



Chances and Limitations of a Hybrid Refrigerant System for Vehicle Air Conditioning

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Content

- Introduction and Background
- Technical Solutions and draw backs
- Concept
- Flammability
- Components
- Efficiency
- Summery

- This is not about a hybrid vehicle
- It is about a system using a hybrid refrigerant option

- **DIRECTIVE 2006/40/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006**
 - January 1st, 2011: no type-approval for vehicle fitted with an A/C system designed to contain fluorinated greenhouse gases with a GWP > 150
 - January 1st, 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

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HFO-1234yf:

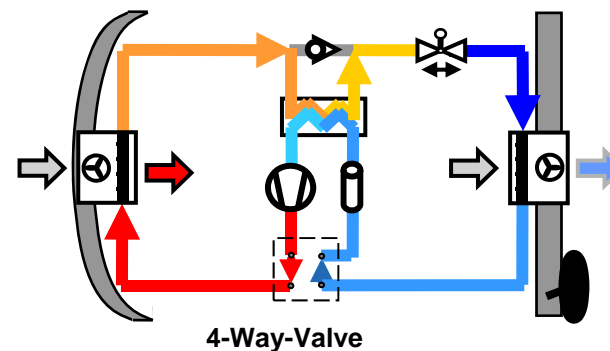
- Mildly flammable
- Developed as #1 alternative solution
- About 100.000 cars in the field in Germany
- Test: "Unexpected fire occurred"
 - Ignition in presence of oil
@ 600 .. 800 °C
 - Decomposition products include:
hydrogen fluoride (HF, LC50 = 966 ppm) and
carbonyl fluoride (COF₂, LC50 = 360 ppm) /Graz, 2008/



- HFO-1234yf not considered safe enough by certain OEM

R744:

- Non flammable
- Natural refrigerant
- Limited safety concerns
- High capacity also in heat pump mode
- Rather far developed and tested until about 2005

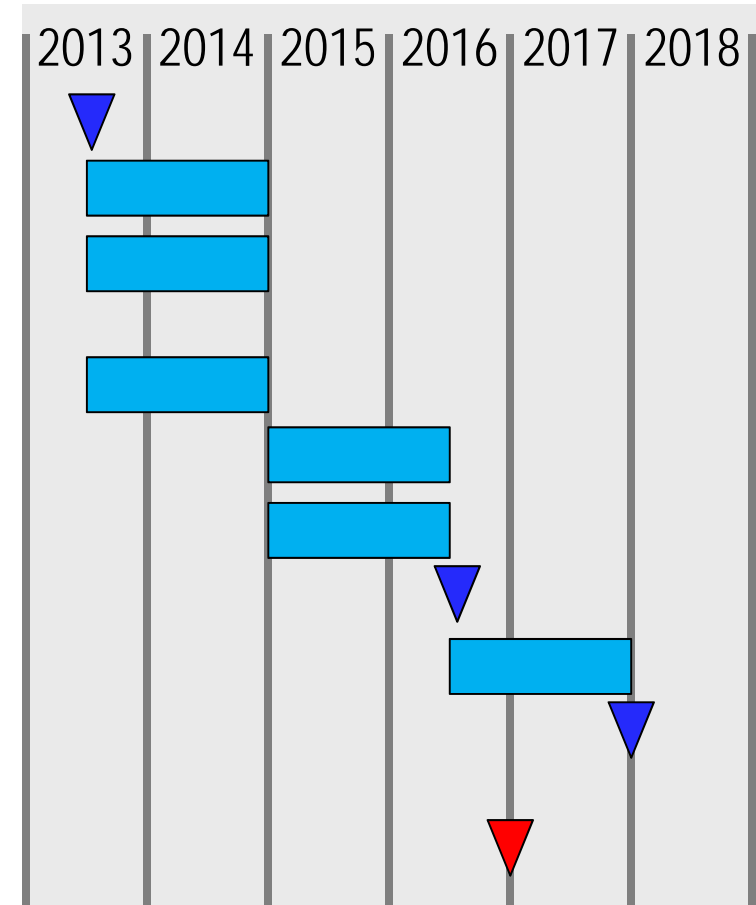


/SAE Phoenix Symposium 2004/

- Key question:
Time schedule sufficient for a sound design?

