TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Maschinenwesen, Institut für Energietechnik, Bitzer–Stiftungsprofessur für Kälte-, Kryo- und Kompressorentechnik

Thermal Systems for Vehicle Thermal Management, Air Conditioning, Heat Recovery and Future Fuels

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Ingolstadt, 26.09.2013

Engine Cooling only

/http://pdphoto.org/PictureDetail.php?mat=pdef&pg=7906/

Electric Powertrain and Passenger Comfort

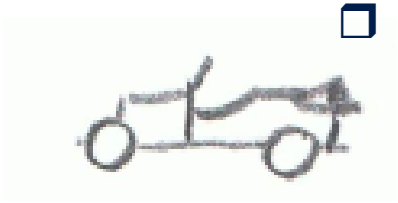
/ATZ-Online/

Content

- **Road map and definitions Thermal management**
- **Temperature levels**
- **Engine thermal management**
- **MAC – mobile air conditioning**
  - **Working fluids**
  - **Functionalities**
- **Waste heat recovery**
- **Future fuel**
- **Conclusion**

Road Map
Vehicle Thermal Management

- ❒ future fuel
- ❒ electric powertrain
- ❒ waste heat recovery
- ❒ A/C with new refrigerants
- ❒ engine thermal management
- ❒ air conditioning (A/C)
- ❒ engine cooling and heating
- ❒ engine cooling only



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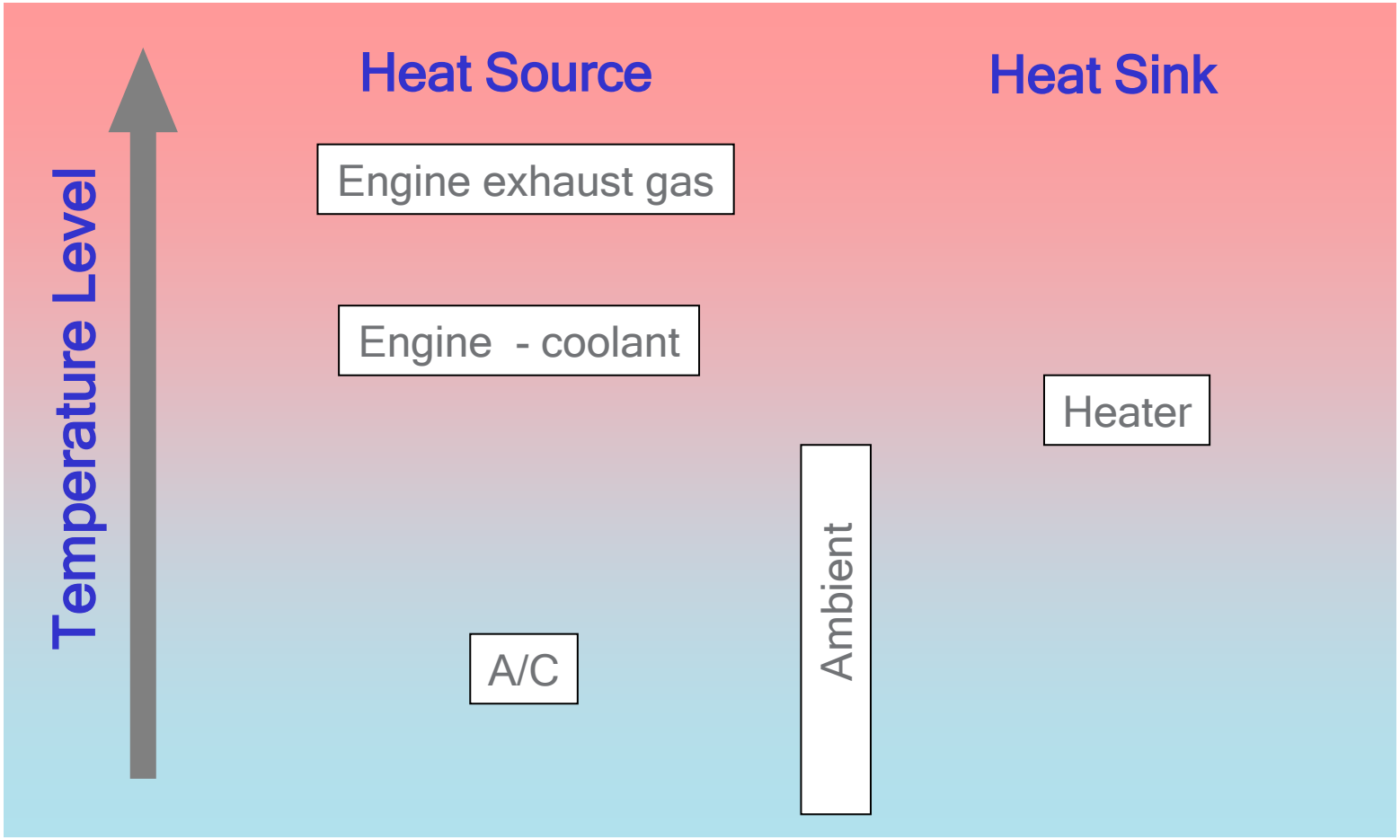
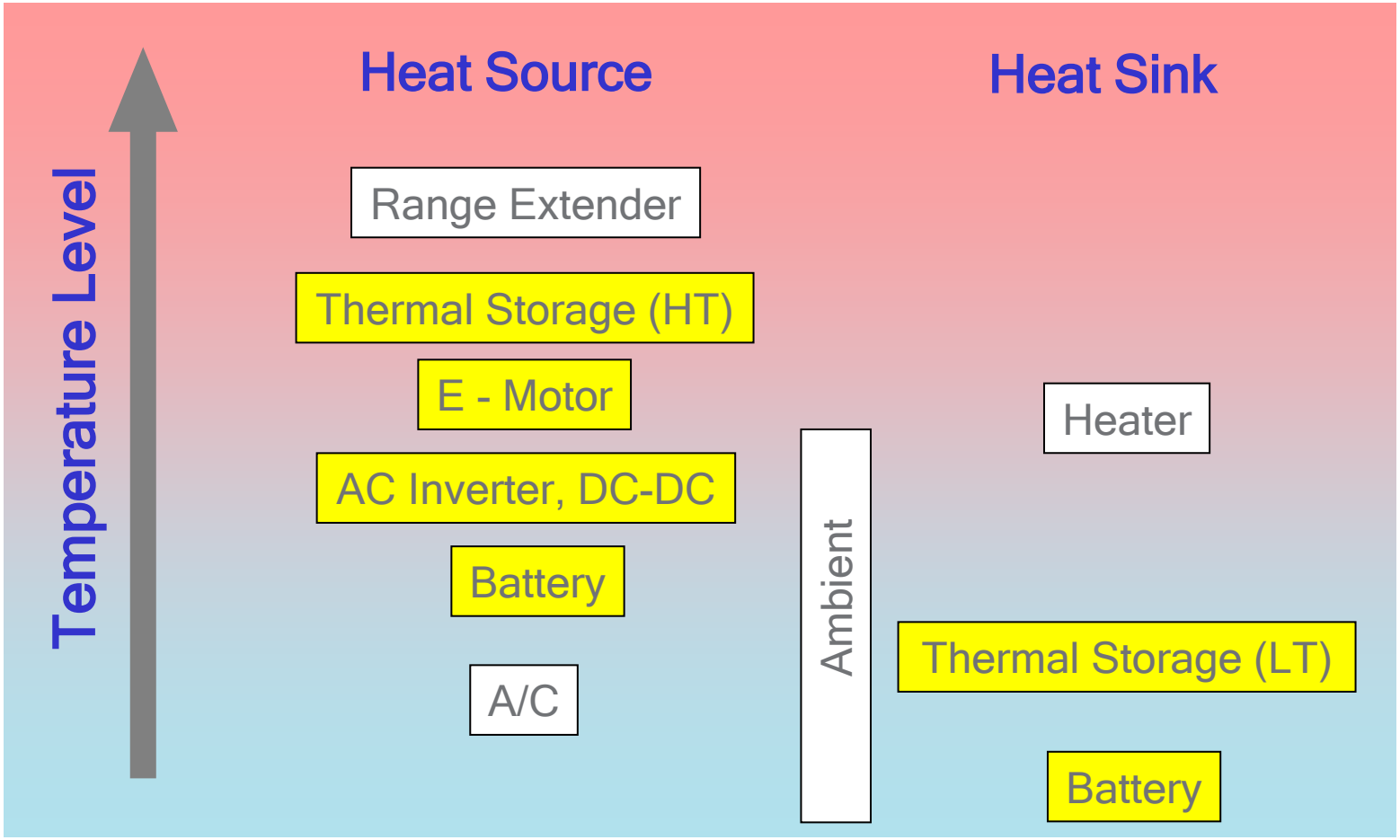
Temperature Levels

