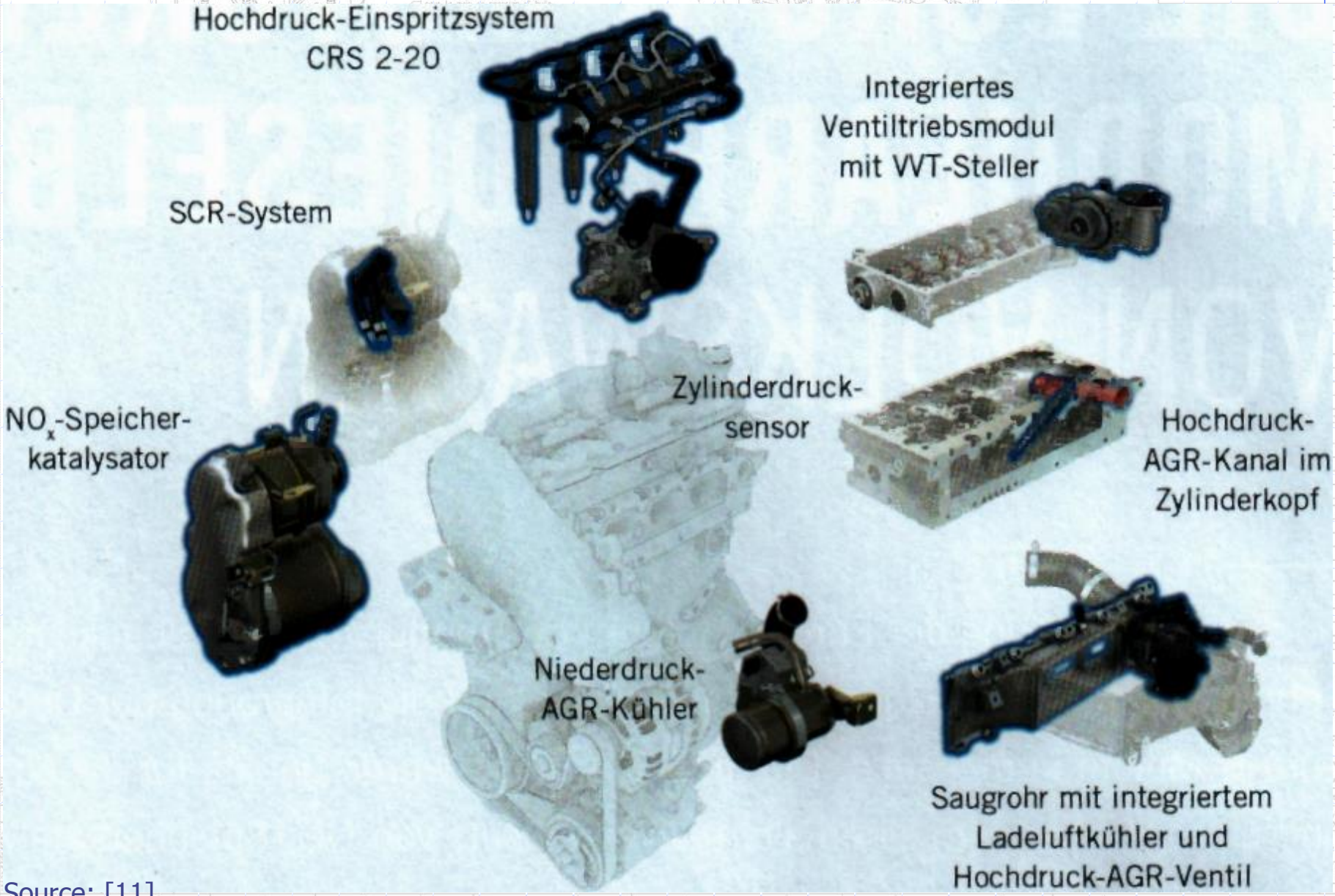




		MDB 1,6 l	MDB 2,0 l	
Nennleistung	kW bei 1/min	81 bei 3500 – 4000	110 bei 3500 – 4000	135 bei 3500 – 4000
Nenndrehmoment	Nm bei 1/min	250 bei 1500 – 2750	320 bei 1750 – 3000	380 bei 1750 – 3000
Abgasstufe Euro 4	–	–	X	–
Abgasstufe Euro 5	–	X	X	X
Abgasstufe Euro 6	–	X	X	X

Source: [11]

Present – the EA288 TDI



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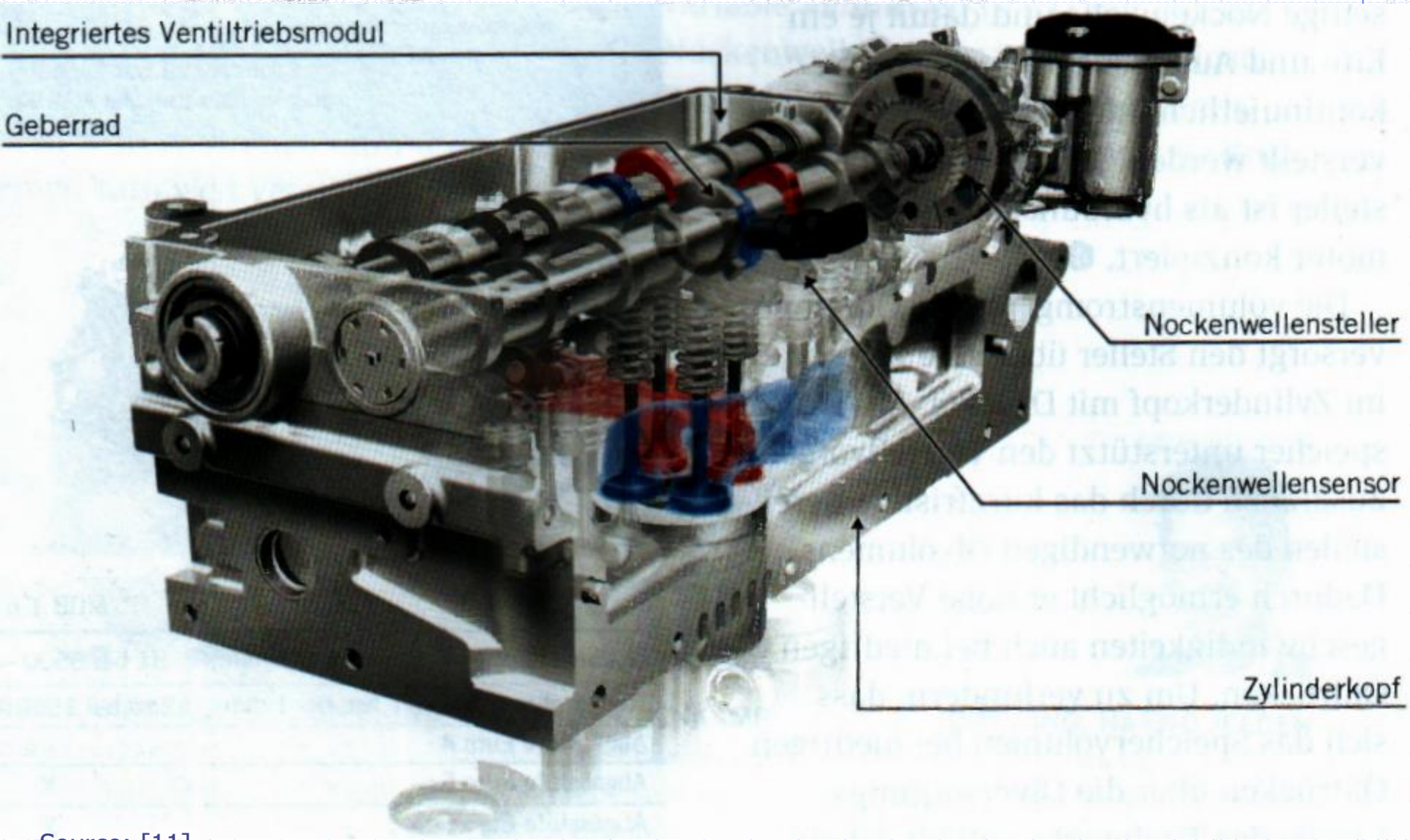