An approach for MAC:

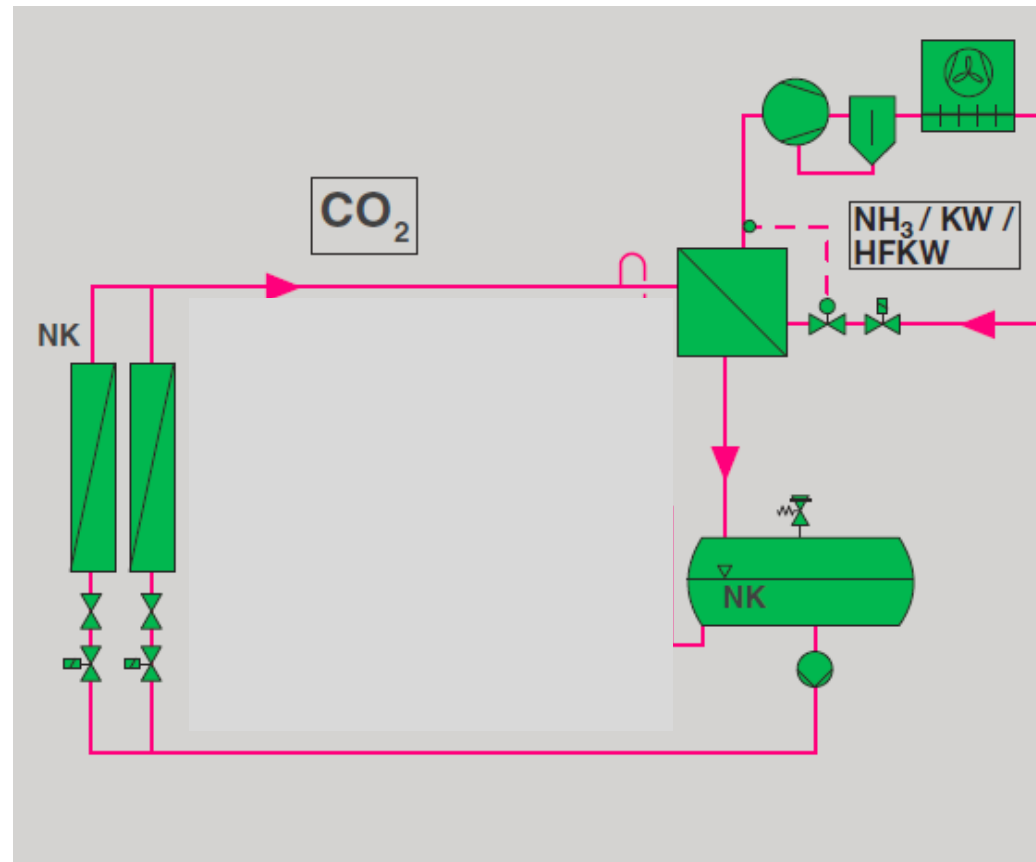
- Restart of development
- Building base of serial suppliers
- Enhance efficiency and NVH (competitive to current R134a)
- Development
- Serial project development
- Process and industrialization
- Of tool samples
- Full validation
- SOP and begin of ramp-up
- DIRECTIVE 2006/40/EC:
phase out of R134a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



