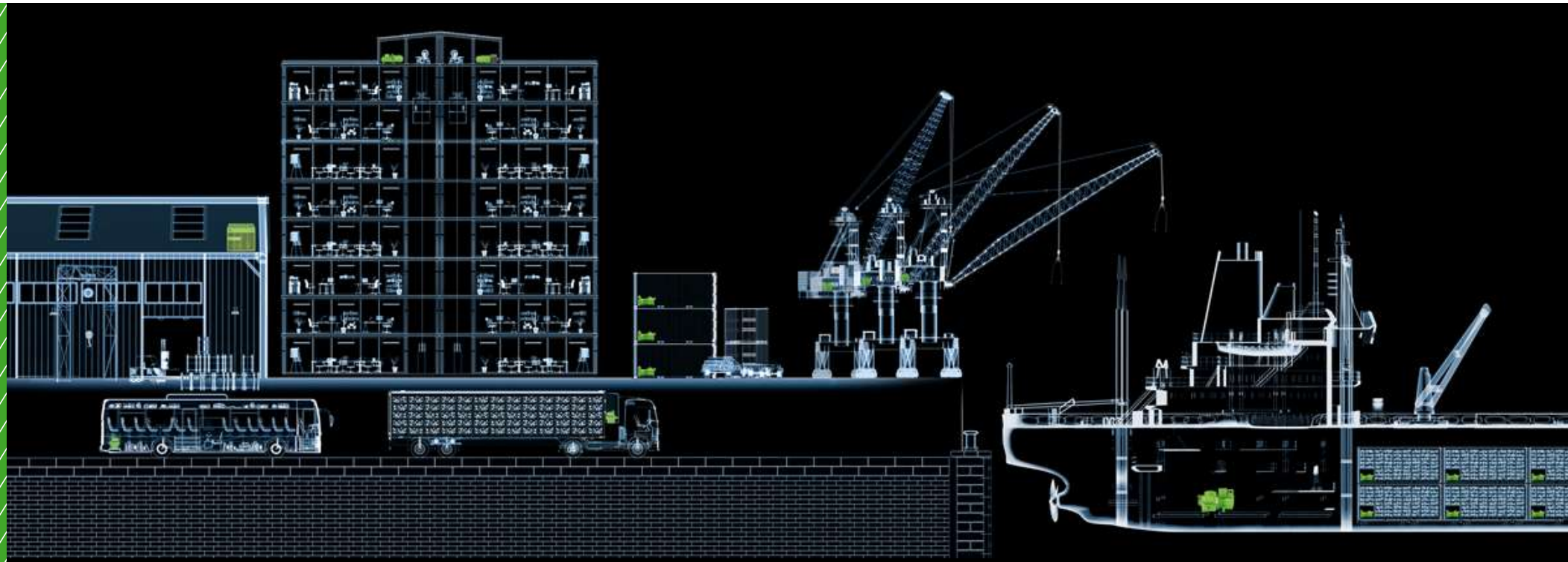

HIGH EFFICIENCY CARBON DIOXIDE COMPRESSOR AND SYSTEM

Shanghai, 04.2021

Wang Yi

Bitzer

DAS HERZ DER FRISCHE

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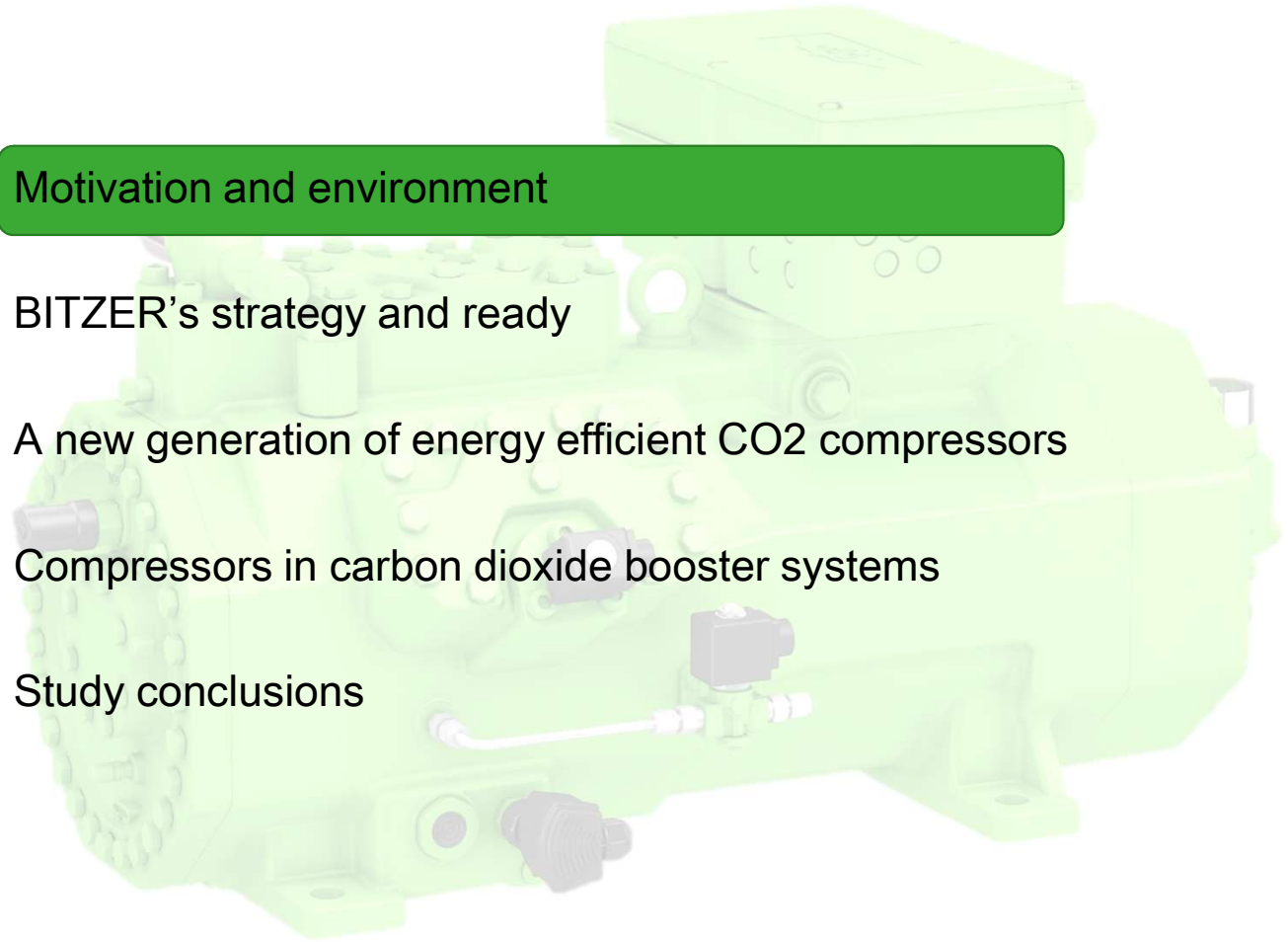
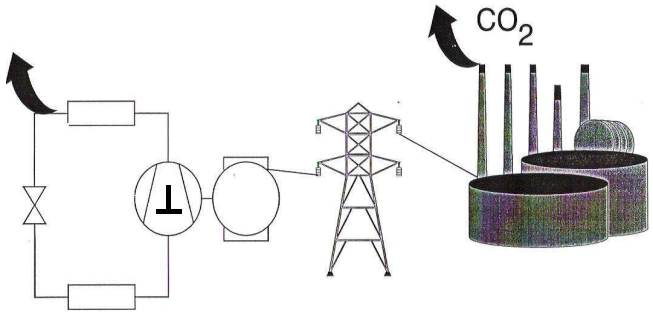