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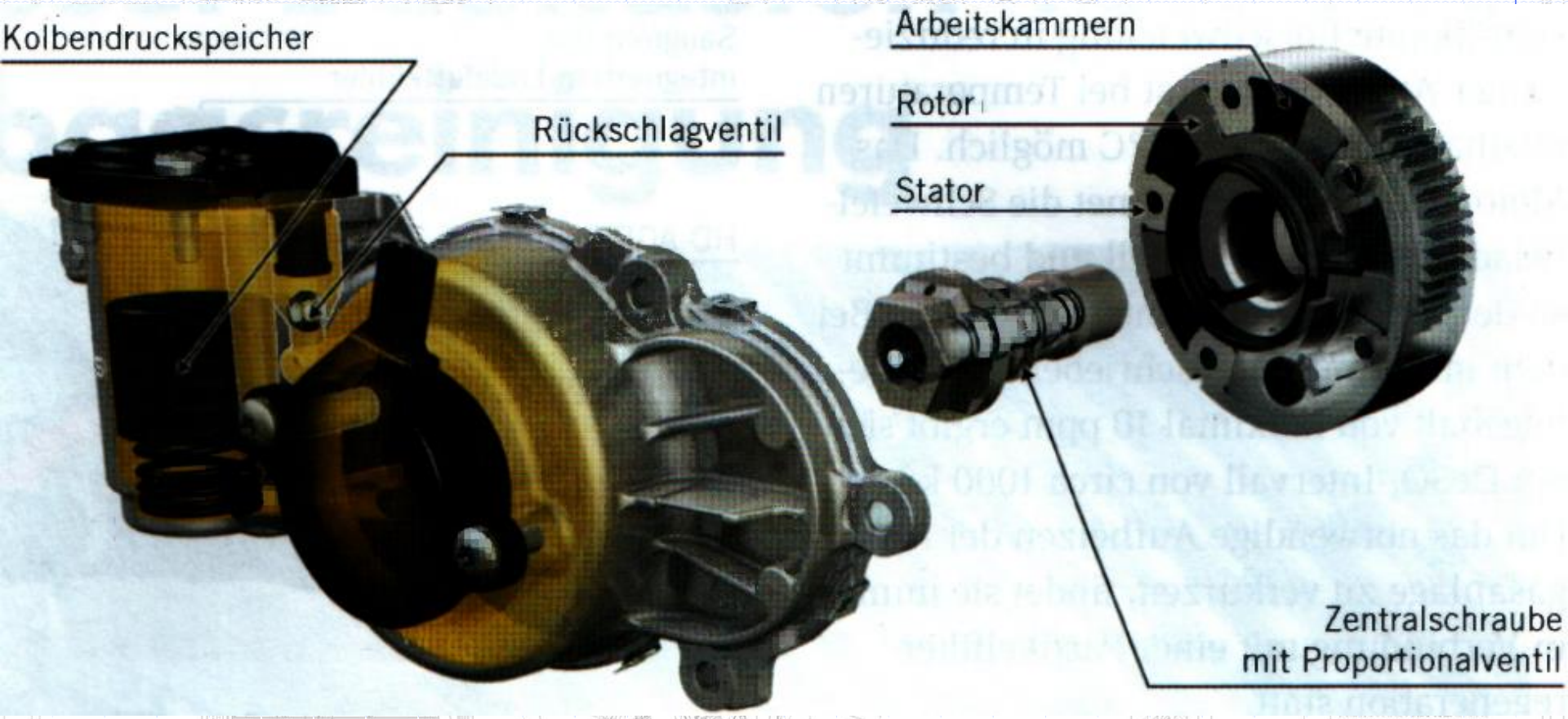