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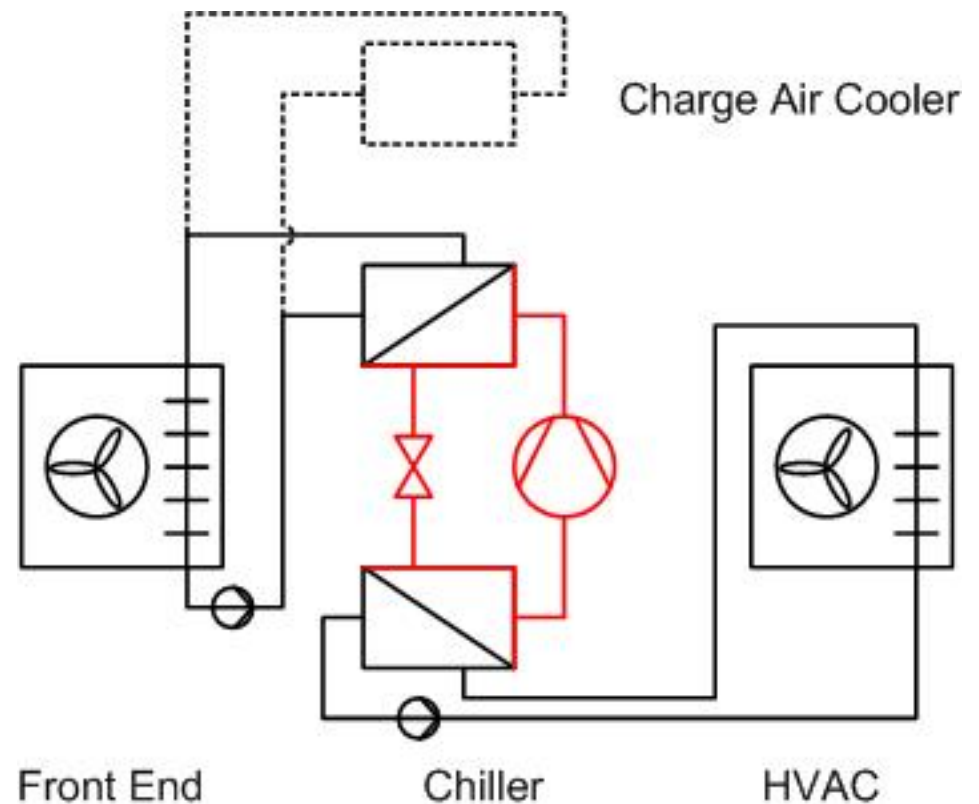
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- Time schedule for R744 is “tight”
- Development, industrialization and validation
 - HX: appears possible based on 2005 technology
 - Expansion device, lines, pipes fittings and secondary components: appears possible
 - Compressor: biggest risk
- Good enough reason to search for other options
- Preferred option:
 - Guiding the way into a sustainable future refrigerant



R744 as secondary refrigerant and cascade system (Bitzer 2010)

- Flammable refrigerant -
- Water cooled condenser (current trend with downsized engines)
- R744 as secondary refrigerant with phase change



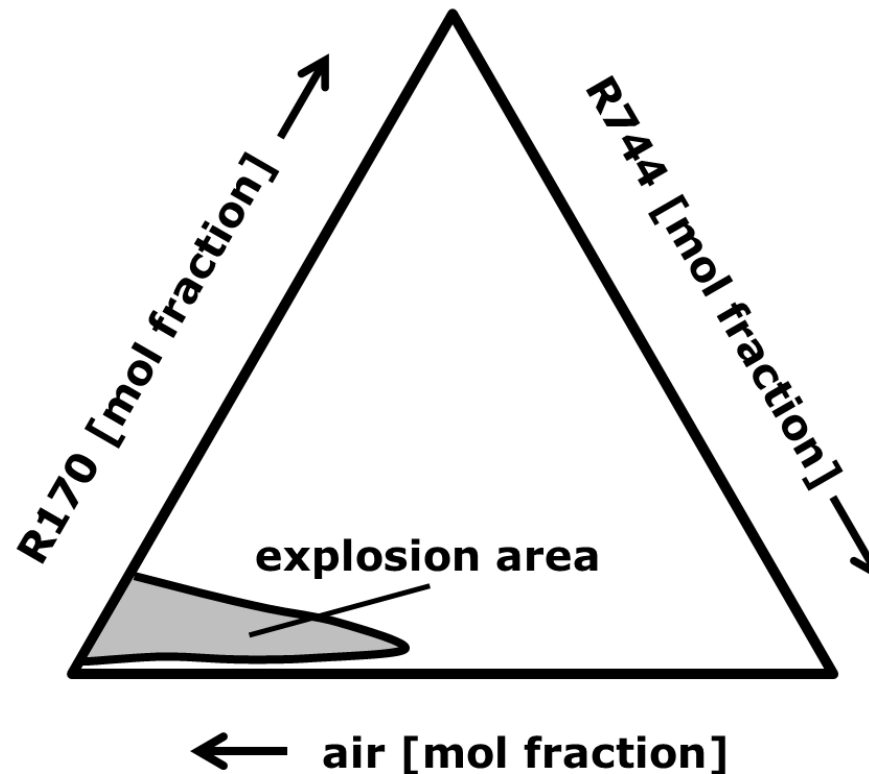
- Primary refrigerant:
 - Flammable fluid: HFO-1234yf, R290 or R436
 - Low charge
- Secondary refrigerant for HVAC:
 - R744 as secondary refrigerant with phase change
 - Close to R744 vapor compression
 - Small pump and good heat transfer
- Fire extinguisher:
 - Secondary task for R744 - Release of primary and secondary refrigerant together when risk is detected
 - e.g. air bag signal
 - release of non-flammable mixture