MOTIVATION

// General targets

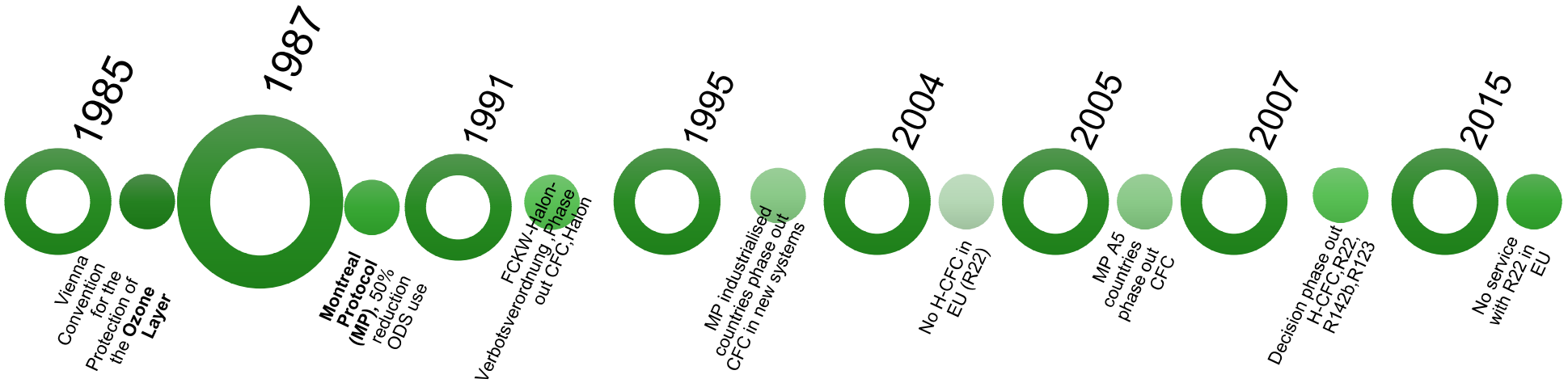
- Increase of energy efficiency
- Minimize carbon emission
- Cutback the use of HFC's

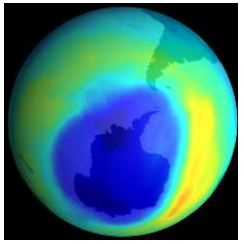


In an ideal situation, highest annual energy efficiencies are achieved with a natural refrigerant in a simple and cost effective way!