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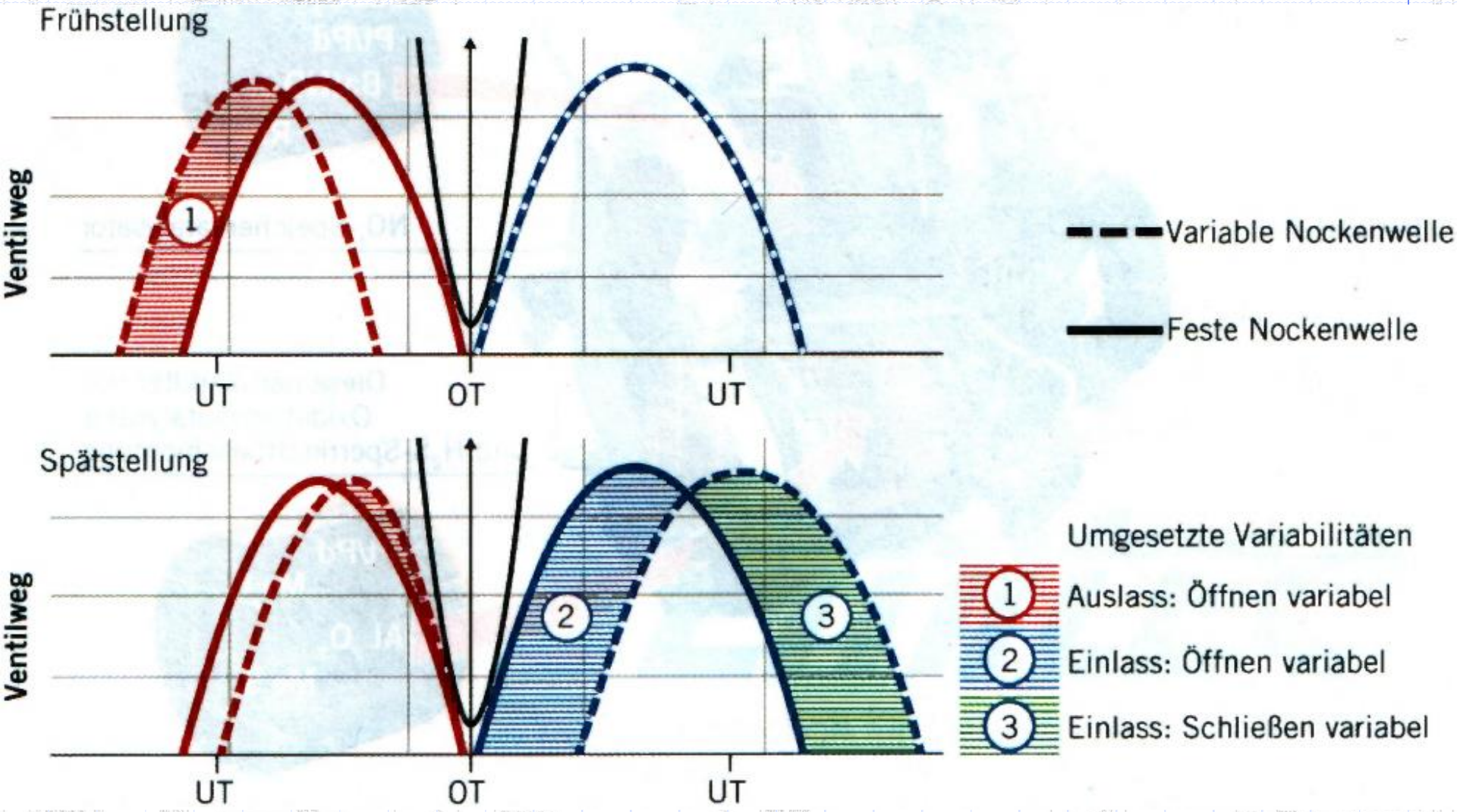

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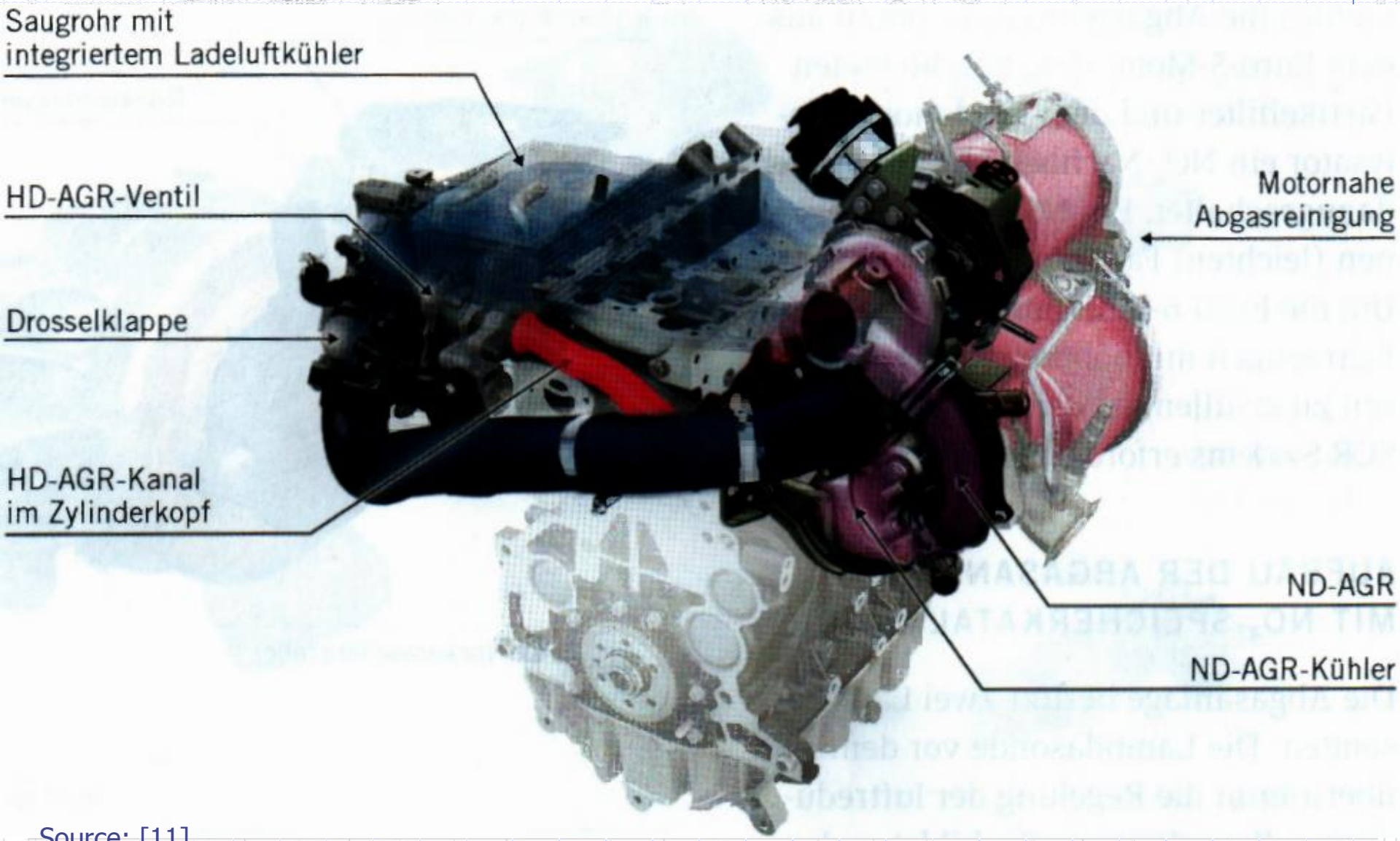