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Explosion limits of flammable refrigerants with R744

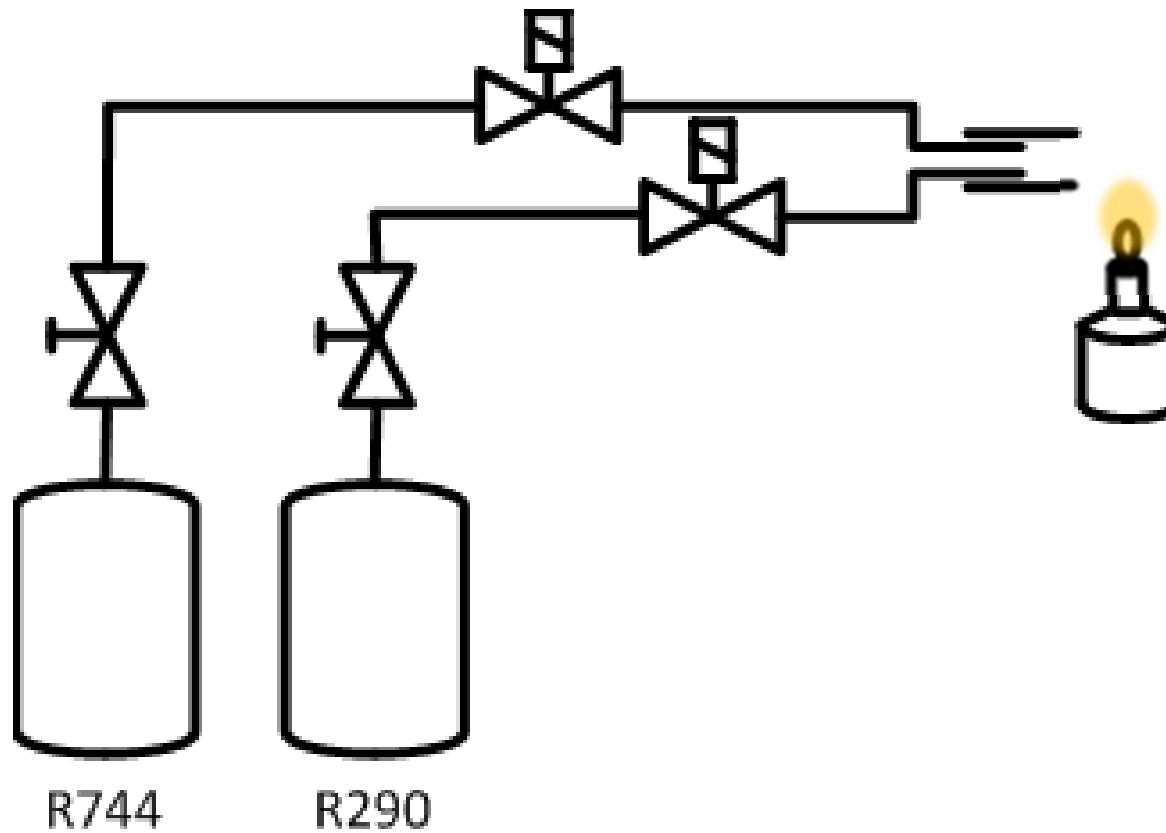
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Explosion limits of the system R170, R744 and air