INTERNATIONAL ENVIRONMENT

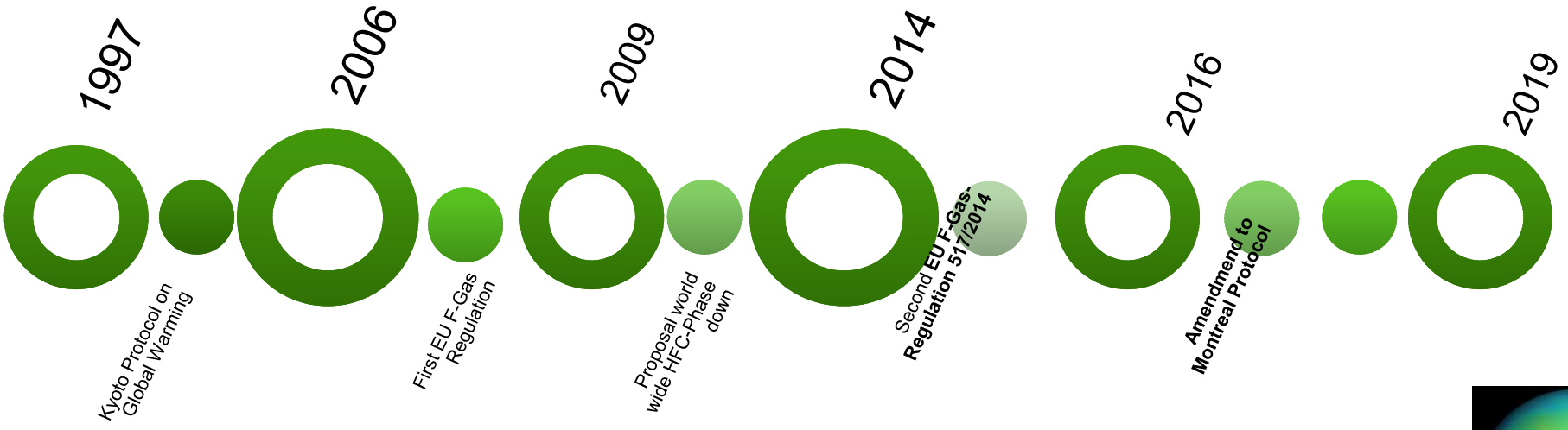
TIME LINE 1: OZONE DEPLETION ODP

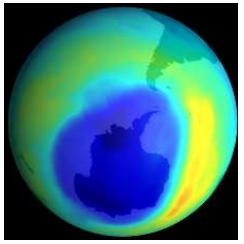




INTERNATIONAL ENVIRONMENT

TIME LINE 2: GLOBAL WARMING GWP



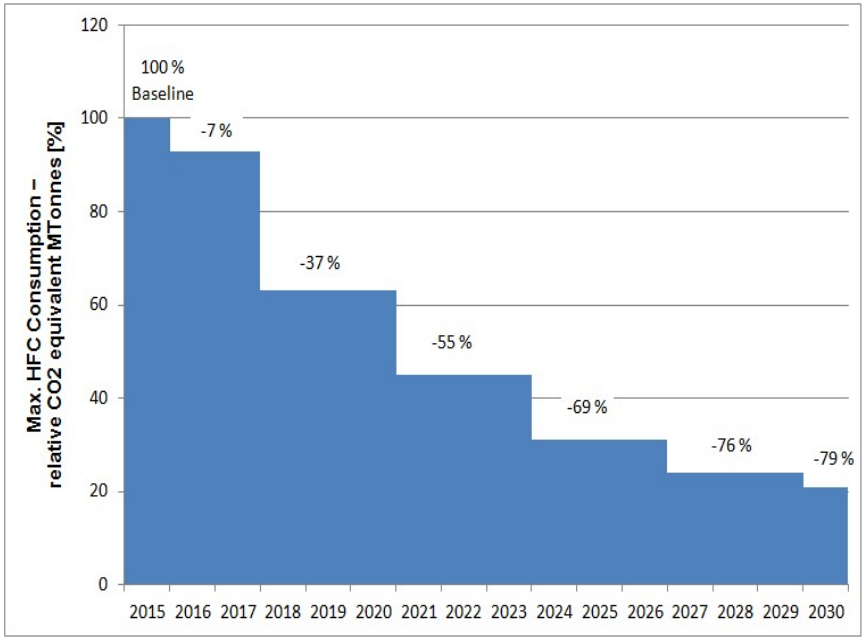


INTERNATIONAL ENVIRONMENT

EU F-GAS REGULATION 517/2014

// HFC use bans in RAC sectors from 2015 on (selection)

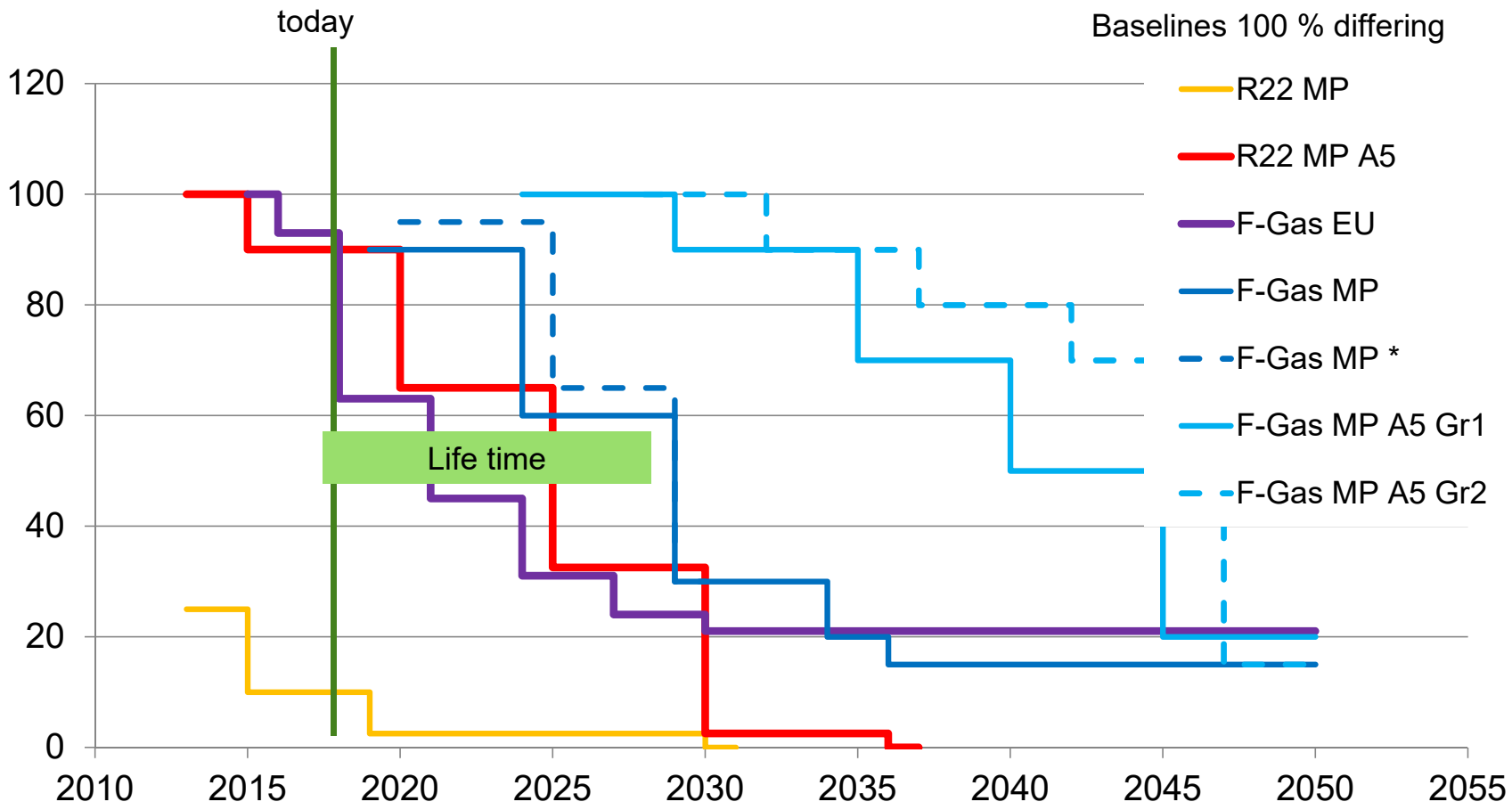
- 2015 domestic R + F
- 2020 Stationary Refrigeration GWP > 2500
  Commercial R + F GWP > 2500
  Movable AC GWP > 150
  - Exception for Refr. <-50 °C
- 2022 Commercial R + F GWP > 150
  Multipack commercial … GWP > 150
  - Cascade primary system GWP > 1500
- 2025 Split AC GWP > 750



ECONOMIC AND POLITICAL ENVIRONMENT IN CHINA

// 1989 Environmental Protection Law P.R.C
Energy Conservation Law P.R.C
// 1991 Agreement in Montreal Protocol
// 2000 Air Pollution Prevention and Control Law
// 2009 CO2 Emission/GDP in 2020 40%~45%↓ (compared with 2005)
// 2014 National plan for tackling climate change (2014-2020 years)
// 2016 Amendmend to Montreal Protocol
(HFC use 85%↓ in 2020-22 by 2045)
// 2019 **Kigali Amendment**
(HFC 80%↓ by 2045, <0.5degree increase by end of 21century)