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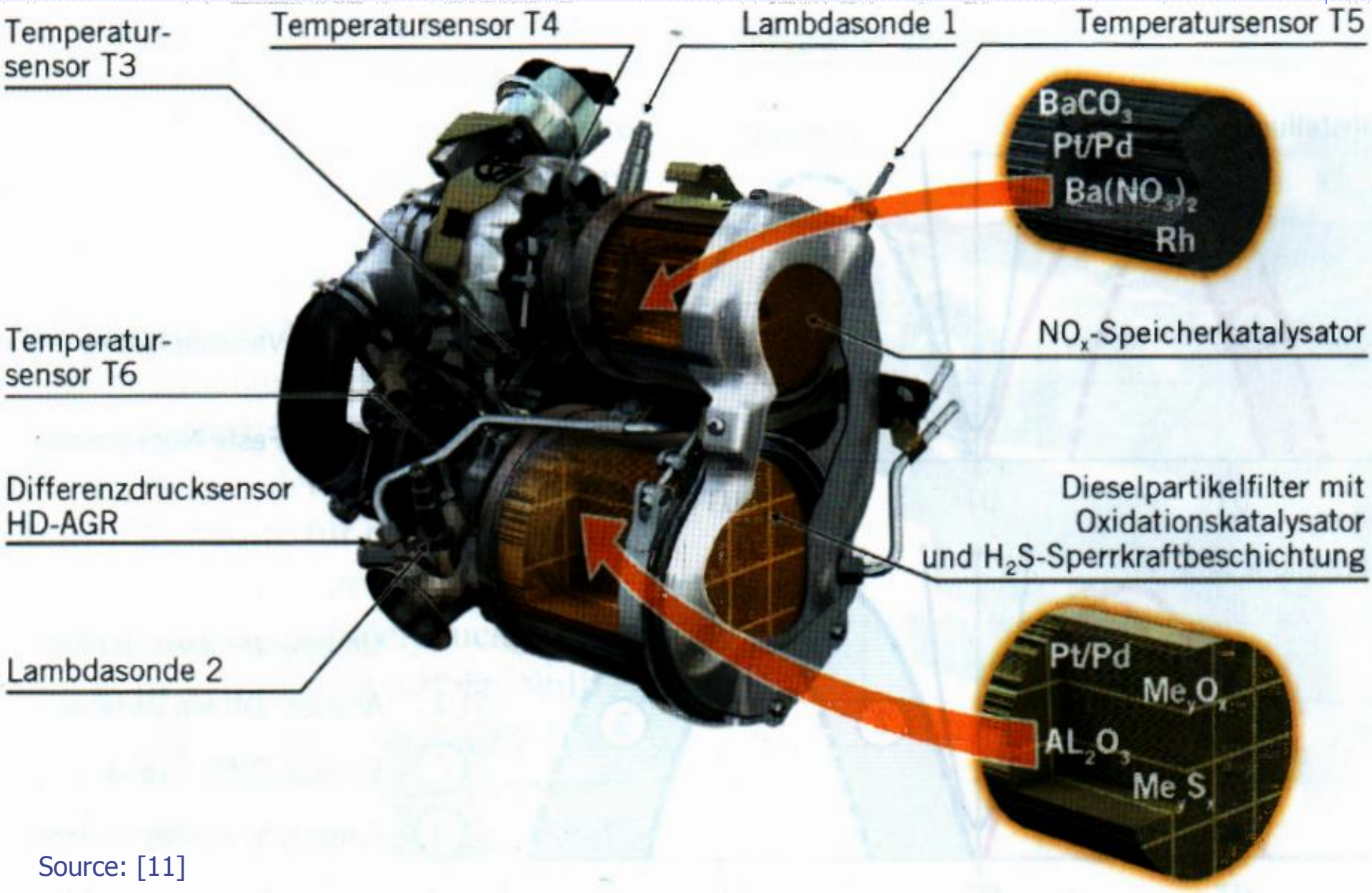