Data from:

/Zabetakis, Michael G. (1965). *Flammability characteristics of combustible gases and vapors (Buletin 627)*. US Bureau of Mines, Wash., D.C. p. 129/



Demonstrator for suppressed flammability

Demonstrator results:

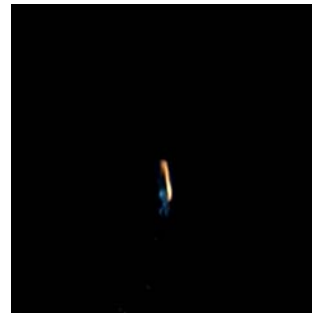
a) ignition source only



b) R290 blow-out



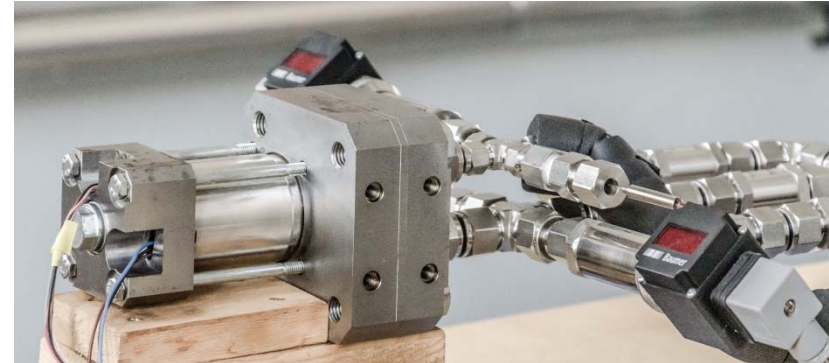
c) R744/R290 blow-out



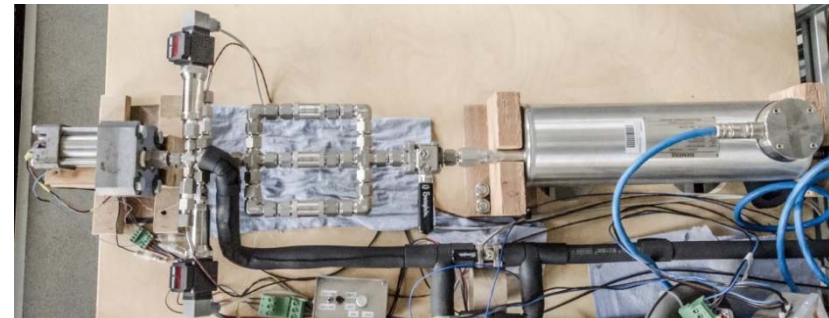
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- R744 pump
(developed for a non-MAC application)



- R744 pump test loop



- R744 state at evaporator inlet: saturated liquid
- Faster development than compressor

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R744 secondary refrigerant loop