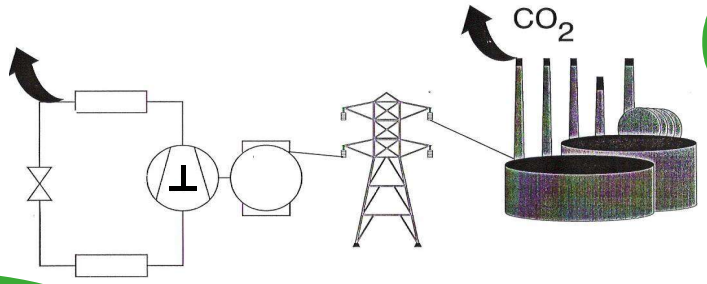
CHALLENGES IN REFRIGERATION



STRESS FIELD OF NEW DEVELOPMENTS

Increasing demand for R&AC in societies and industry

Impact of R&AC to global warming



BITZER: low complexity, with higher efficiency at low cost

Regulations on use of HFC's, e.g. F-Gas-Regulation

Systems: Rising relevance of efficiency at low costs

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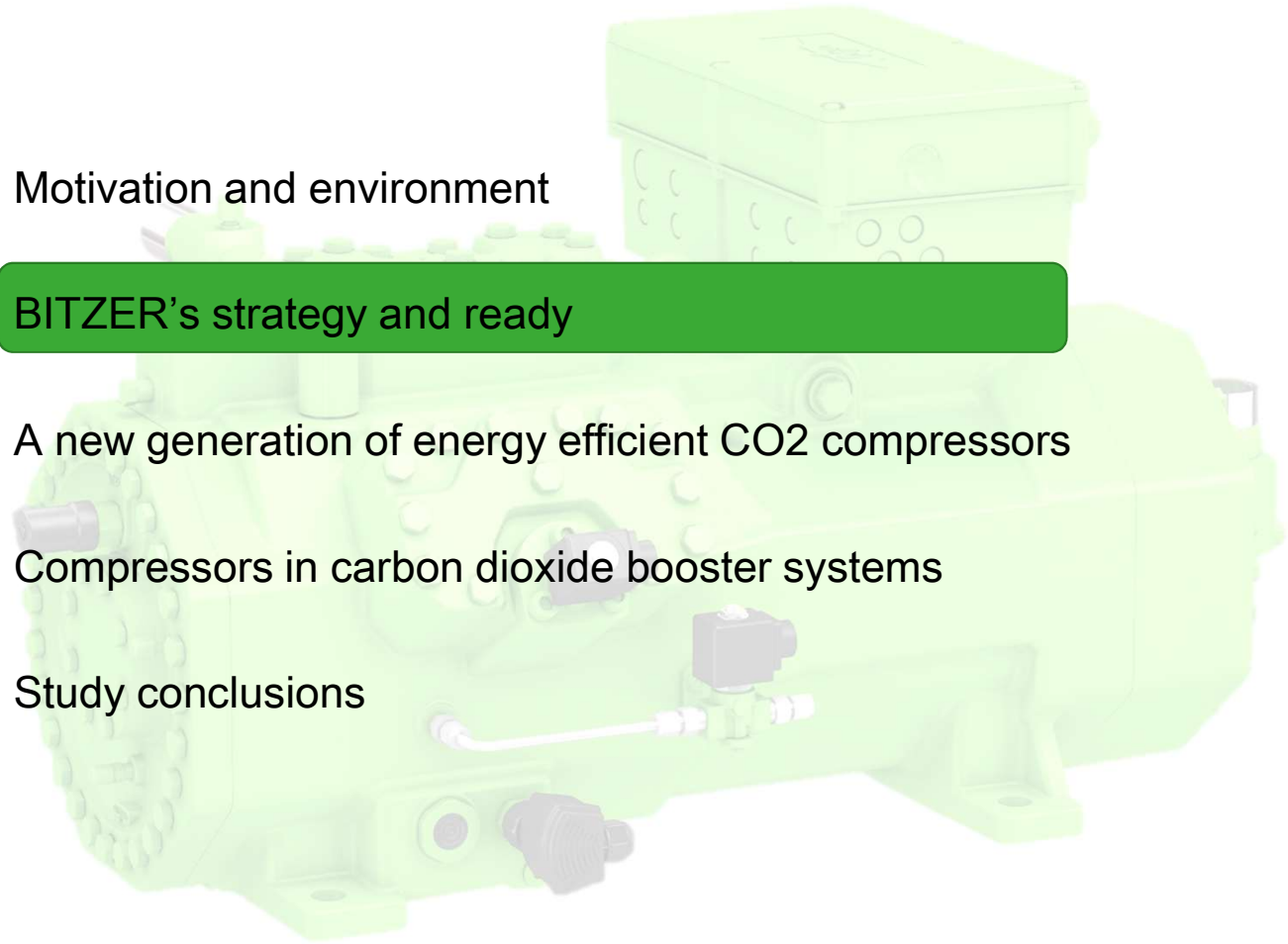