Combustion Engine

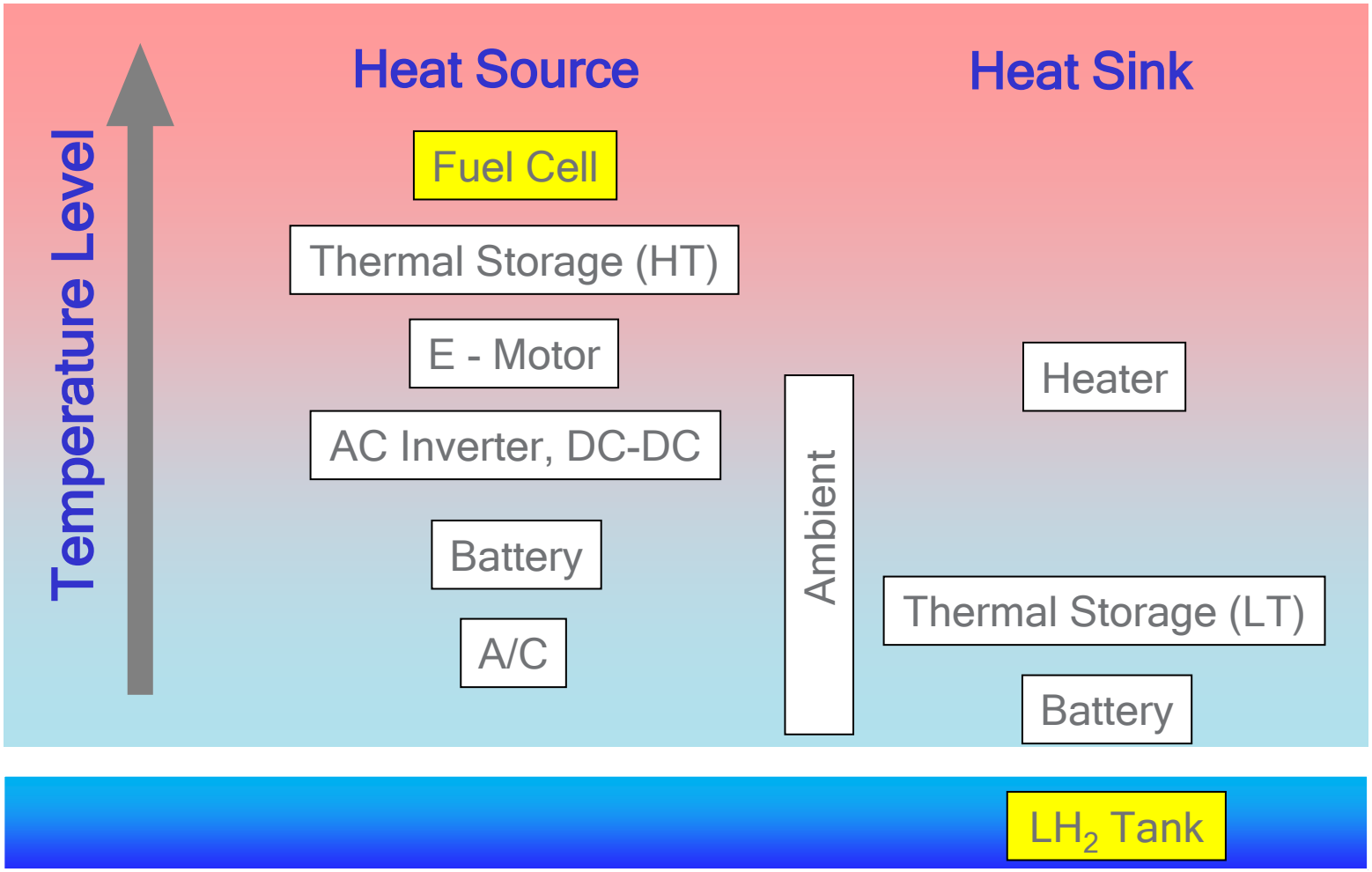


Temperature Levels

Electric Vehicle



Fuel Cell Electric Vehicle with LH_2 Tank



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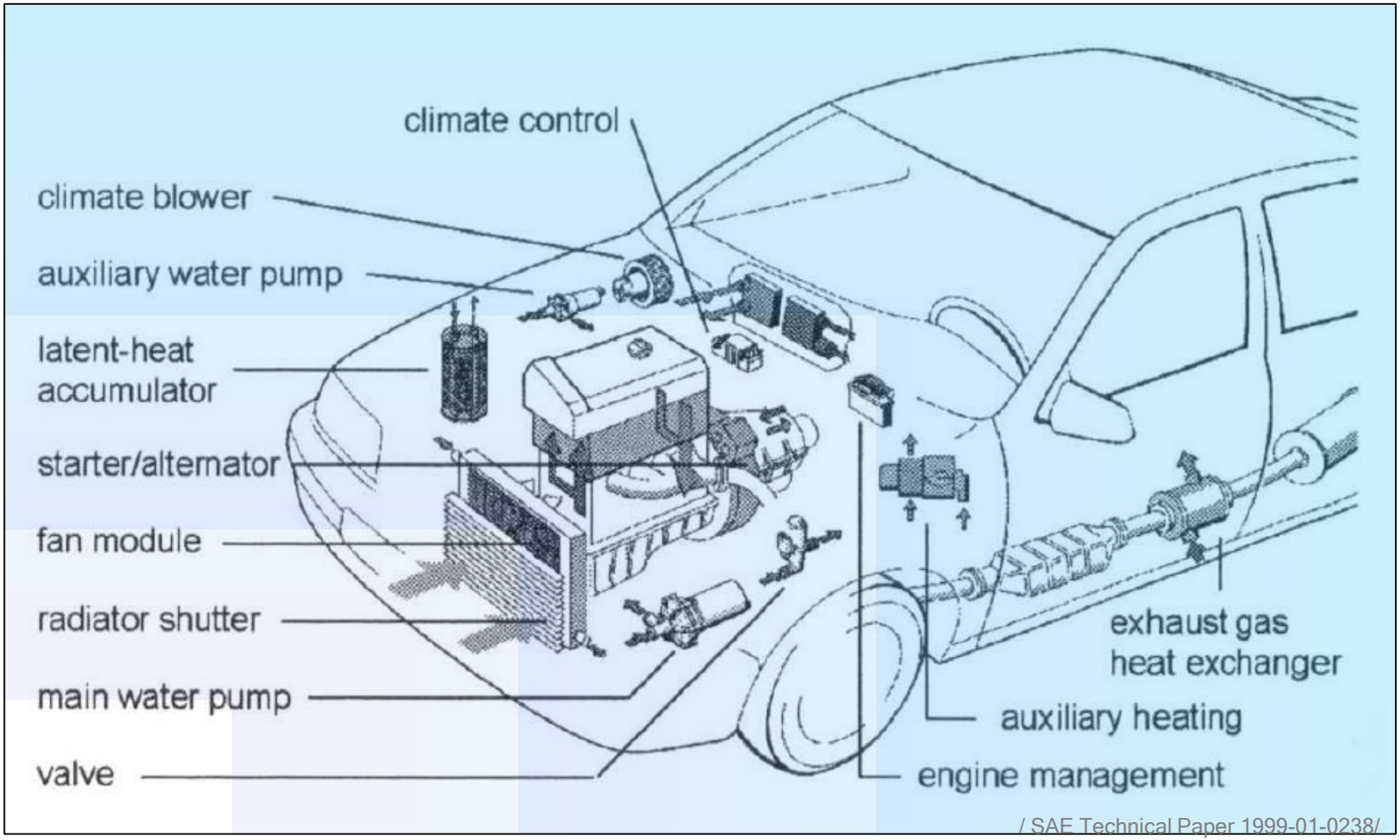
Combustion Engine
Vehicle Thermal Management

- **Automotive cooling systems**
  - designed for the highest necessary heat rejection
  - this operating state is reached only during 3-5% of operation
  - in most cases the thermal situation is subcritical
  - the engine is overcooled

- **A demand-responsive engine cooling system provides:**
  - 3 to 5 % reduced fuel consumption
  - increased passenger comfort .. faster heat-up
  - environmental compatibility .. reduced tail pipe emissions

- **specific components**
- **specific control strategies**
- **demand-responsive cooling system**

Components of a Thermal Management System - Overview



/ SAE Technical Paper 1999-01-0238/

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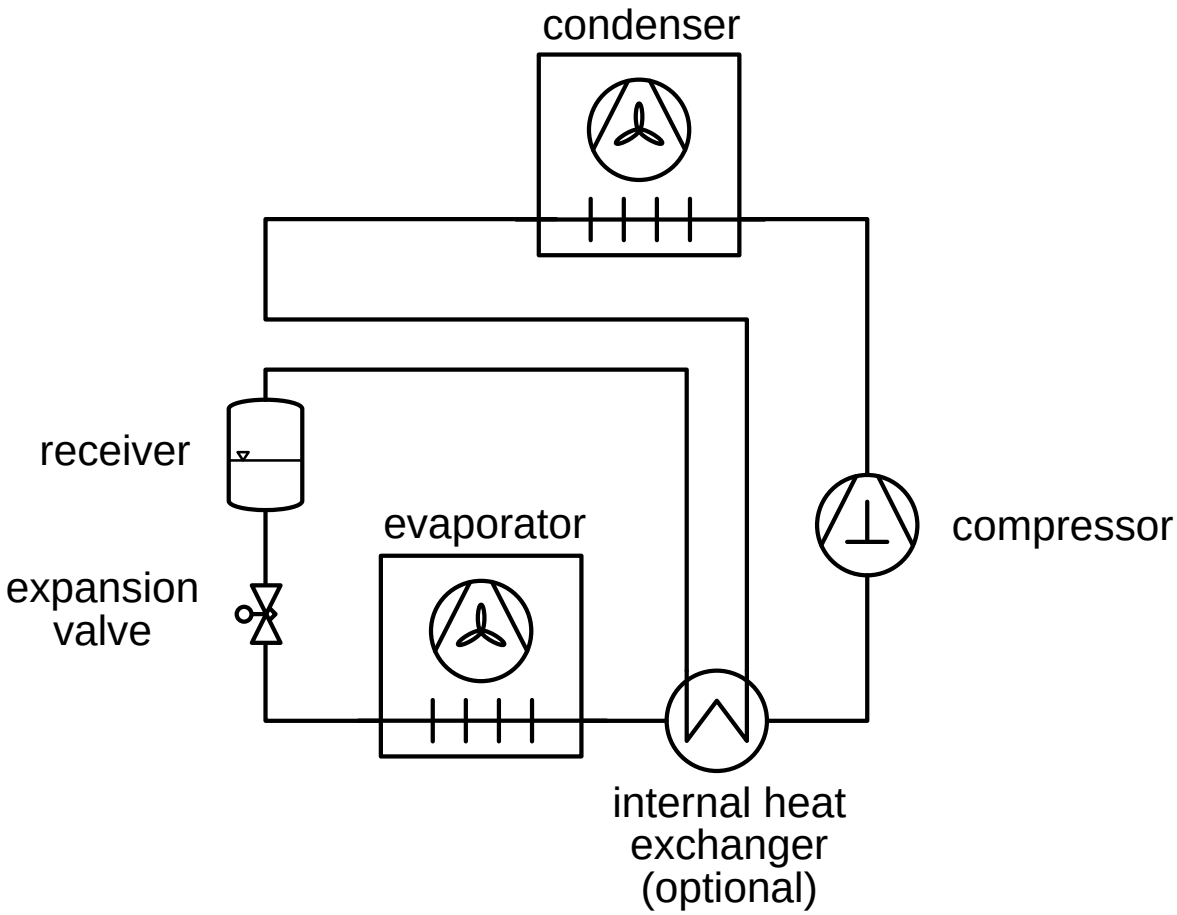
Automotive Air Conditioning