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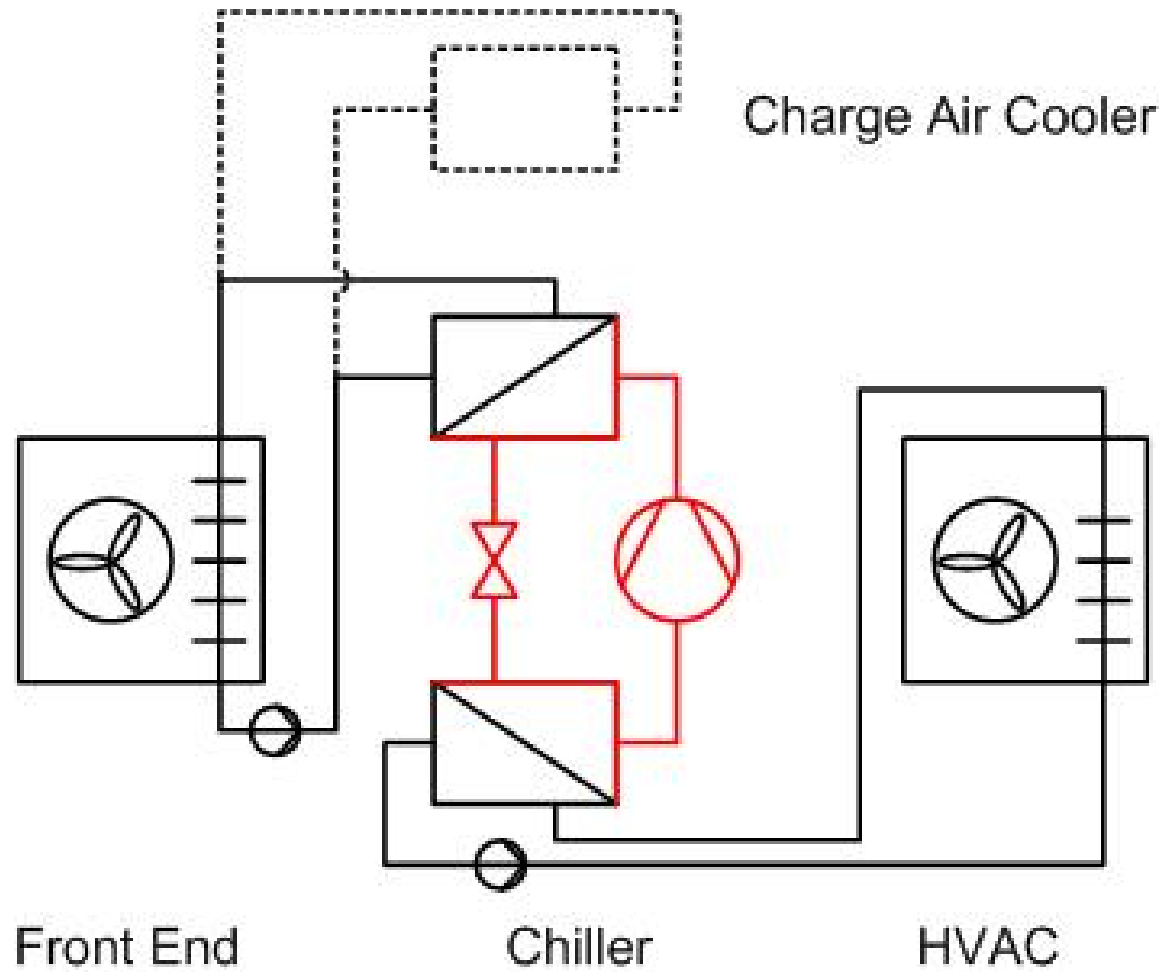
refrigerant	R1234yf	R1234yf	R1234yf	R290
concept	direct	indirect	indirect	indirect
		warm side: water/glycol (temp. diff. 10K)		
		cold side: water glycol (temp. diff. 10K)	cold side: R744 (temp. diff. 5K)	
cooling capacity	5 kW	5 kW	5 kW	5 kW
suction line pressure drop	0,05 MPa	-	-	-
evaporation temp.	0 °C	-10 °C	-5 °C	-5 °C
condensation temp.	50 °C	60 °C	60 °C	60 °C
superheat	5 K	5 K	5 K	5 K
subcooling	5 K	5 K	5 K	5 K
suction line superheat	10 K	0 K	0 K	0 K
compr. efficiency	0,7	0,7	0,7	0,7
COP	2,34	1,62	1,85	1,99
volumetric cooling capacity	1420 kJ/m³	1026 kJ/m ³	1268 kJ/m ³	1962 kJ/m ³
pressure drop sec. Loop	-	0,2 MPa	0,2 MPa	0,2 MPa
power secondary loop	-	300 W	160 W	160 W
COP total	2,34	1,48	1,75	1,87