PRODUCT STRATEGY

Three Main Product Development Tracks

Low GWP/
Natural Refrigerants

Efficiency Increase
in Full- and Part-Load

Intelligent Products &
User-Friendliness

BITZER READY
FOR NATURAL REFRIGERANTS

- BITZER product with nature refrigerants
  - CO2 Reciprocating Compressor

1998

- 1st subcritical CO_2 compressor

2003

- 1st transcritical CO_2 compressor

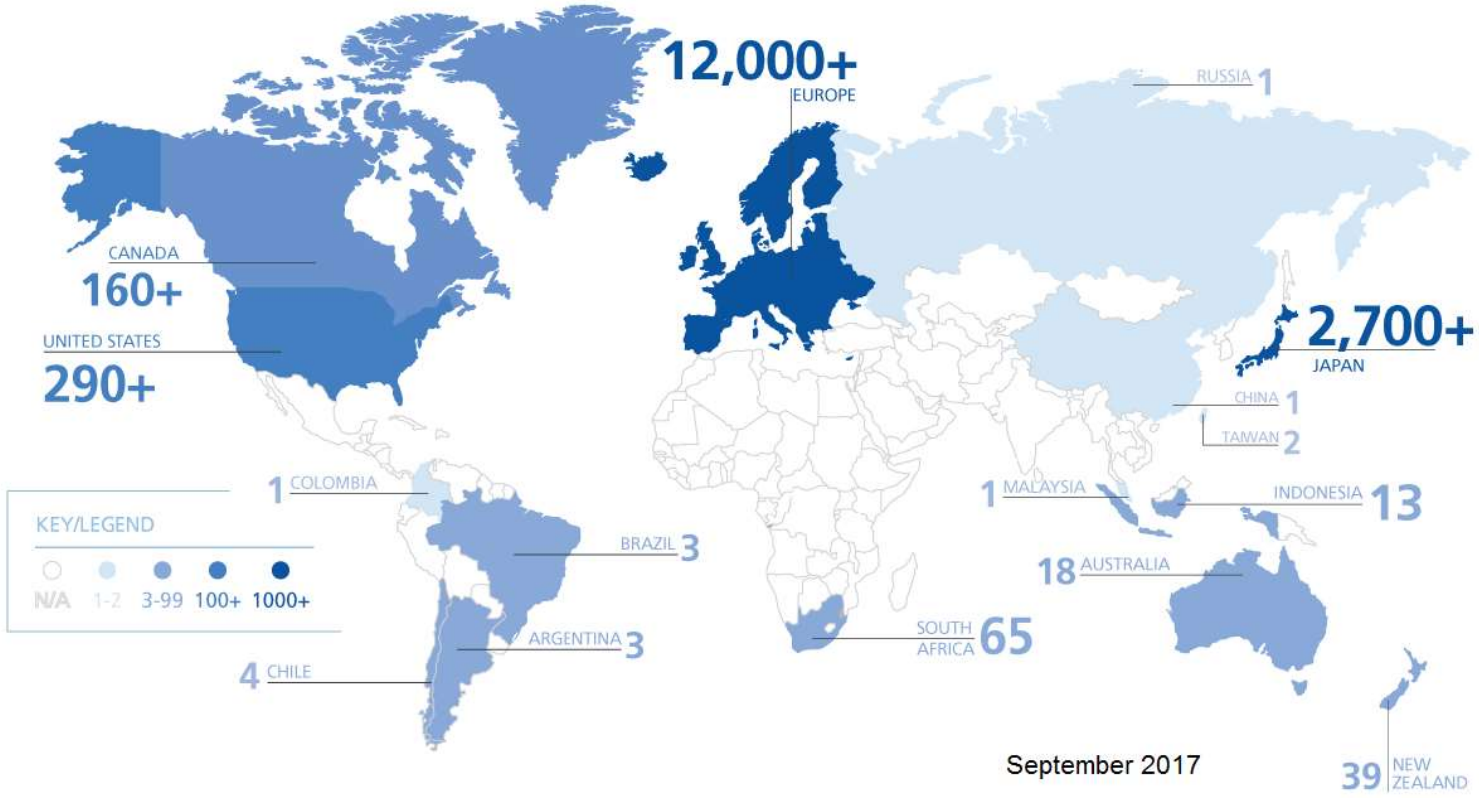
2016

- CO_2 Seminar in Schaufler Academy

2018

- 10,0000th CO_2 Compressor produced in SKZ

BITZER READY
FOR NATURAL REFRIGERANTS

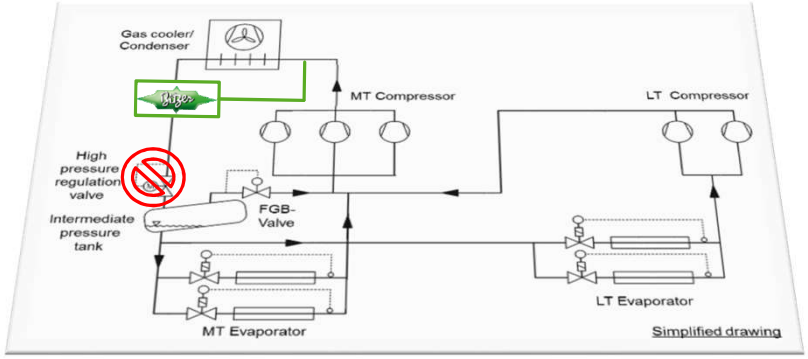


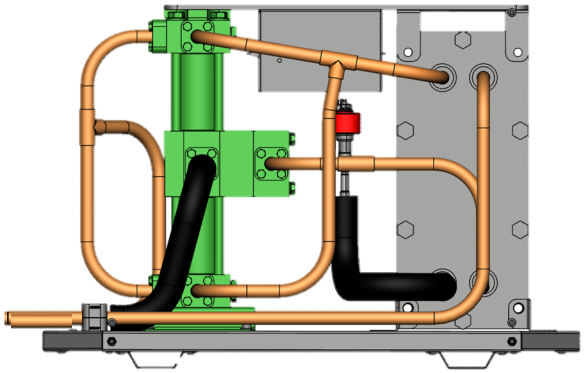
BITZER: > 100,000 sold CO_2 compressors, mainly in commercial refrigeration!

BITZER READY
FOR BETTER EFFICIENCY-CONSISTENTLY&PERMANENTLY

Improving performance of system:

// Expander compressor unit with heat exchanger to „sub cool“ the main CO2 stream





– Efficiency increase (SEPR* +13 %)
– Capacity increase (Qo** +20 %)