Air conditioning only

- Refrigerant: R134a
- HVAC Evaporator
- Frontend Condenser
- Belt driven compressor
  - variable capacity
  - fixed capacity

/Source: IPETRONIK/

/Source: Behr/

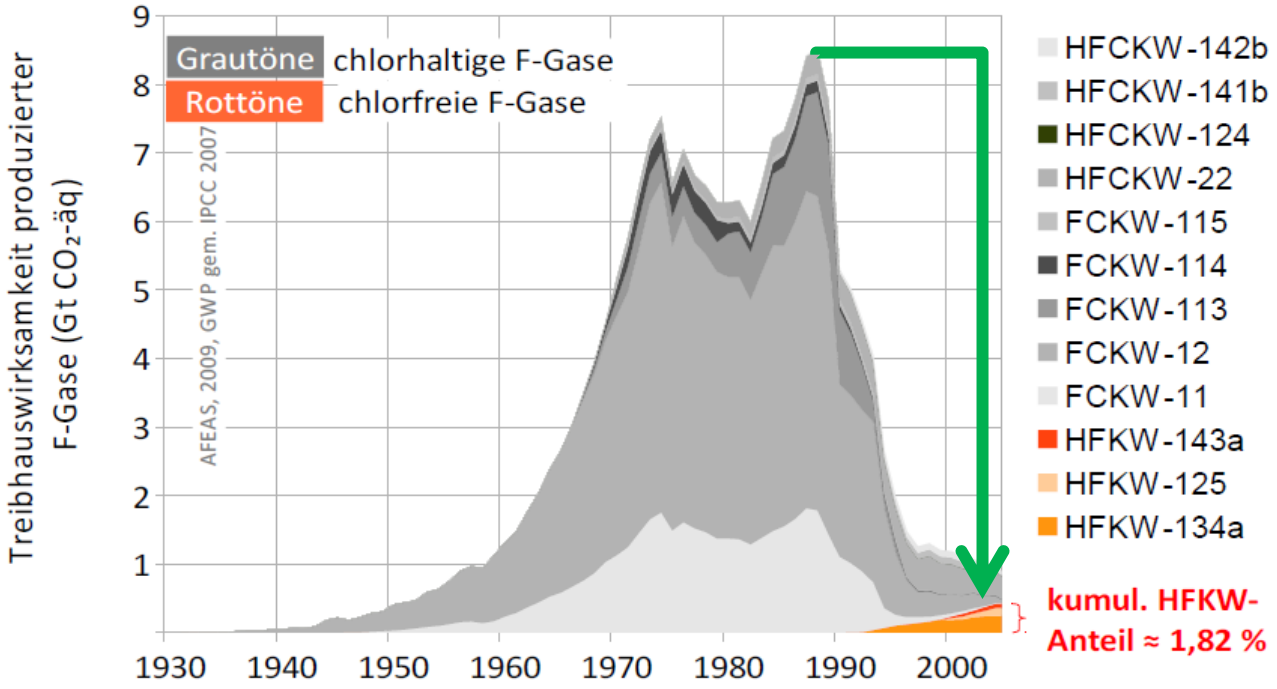


R134a system

Automotive Air Conditioning

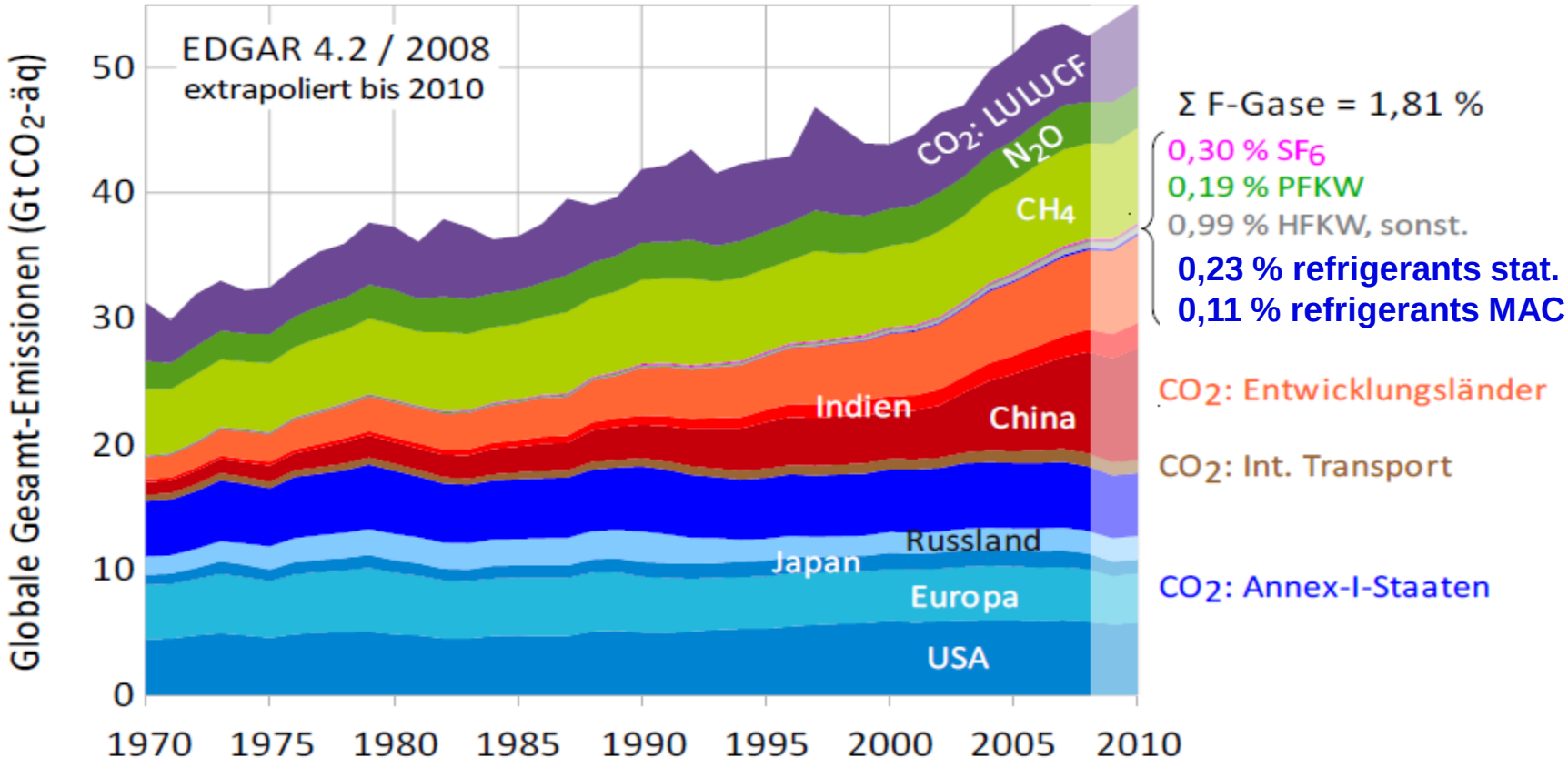
- **Passenger comfort**
- **Performance .. cool down**
- **Environment .. ozone depletion** ✓
- **Environment .. global warming** ●
- **Enhanced efficiency .. fuel consumption => credits**
- **Extended functionality .. heat pumping,**
  el. powertrain cooling
  (battery, inverter, DC/DC)

- **Refrigerants: Transition CFC-12 to HFC-134a**
  - Omission of ozone depletion
  - Significant reduction of **global warming effect**



F-gases: effect of globaly produced F-gases as Gt CO_2 equivalent (grey: CFC and HCFC, red: HFC)

Automotive Air Conditioning



- 0,11 % of total global greenhouse emissions are due to the HFC refrigerants used in mobile air conditioning (MAC)

DIRECTIVE 2006/40/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006

- 1 January 2011: no type-approval for vehicle fitted with an A/C system designed to contain fluorinated greenhouse gases with a GWP > 150

- 1 January 2017: new vehicles fitted with an air-conditioning system designed to contain fluorinated greenhouse gases with a GWP > 150:
  (a) certificates of conformity no longer considered
  (b) registration refused and sale & entry into service prohibited

GWP (global warming potential): R134a: 1430, R1234yf: 4, CO_2: 1 /IPCC/

Refrigerants:

- **HFO 1234yf**
  - Properties and behavior close to R134a
  - GWP: 4 /IPCC/ resp. <1 /Reviews of Geophysics; Volume 51, June 2013/
  - Serial vehicles already in the market

  - **Mildly flammable**
  - Ignition in presence of oil @ 600 .. 800 °C
  - Decomposition products include hydrogen fluoride (HF, LC50 = 966 ppm) and carbonyl fluoride (COF_2, LC50 = 360 ppm) /Graz, 2008/

  - R1234yf:
    ignition of refrigerant in a test car after a simulated accident with a refrigerant leakage
    (some do some do not ignite)

Refrigerants:

- **Natural refrigerants**
  - hydro carbons, e.g. propane (R290) GWP = 3
  - CO_2 (R744) GWP = 1

- **Propane:**
  - Similar pressure levels and components
  - Efficient refrigerant
  - Used already in not OEM approved „retrofit“
  - Highly flammable
    => Secondary fluid needed
    => Reduced efficiency

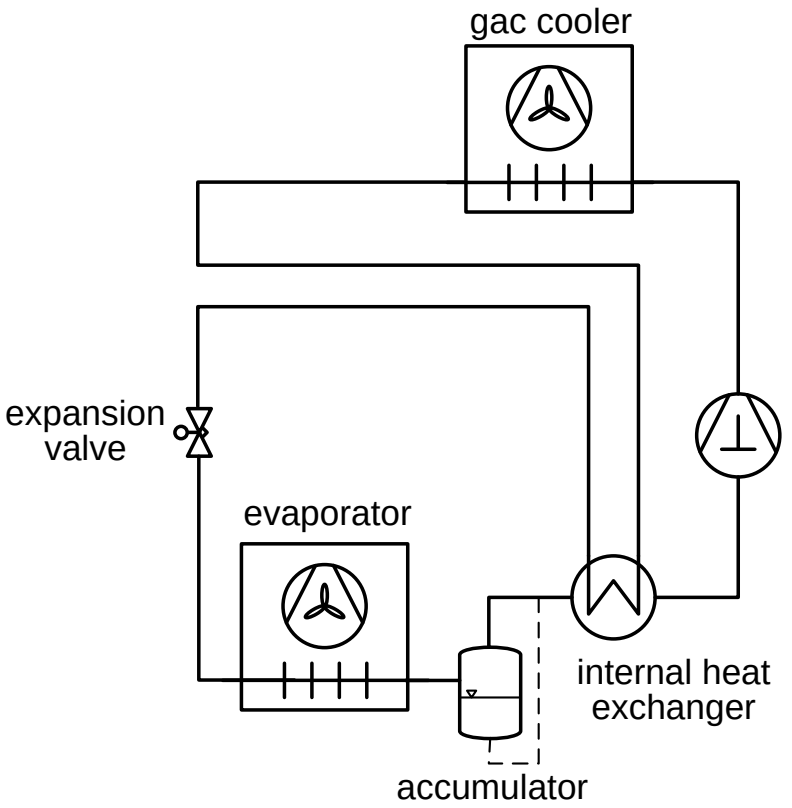
Refrigerants:

- **CO_2 (R744):**
  - Transcritical cycle
  - Pressure level 120 to 160 bar (25 to 32 bar with R134a)
  - All new components and control

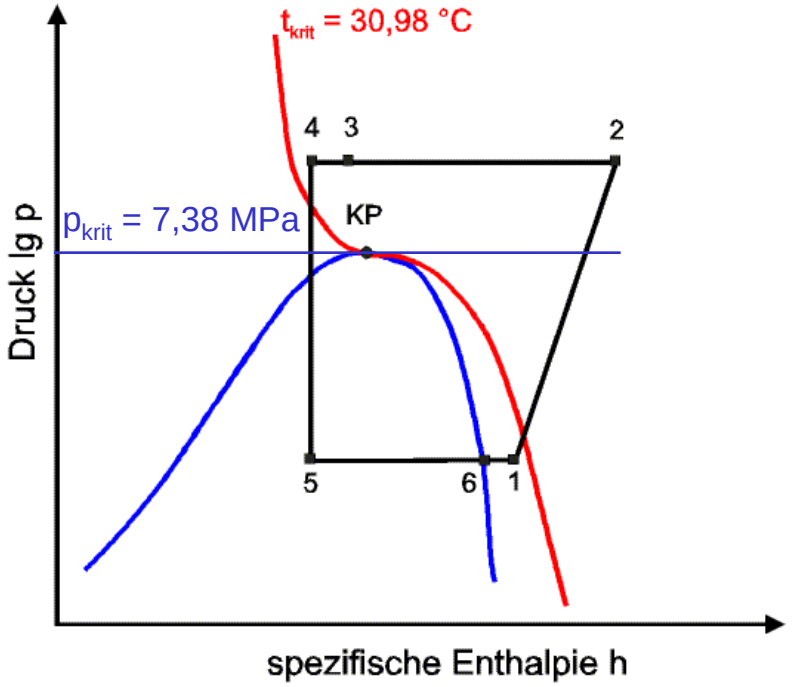
  - Also interesting for heat pump function

  - Higher efficiency than R134a at lower ambient temperature
  - Lower efficiency than R134a at high ambient temperature

  - Development of application for MAC had been terminated in 2005

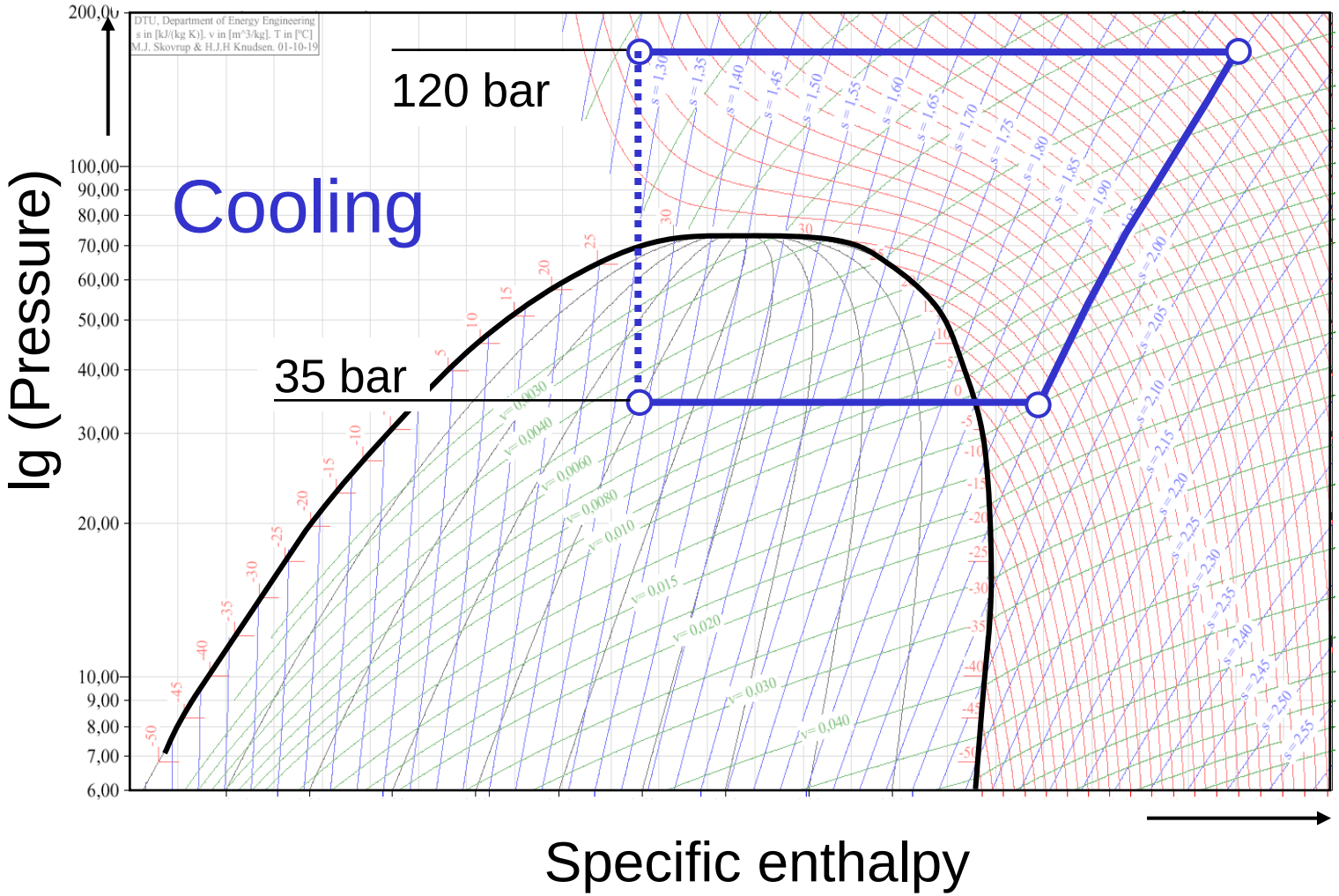


CO_2 system



transcritical process

Process with CO_2 (R744)