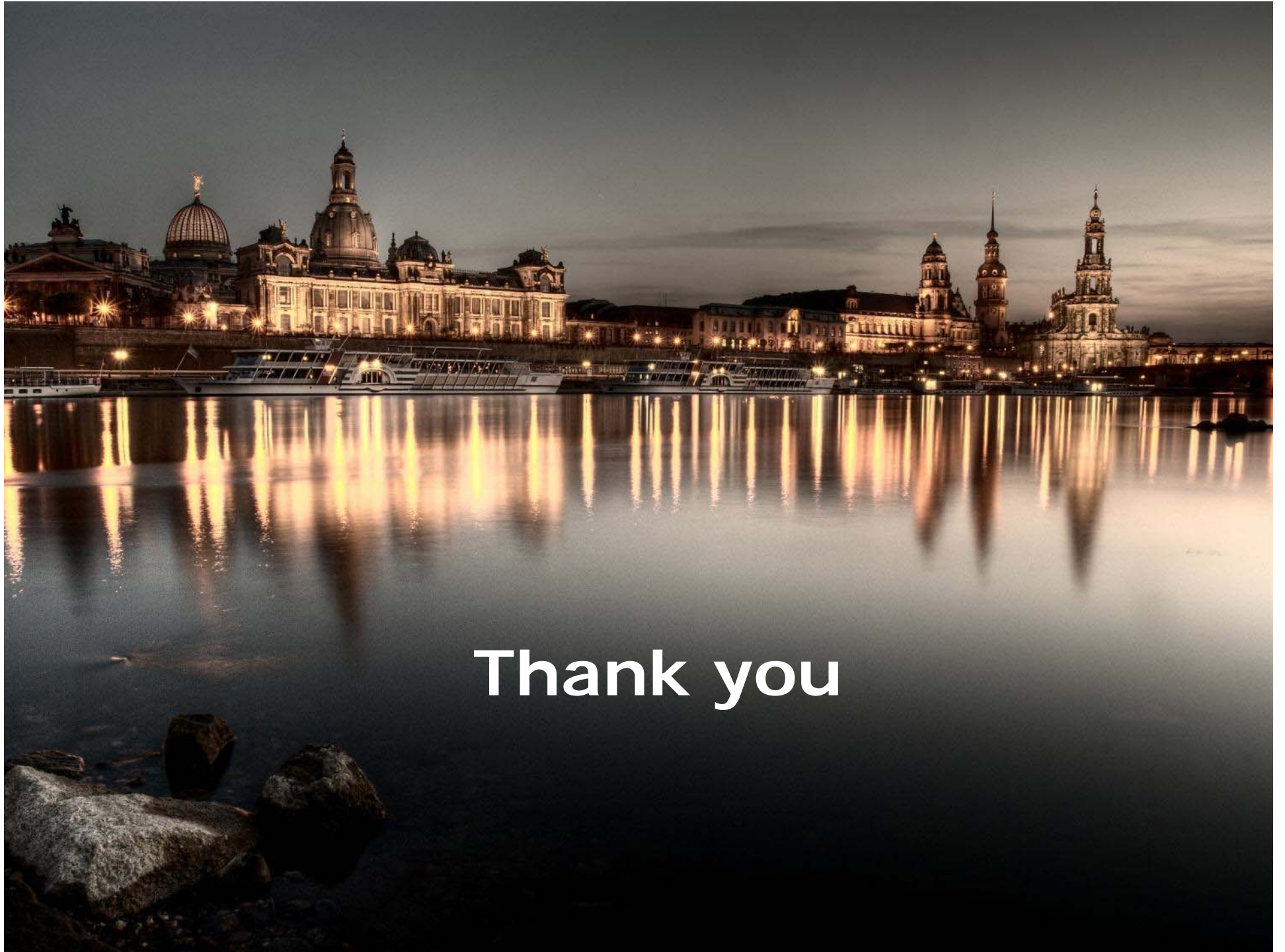
Comparison of secondary refrigerant options with a baseline system

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- No new vehicles with R134a as of Jan. 1st 2017
 - HFO 1234yf: flammability concerns
 - R744: time to market
- Concept: R744 as secondary refrigerant
 - R744 can suppress flammability even with R290
 - Development of R744 as secondary refrigerant is faster than R744 compressor development
 - Experiences from other applications exist
- Thus option to overcome time restriction and flammability issue
- On the way to a R744 vapor compression system





Thank you