* Strassbourg climate
** 32°C ambient temperature

BITZER READY
FOR INTELLIGENT PRODUCT AND BETTER FRIENDLINESS

// Better products & better Service

– Bitzer Software

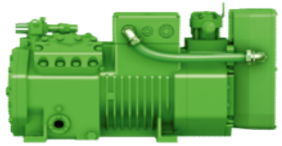
– BEST

BEST APP

– IQ Module

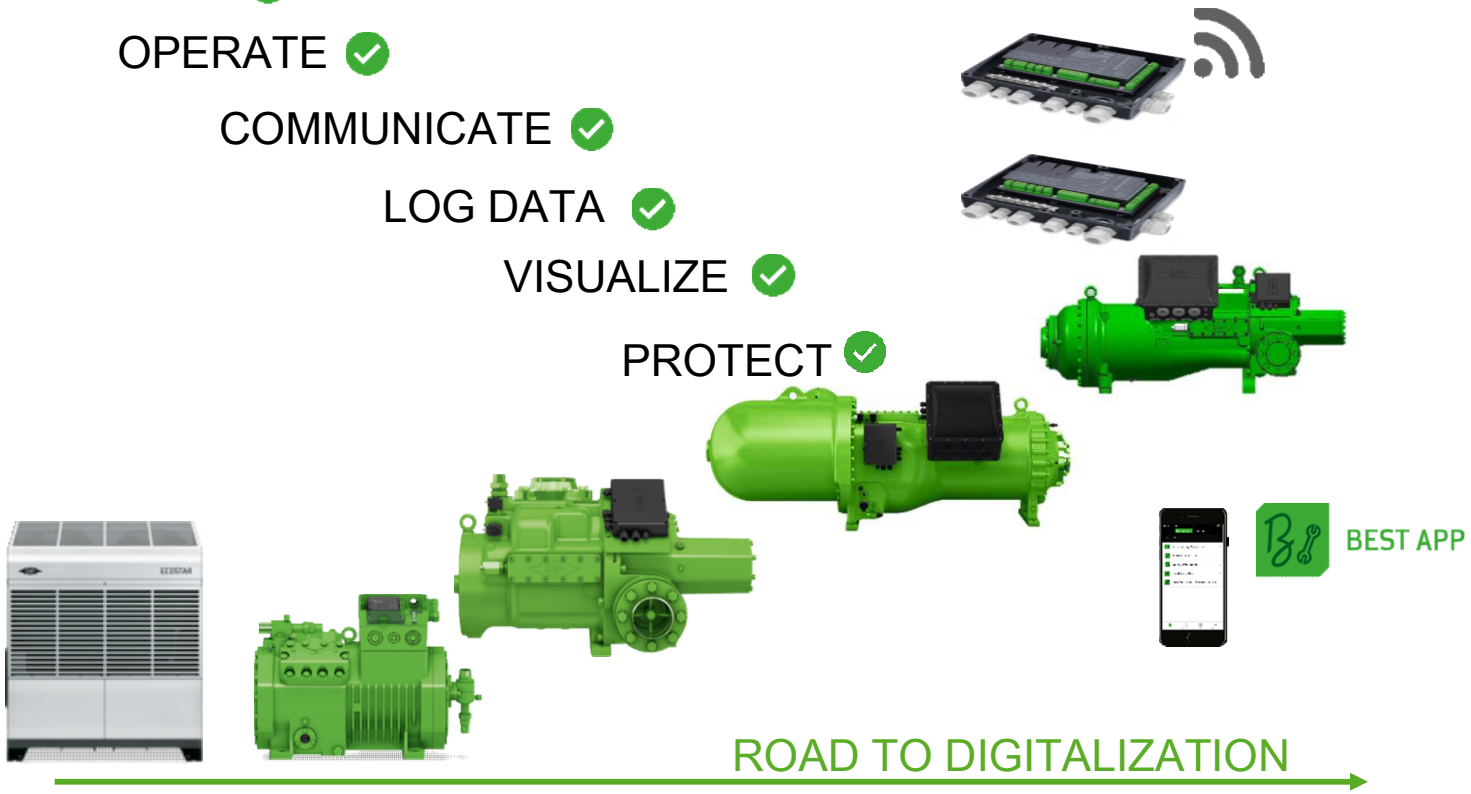
IQ

– Varipack & Varispeed



INTELLIGENT PRODUCT AND FRIENDLINESS

- INSTALL
- OPERATE
- COMMUNICATE
- LOG DATA
- VISUALIZE
- PROTECT



BITZER READY
FOR INTELLIGENT PRODUCT AND BETTER FRIENDLINESS

Broad service fortfolio

// Our worldwide service network Green Point ensures that our customers find the service they need wherever they are:

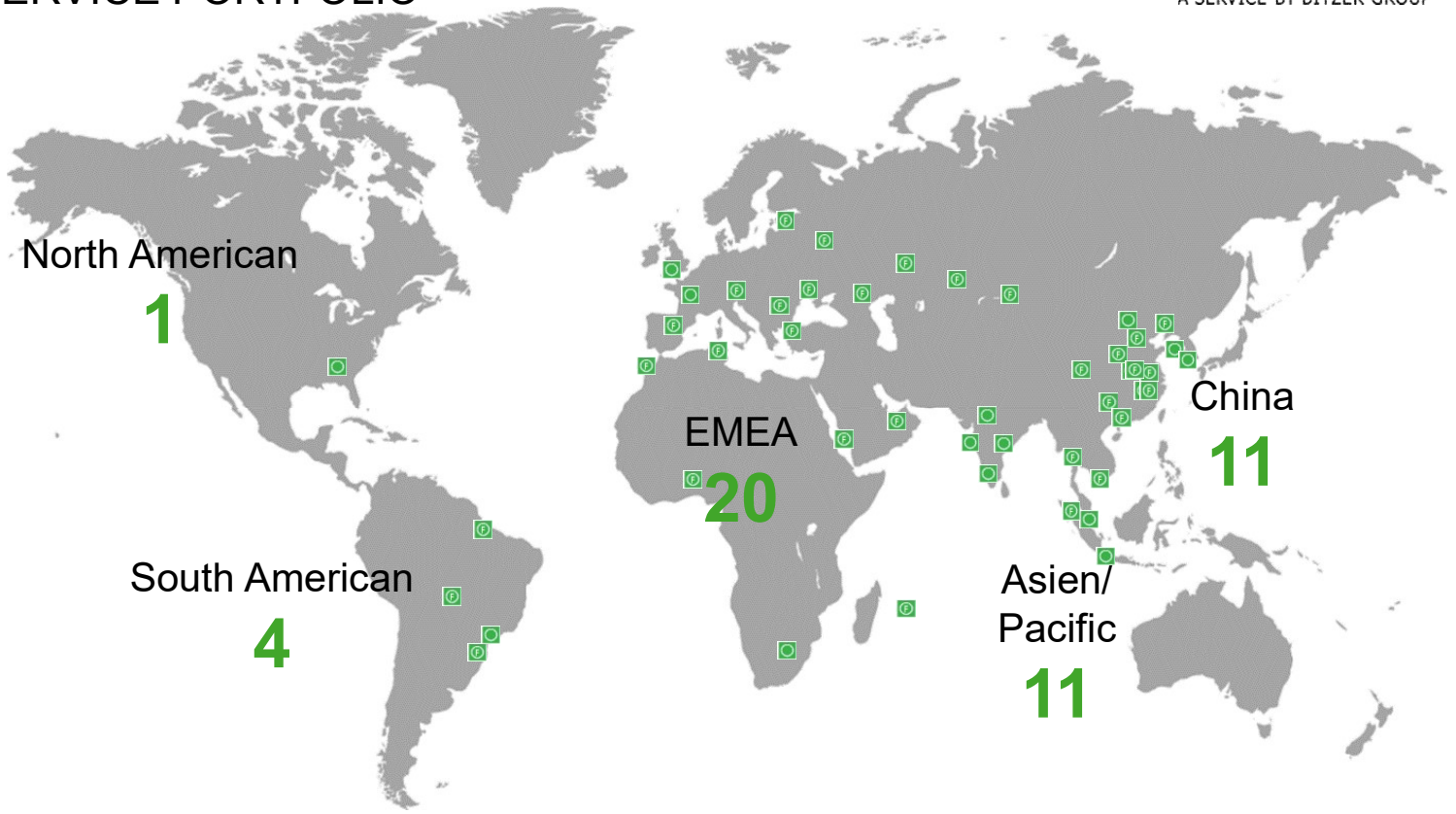
Green Point®
A SERVICE BY BITZER GROUP

- Compressor repairs and overhauls by compressor specialists
- Technical training and expertise
- Detailed documentation of our products