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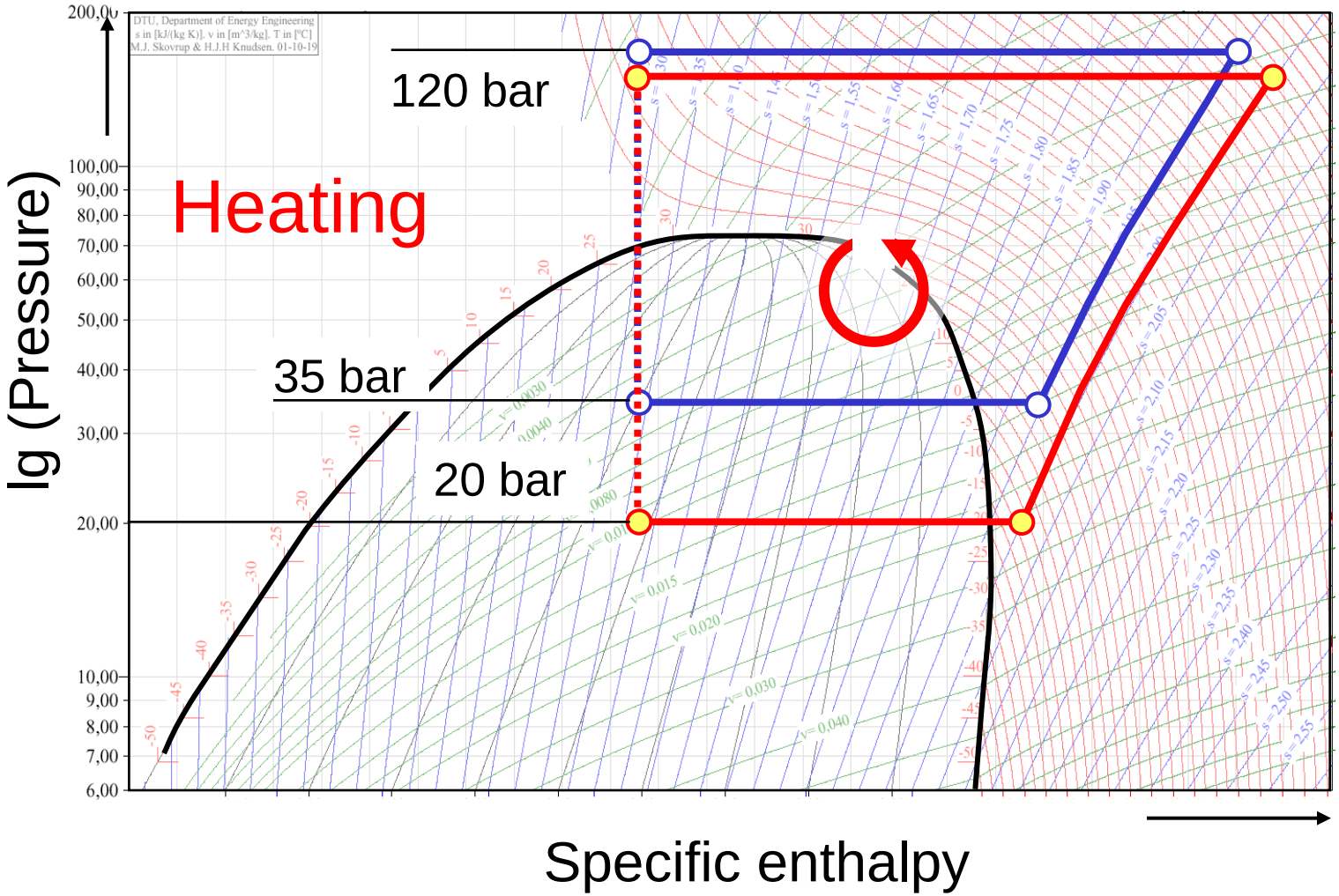
Process with CO_2 (R744)



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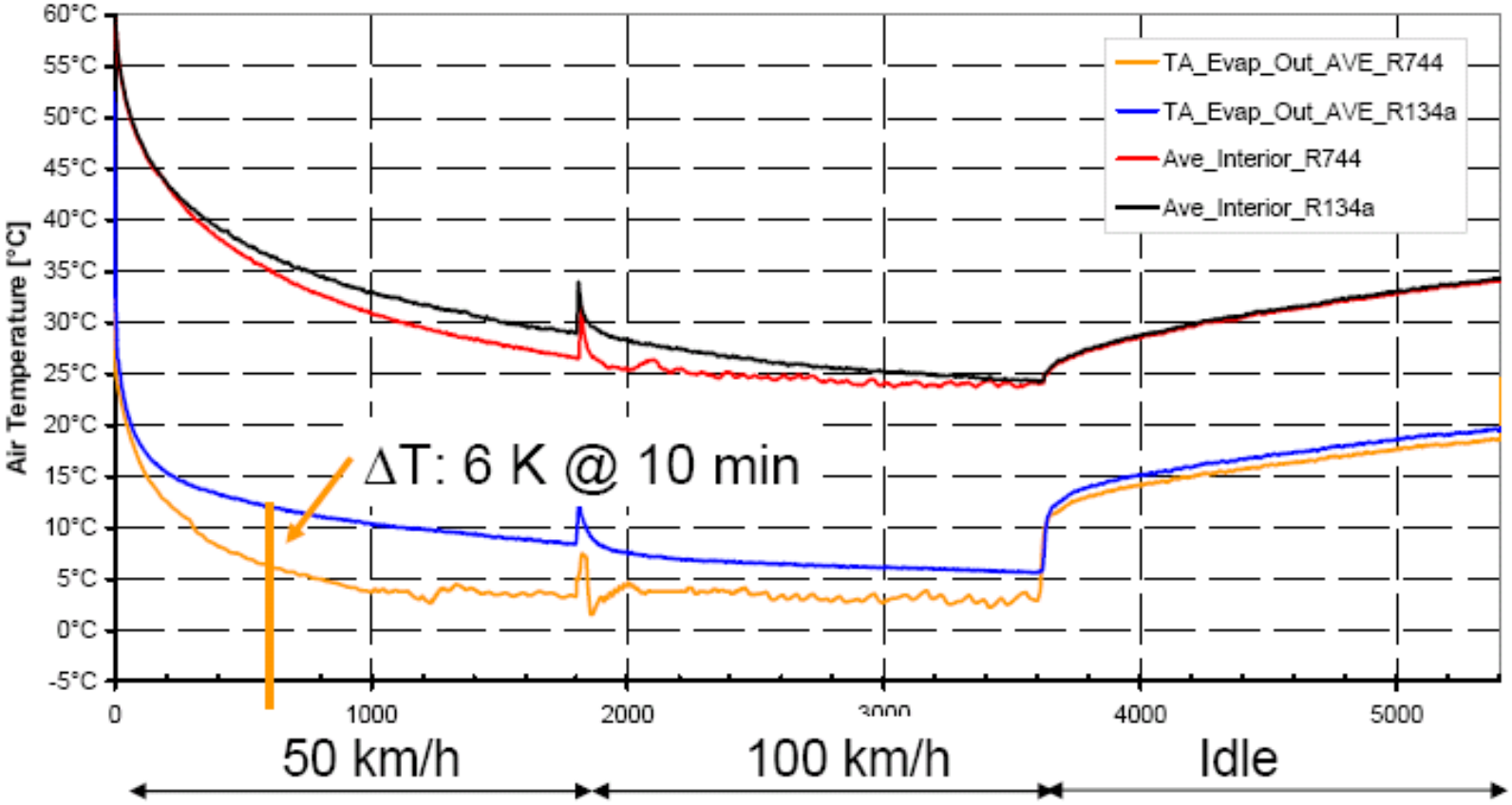
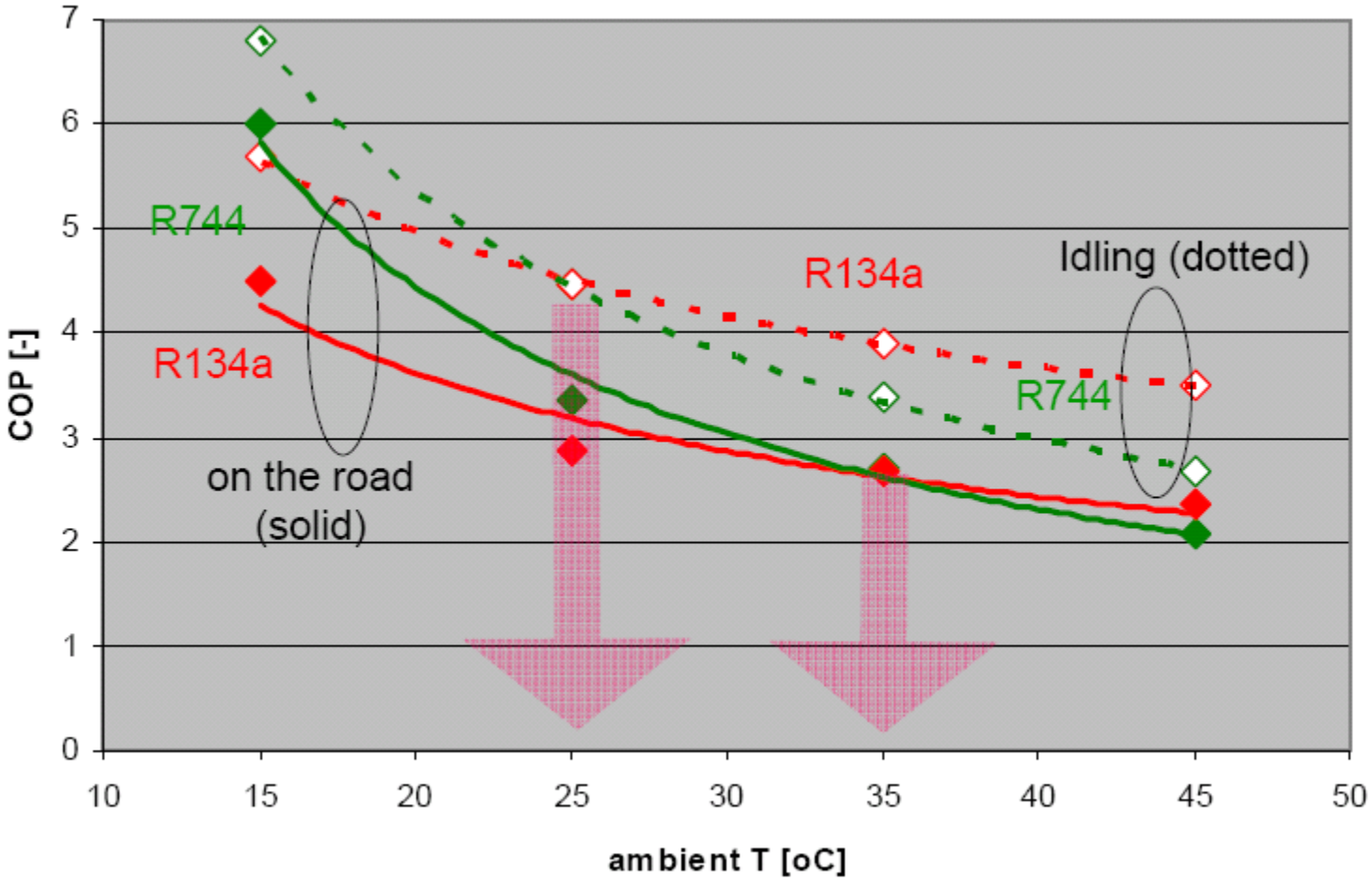
Cool Down Performance R744 / R134a