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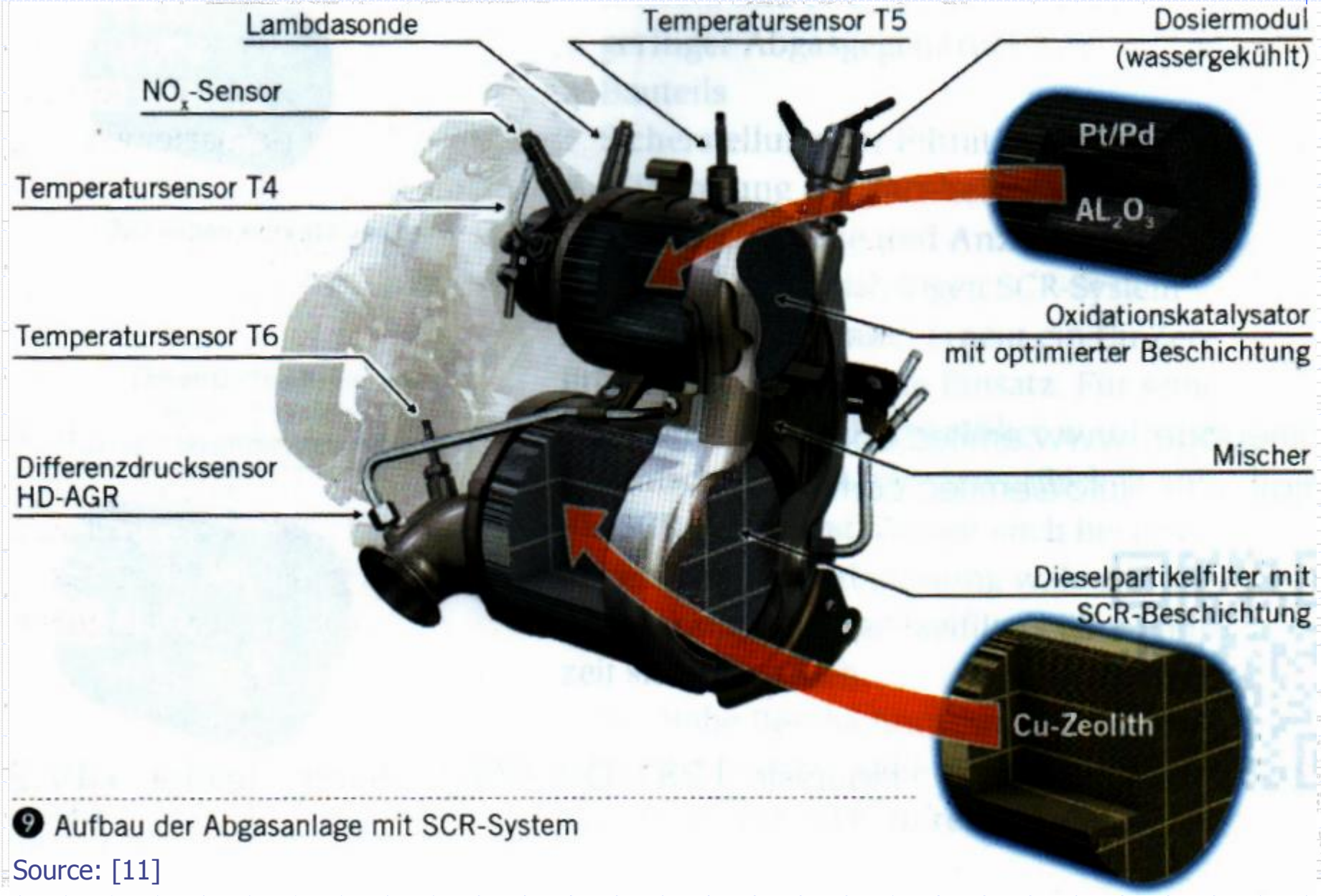
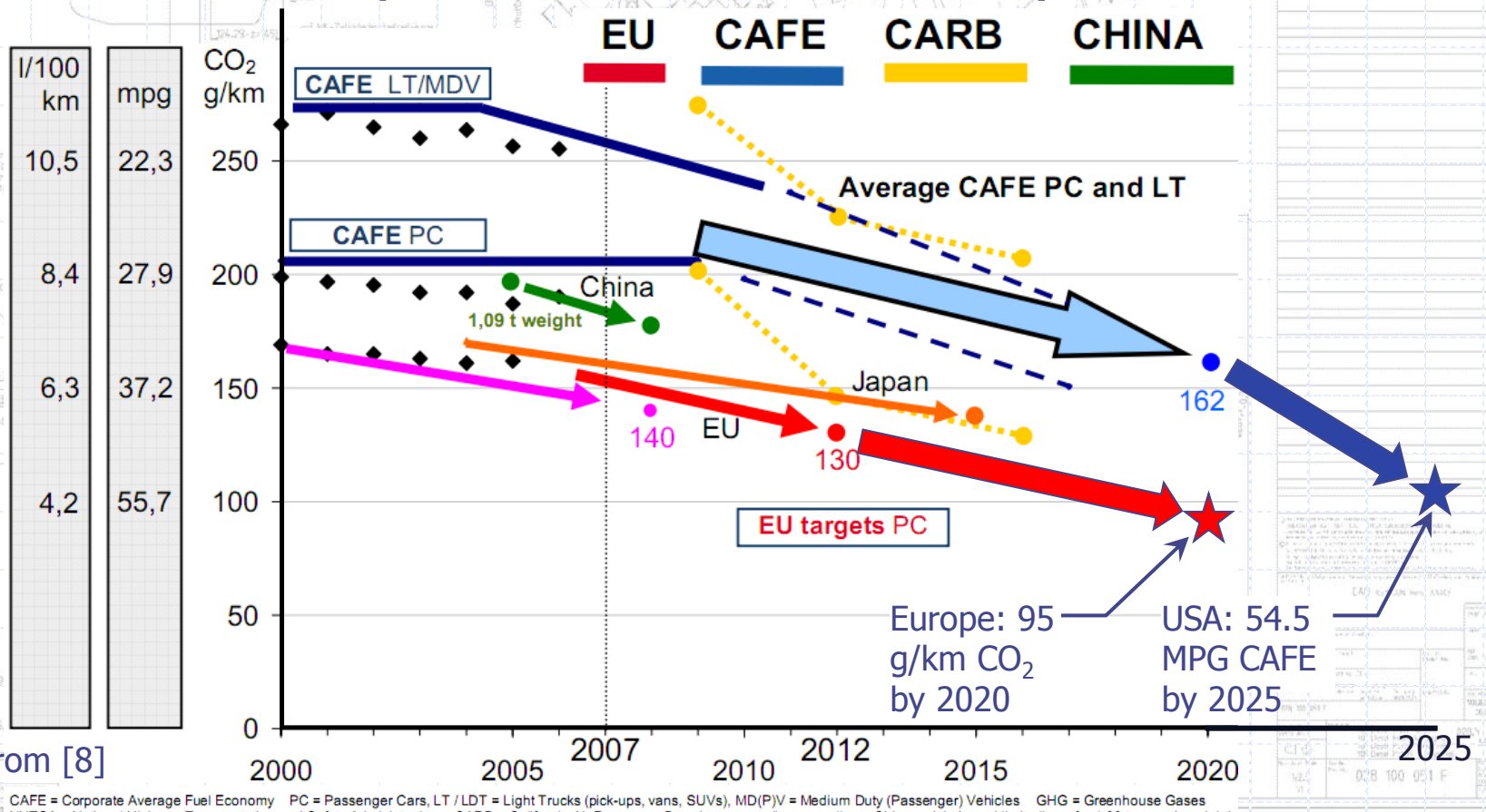


❾ Aufbau der Abgasanlage mit SCR-System

Source: [11]

Future Trends

- Engine development will focus upon reduced fuel consumption and sustainability



Adapted from [8]

CAFE = Corporate Average Fuel Economy PC = Passenger Cars, LT / LDT = Light Trucks (pick-ups, vans, SUVs), MD(P)V = Medium Duty (Passenger) Vehicles GHG = Greenhouse Gases
NHTSA = National Highway Transportation and Safety Administration CARB = California Air Resources Board mpg = miles per gallon China weight based limits (here for 1,09 tons curb weight)

Future Trends

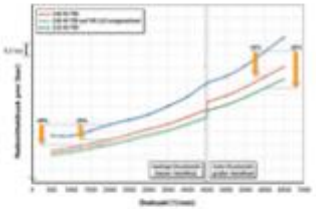
- The focus on reducing fuel consumption are being attacked on multiple fronts
  - Gasoline engines: Downsizing/downspeeding, charge boosting, direct injection, cylinder deactivation, variable valve timing, laser/plasma ignition, combustion process
  - Diesel engines: Two-stage turbocharging, even higher injection pressures (2200-3000 bar), exotic injector technology, novel combustion processes
  - Commonalities: Engine start-stop, hybridization, thermal/friction management, weight reduction,

Measures for further consumption reductions

Charging: Turbo and/or compressor

Direct injection

Optimization of friction



Variable valve control

Thermo management

Oil system

Source: [4]