BITZER READY FOR INTELLIGENT PRODUCT AND BETTER FRIENDLINESS

BROAD SERVICE PORTFOLIO

Green Point®
A SERVICE BY BITZER GROUP



Since 2016: 47 location BITZER GP: 14 Franchise: 33

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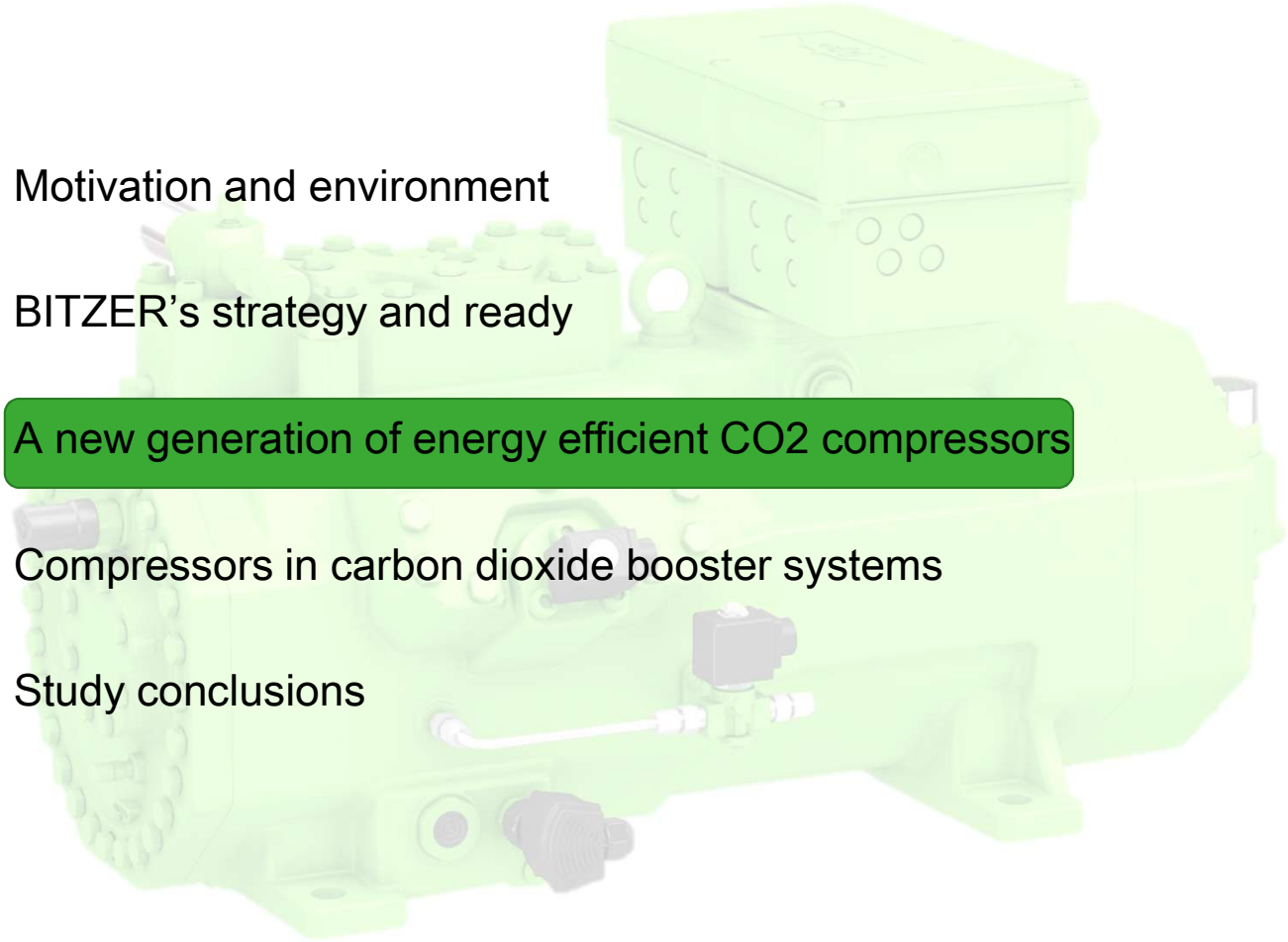


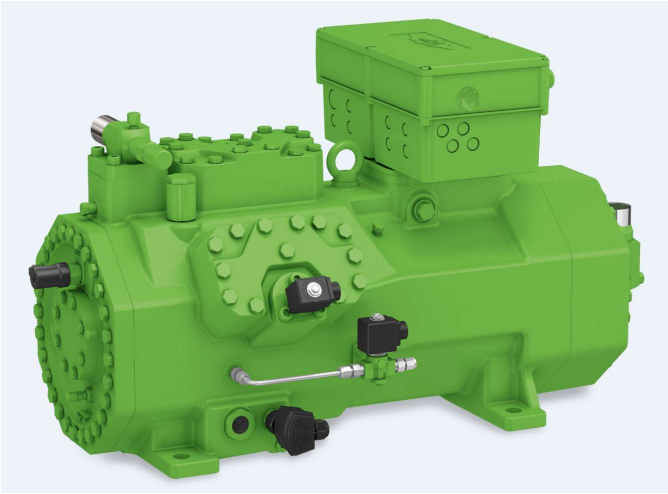
THE NEXT GENERATION OF ENERGY EFFICIENT COMPRESSORS

Highest eco-efficiency

Optimized efficiency for full and part load

Lowest CO_2 footprint, simple, smart, cost-effective

CRII for CO_2: World novelty, step less, easy, flexible



LSPM motor: Efficiency & robustness

New oil return management

IQ module: Operating of integrated functions

THE INTEGRAL APPROACH

ENERGY EFFICIENT

Higher COP

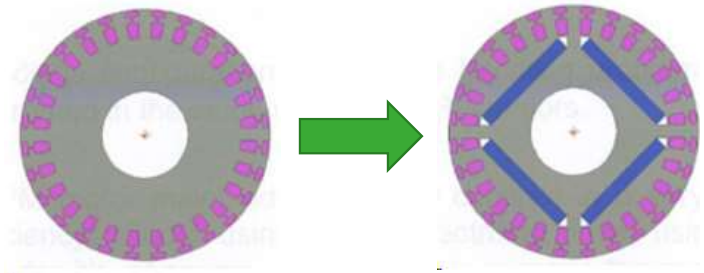
// Increased efficiency is based on
- Higher motor efficiency (**LSPM**)
- Higher mass flow rates due to synchronous speed
- Higher mass flow rates due to higher suction gas density