Ambient temp.: 43 °C, RH: 40 %, Sunload: 1000 W



/F. Wiescholek, Visteon, Small Cars with R744, VDA Wintermeeting, Saalfelden, 2007/

Efficiency R744 / R134a (SAE ARCRP 1)

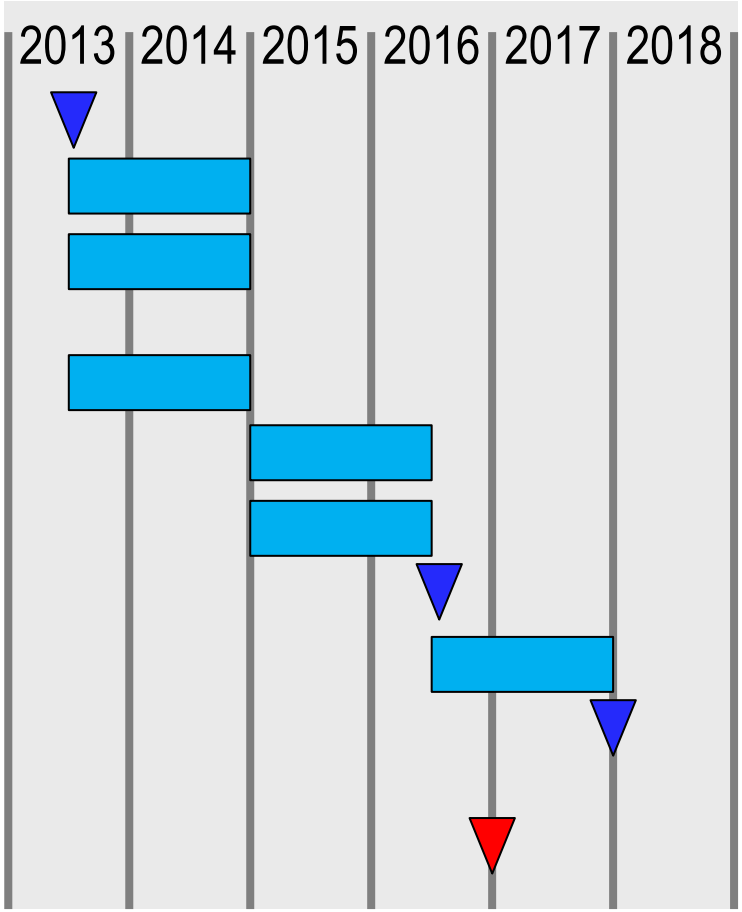


/Pedrag Hrnjak, VDA-Wintermeeting 2007/

CO_2 Time Schedule

An approach:

- Restart of development
- Building base of serial suppliers
- Enhance efficiency and NVH (competitive to current R134a)
- Development
- Serial project development
- Process and industrialization
- Of tool samples
- Full validation
- SOP
- DIRECTIVE 2006/40/EC: phase out of R134a in all new cars by 1 January 2017



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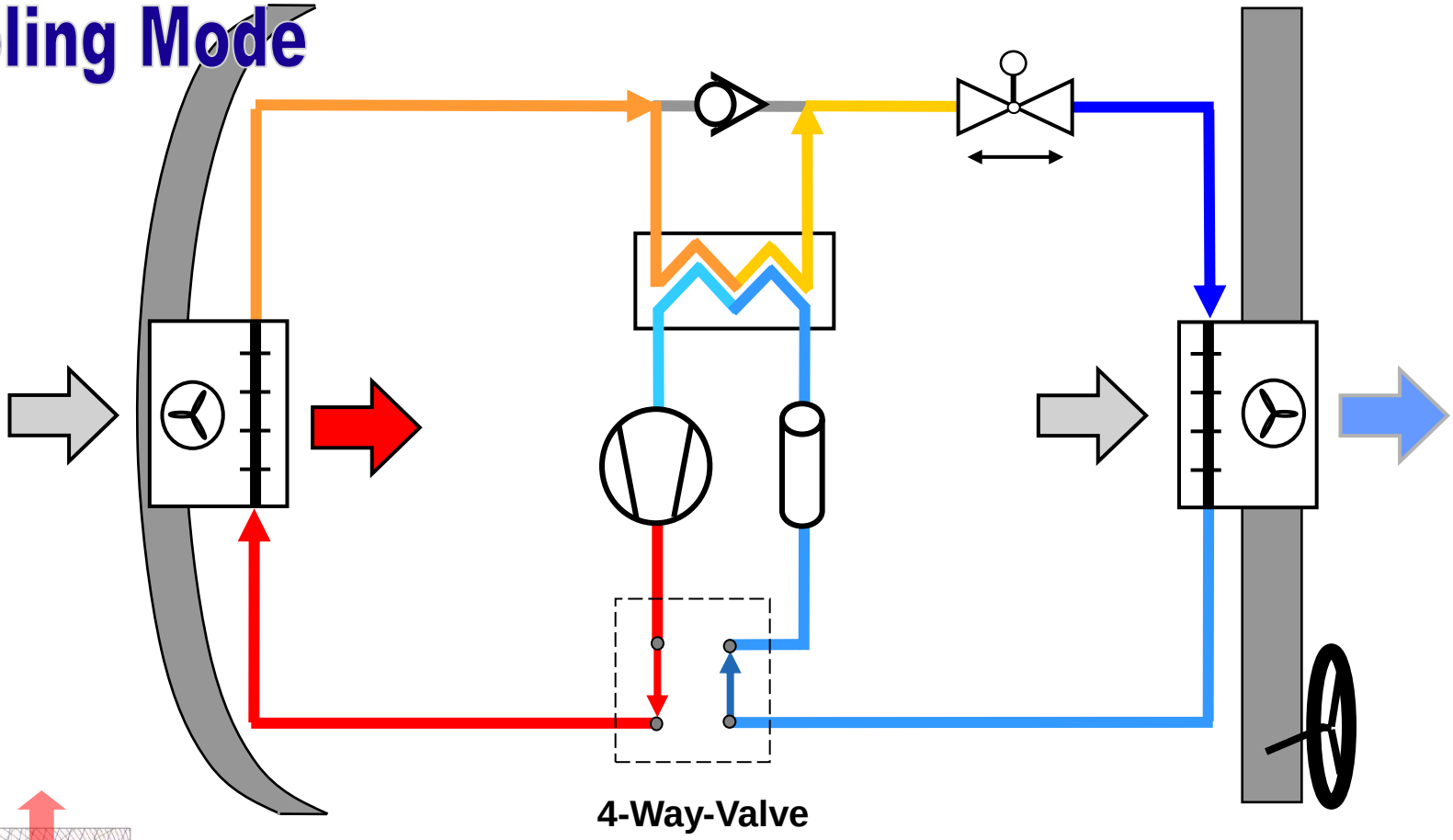
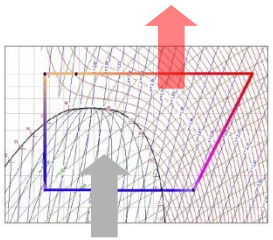
CO_2 Air / Air Heat Pump Cycle