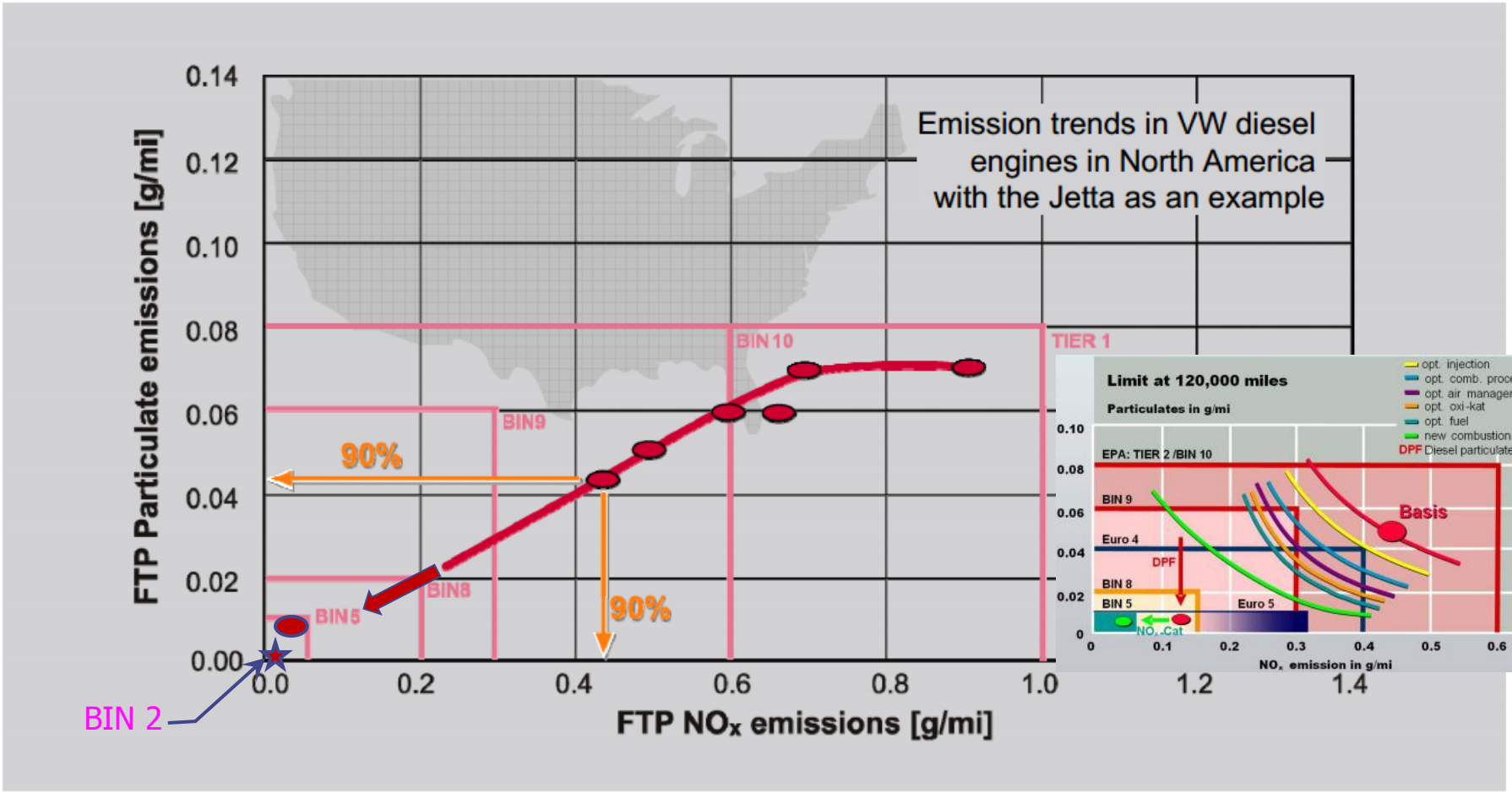
Elements to improve efficiency

- Further optimisation of the engine technology (TDI/TSI/DSG)
- Extended offer of gearbox technology (DSG, S-tronic, tiptronic)
- Alternative mechanical and hydraulic **auxiliary gearboxes**
- Optimization of **energy management**
- Optimization of **aero dynamic**
- Reduction of **mechanical drag**
- Extension of **light weight construction competence**
- Further development of **driver assistance systems**
- **...**

Safe into the future

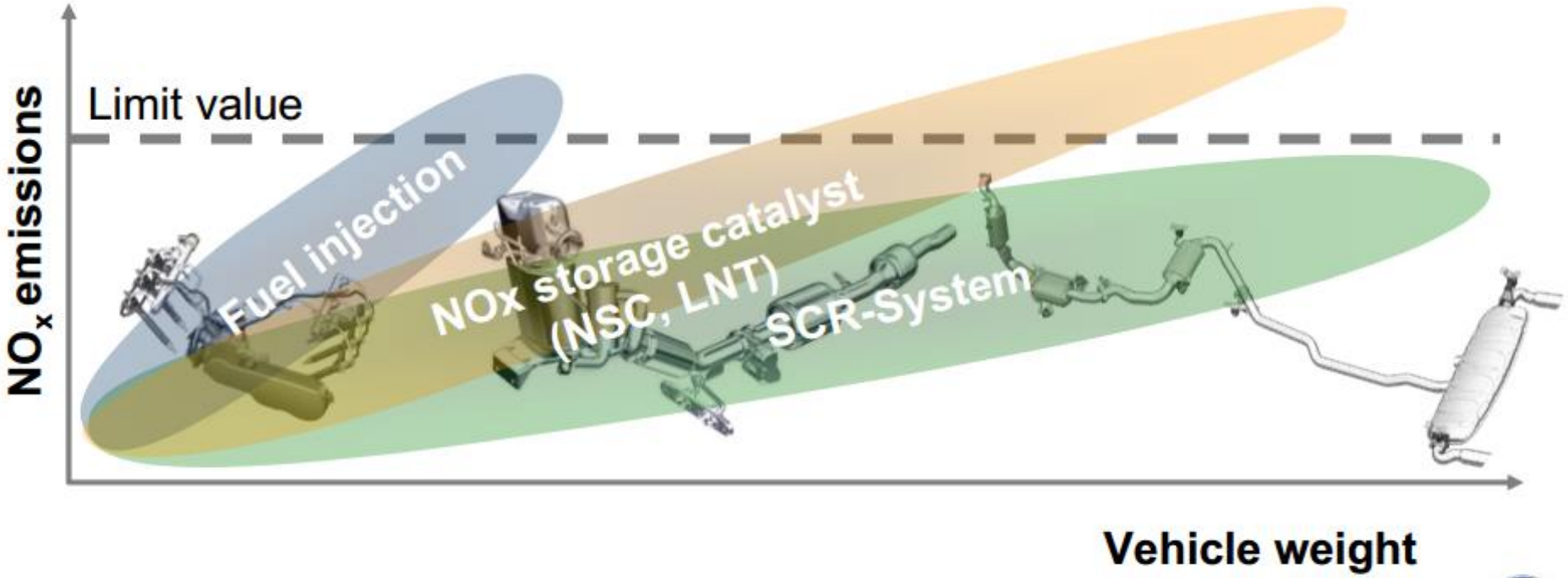
Source: [4]