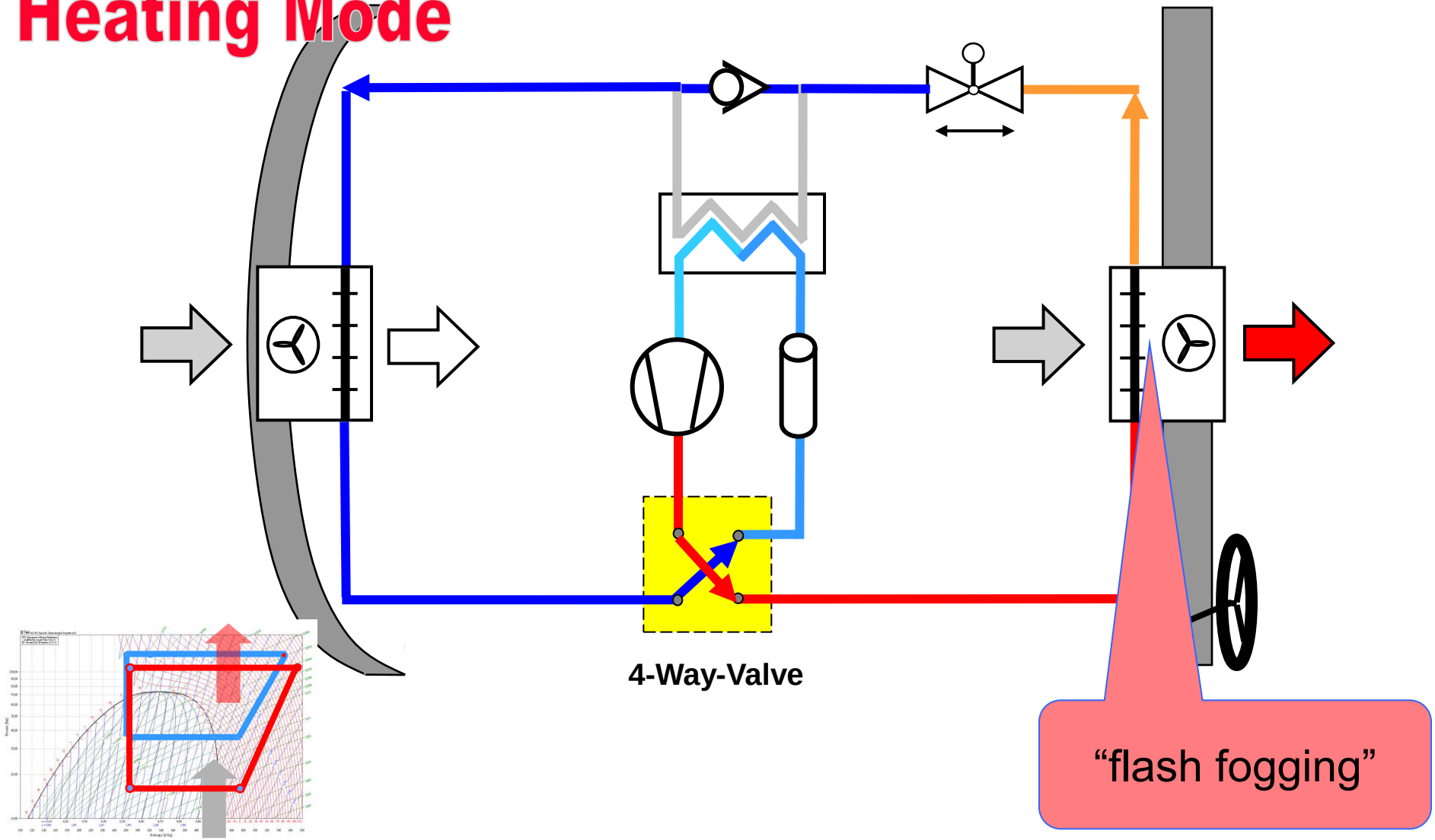
Cooling Mode





CO_2 Air / Air Heat Pump Cycle

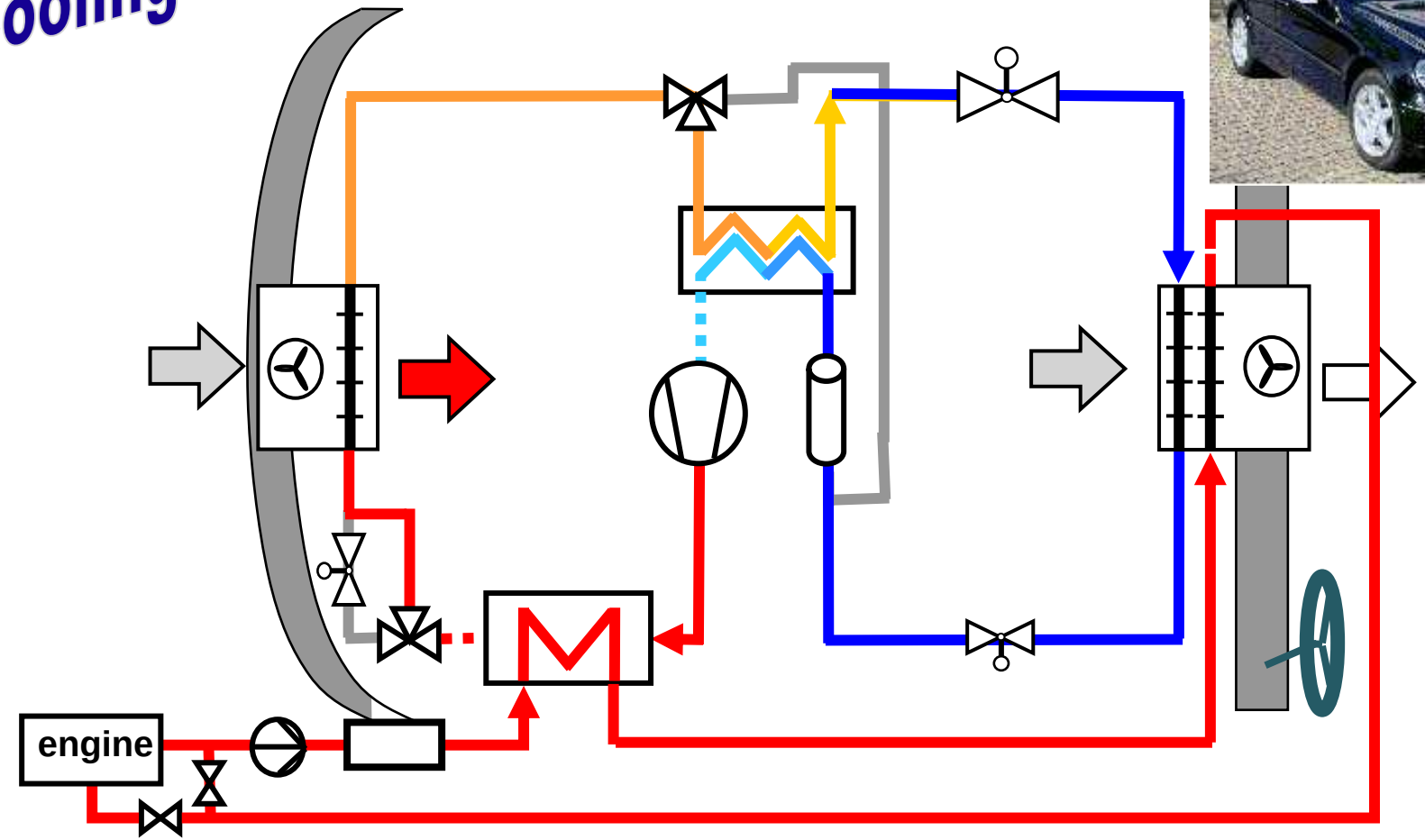
Heating Mode



Flash Fogging

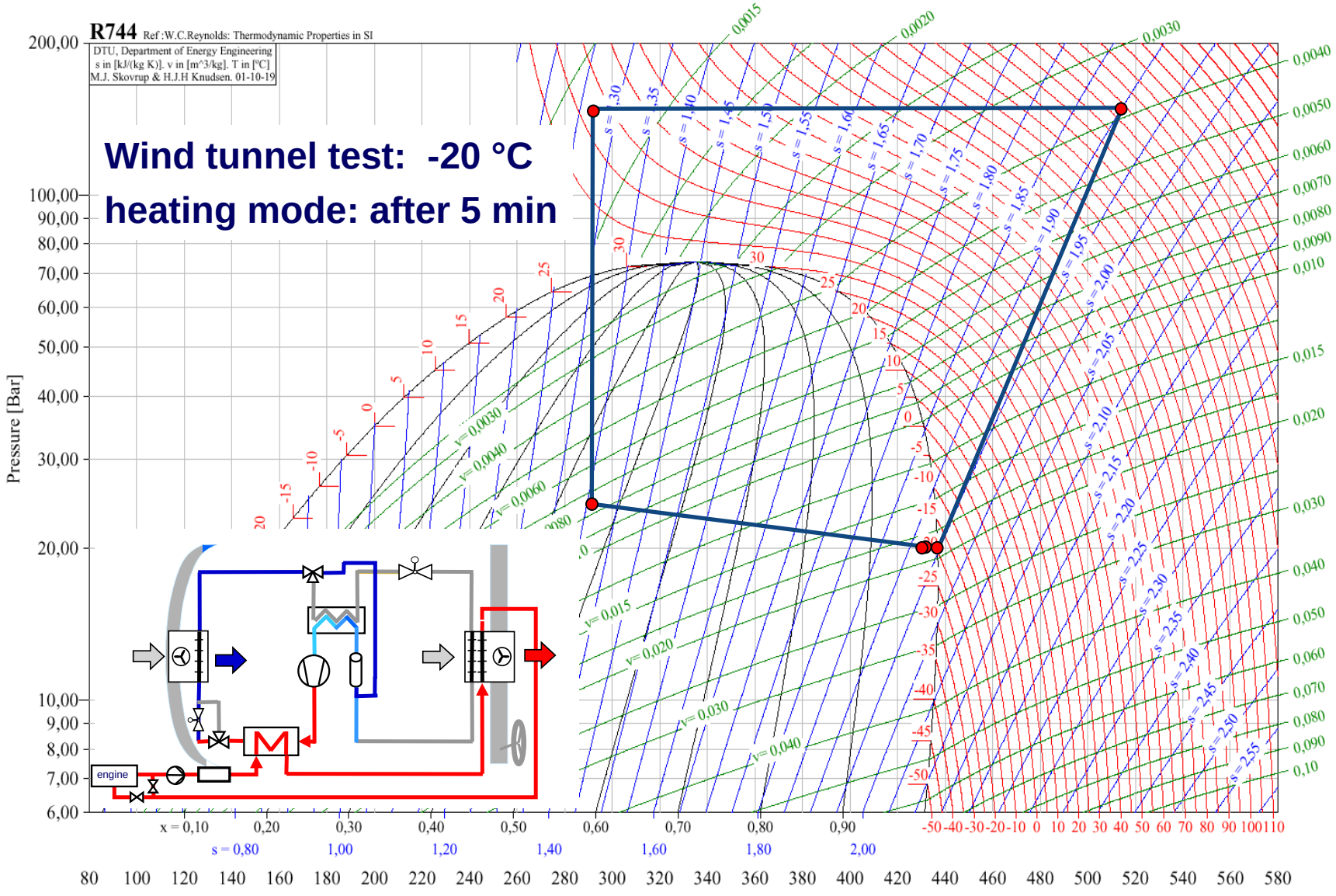
Limited Vision

Cooling Mode



/SAE Phoenix 2004/

Heating mode



Fuel Consumption

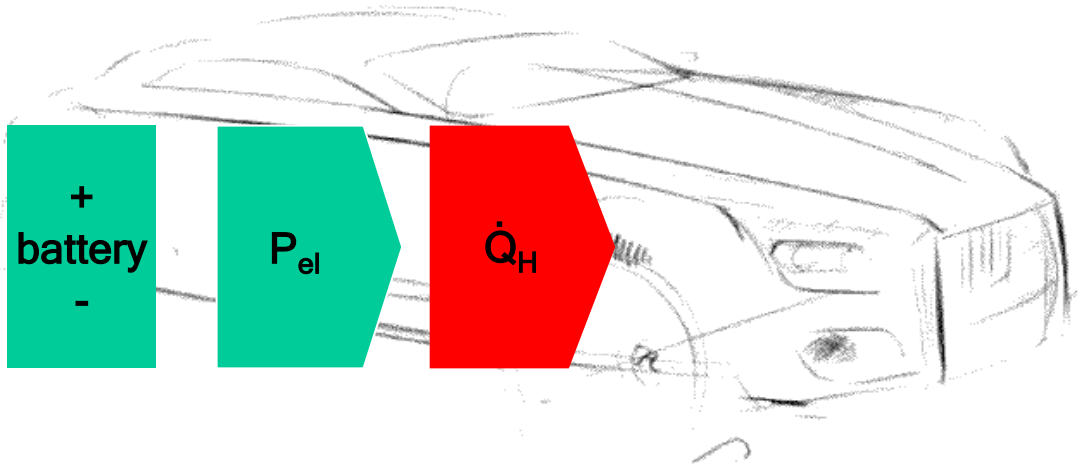
-20 °C, after 30 min., 50 km/h

effect on	head temp.	fuel consumption
el. heater	+ 4.2 K	+ 0,69 lt./100km
	+ 7.3 K	+ 1,21 lt. (100%)
heat pump	+ 7.3 K	+ 0,79 lt. (- 35%)


e-mobility
Italy
smart electric drive


MiEV

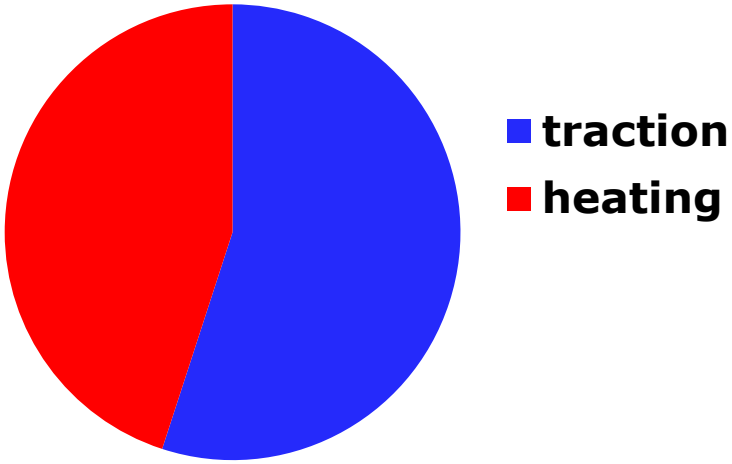
Heat Pump for electric Vehicle



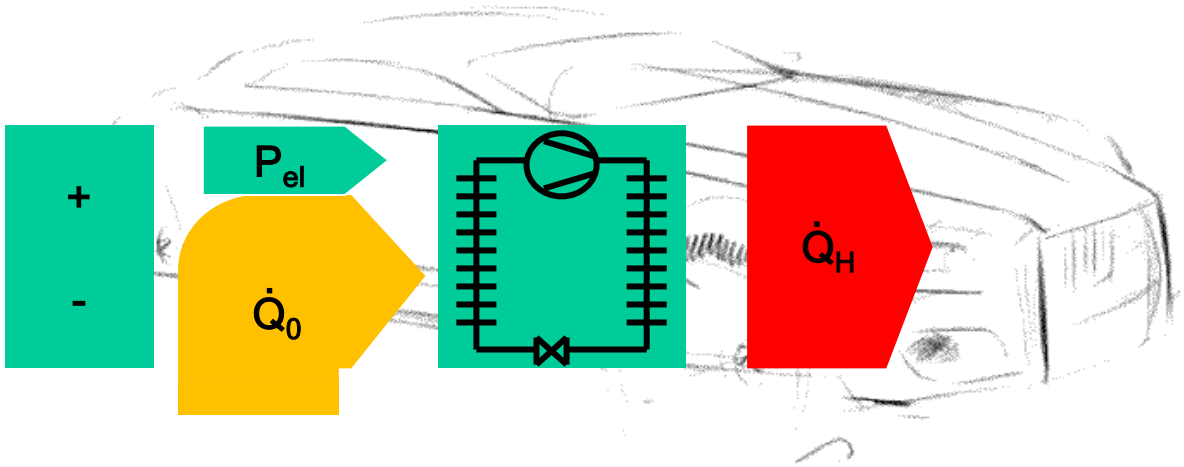
Assumption:

- Heating demand: 3 kW
- Distance: 180 km @ 60 km/h
- Energy Heating 9 kWh
- **45 % of a 20 kWh battery**

battery capacity



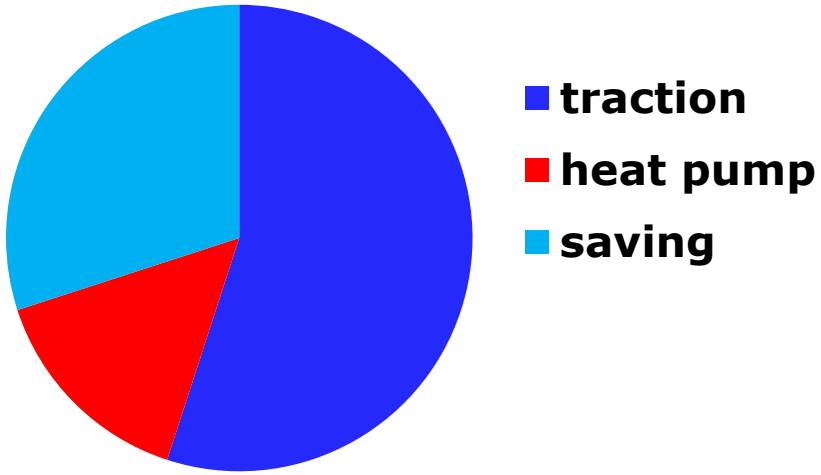
Heat Pump for electric Vehicle



Assumption:

- Heating demand: 3 kW
- Distance: 180 km @ 60 km/h
- Energy Heating 9 kWh
- Heat pump @ a COP of 3
- **15 % of a 20 kWh battery**

battery capacity



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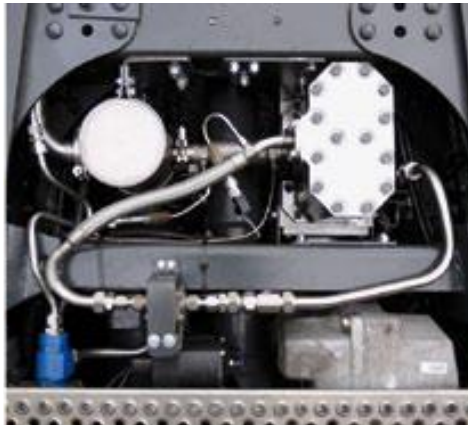
- **Waste heat of a combustion engine**
  - Development of components and system
    e.g.: turbo, piston or scroll expander
  - Conept:
    Rankin Cycle with natural working fluid
  - Savings:
    up to 5% fuel consumption (long distance truck)



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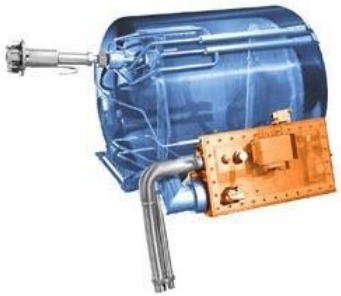
Hydrogen Storage

Compressed Gas	Cryo-compressed	Liquid	Solid storage
 Source: Dynetek	 Source: BMW	 Source: BMW	•Physisorption •Metal hydrides •Complex hydrides •Chemical hydrides
1 kg - 6 kg one or more pressure vessels	**4 kg - 12 kg insulated cryogenic pressure vessel**	**7 kg - 12 kg insulated cryo-vessel**	

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Summary

- **Management of different heat sources and heat sinks**
- **at different temperature levels**
  - **From 22 K (LH_2)**
  - **Around ambient temperature**
  - **Up to 800 K (exhaust gas)**
- **for powertrain component thermal management and climate control**
  - **Conventional and electric powertrain**
  - **Sustainable A/C and heat pump refrigerants**
- **Benefit**
  - **Efficiency**
  - **Function and durability**
  - **Passenger comfort and safety**

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