North America Region Emission Results



Adapted from [3]; inset: [6]

Measures to meet ultra low emission limits



Source: [4]

Future Trends

- Prognosis for the TDI (and competitors)
  - Short-term:
    - More choice of Diesel car / light truck models in North America in next 2 years
    - Increasing availability of engine start-stop
    - Cost reductions, simplifications, manufacturing economies
    - LNT vs SCR?
      - Increasing comfort level and lower cost to OEM with SCR may result in transition away from LNTs (mileage penalty)
      - On the other hand, advancements in LNT technology…
    - Transmissions with more forward speeds

Future Trends

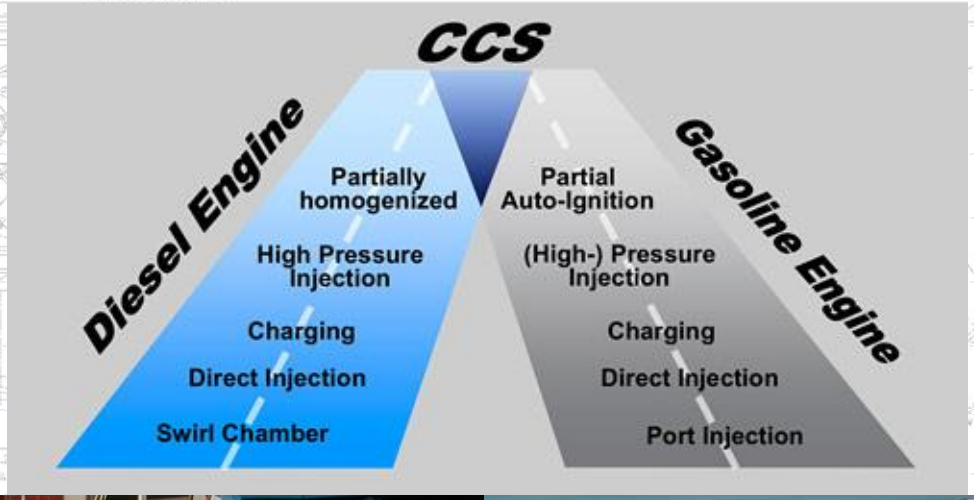
- Prognosis for the TDI (and competitors)
  - Mid-term:
    - Increasing hybridization
      - Diesel hybrids starting to enter the (European) market
      - New technology will be introduced to the high-end first

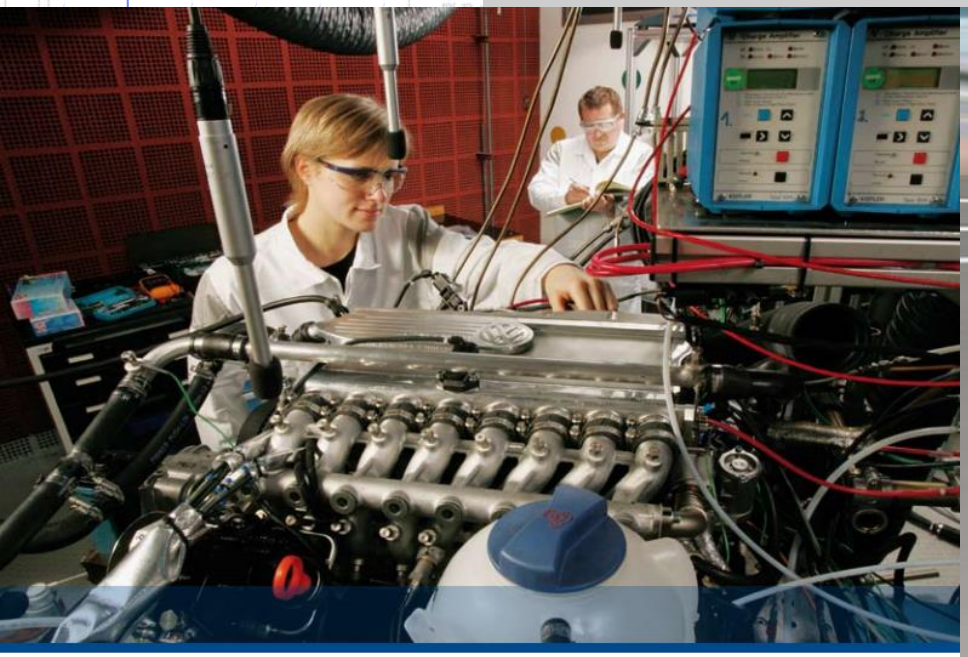
Future Trends

- Prognosis for the TDI (and competitors)
  - Long-term:
    - Further increasing hybridization toward full electrification
      - Full-hybrid integrated to transmission with/without plug-in capability up to 31 mile (50 km) electric range
      - EV with internal combustion engine or FC as range extender

Combined Combustion System
Synergies

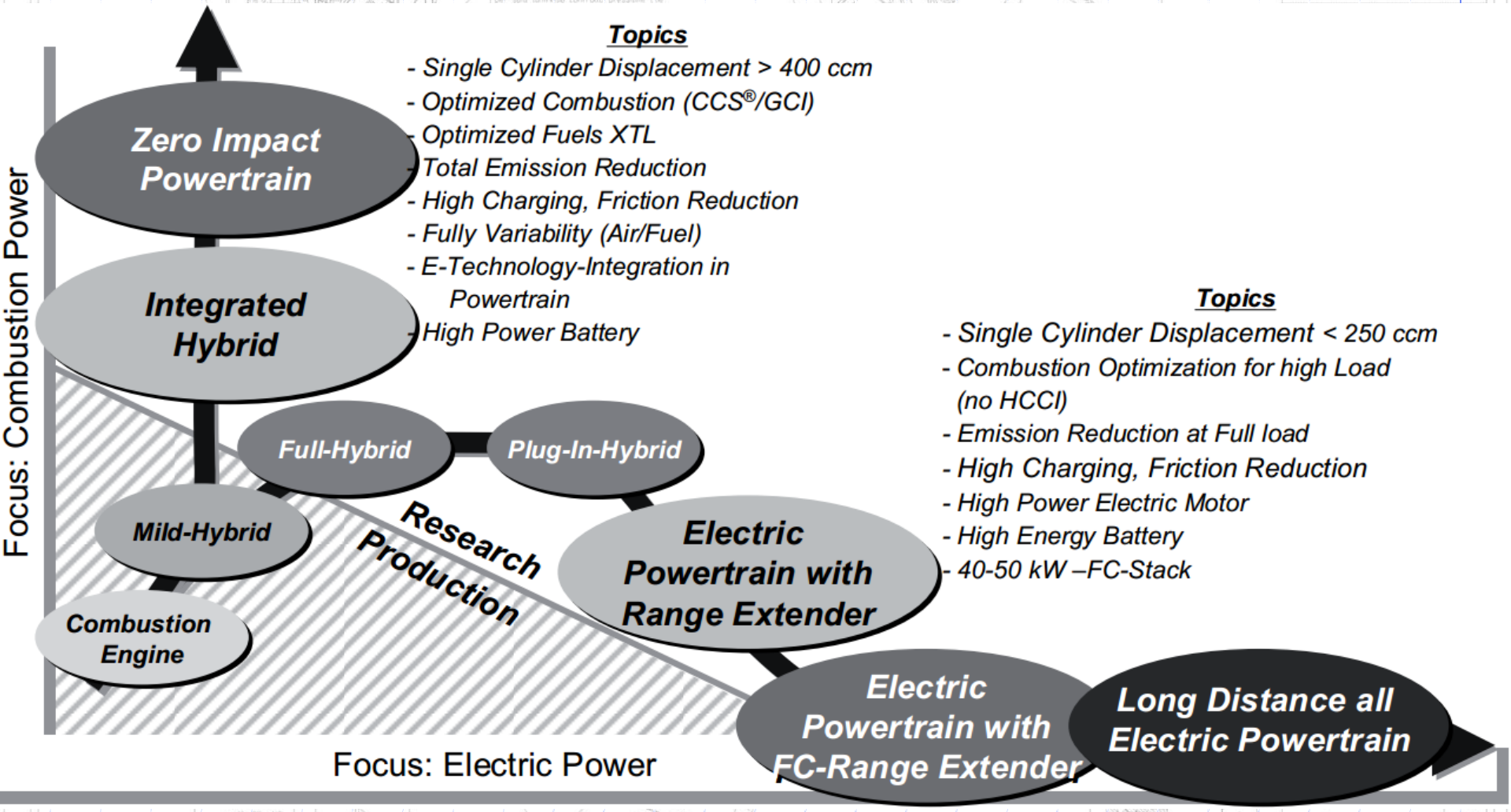
Sources: [9], [10]





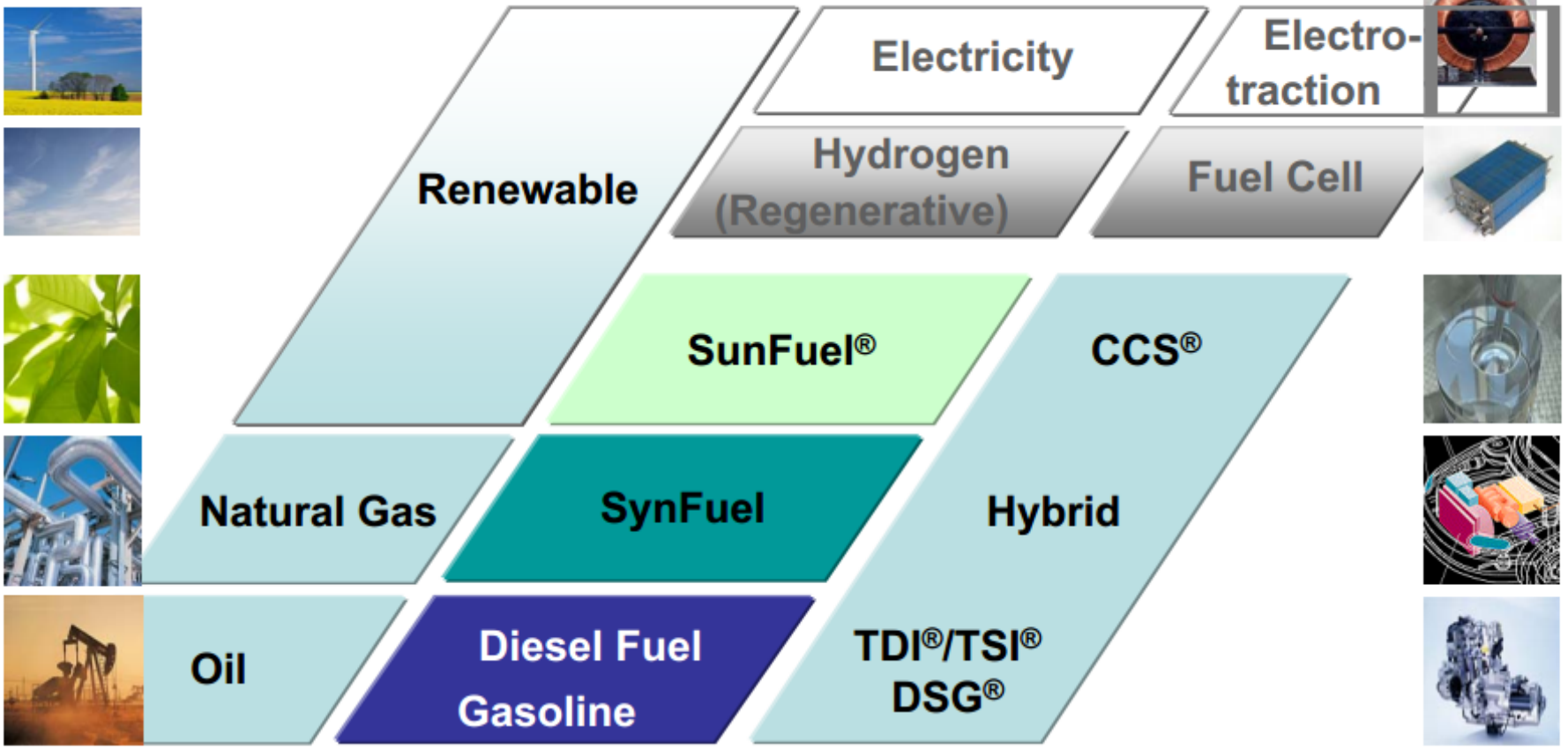
The CCS Combustion System from Volkswagen

Future Trends



Source: [12]

Volkswagen's Fuel- and Powertrain Strategy



Source: [4]

THANK YOU FOR YOUR ATTENTION!

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