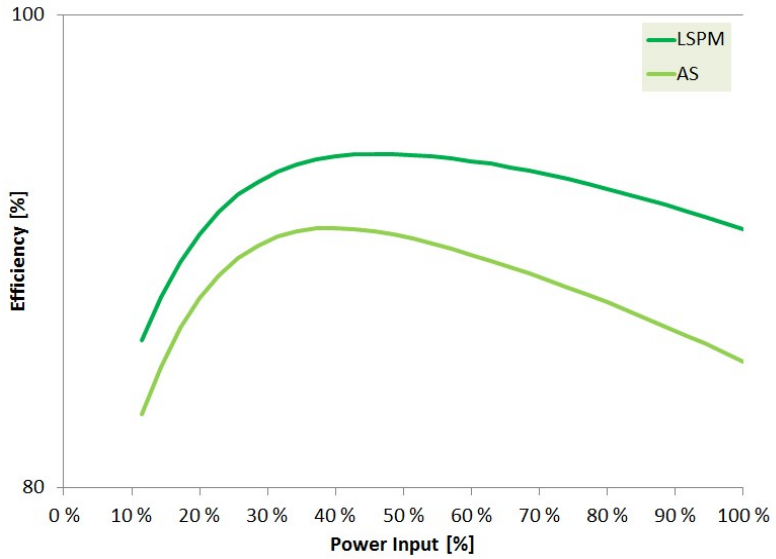
Focus on **annual energy efficiency** is most important

// Benefit dependent on
- Motor size and torque requirement
- System configuration (number and size of comp., VSD, etc.)
- Climate and load profile of the supermarket

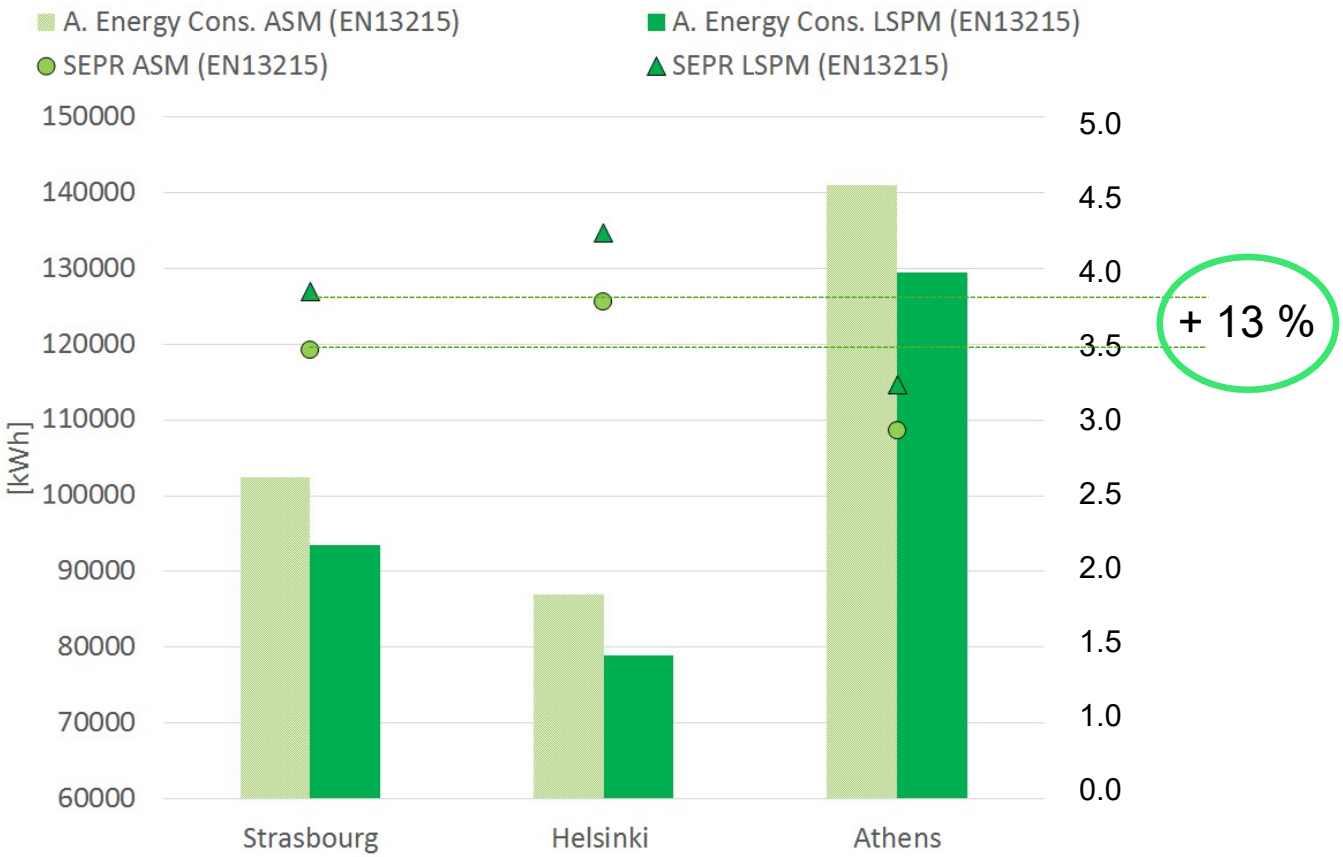
LSPM

- Line Start Permanent Magnet
- Stator generates rotating field
- Start: Squirrel cage generates magnetic field (asynchronous start)
- Operation: Magnetic field in rotor is generated by permanent magnet
- No current dependent losses in squirrel cage due to heating effect caused by induced current = higher efficiency
- Synchronous speed, not dependent on torque requirement
- Higher breaking torque, theoretically acts like a generator at coast down
- Combines efficiency and robustness, flexible operation on mains and VSD





SEPR – EN13215: 4DTC-25K (ASM) VS. 4DTEU-25LK (LSPM)



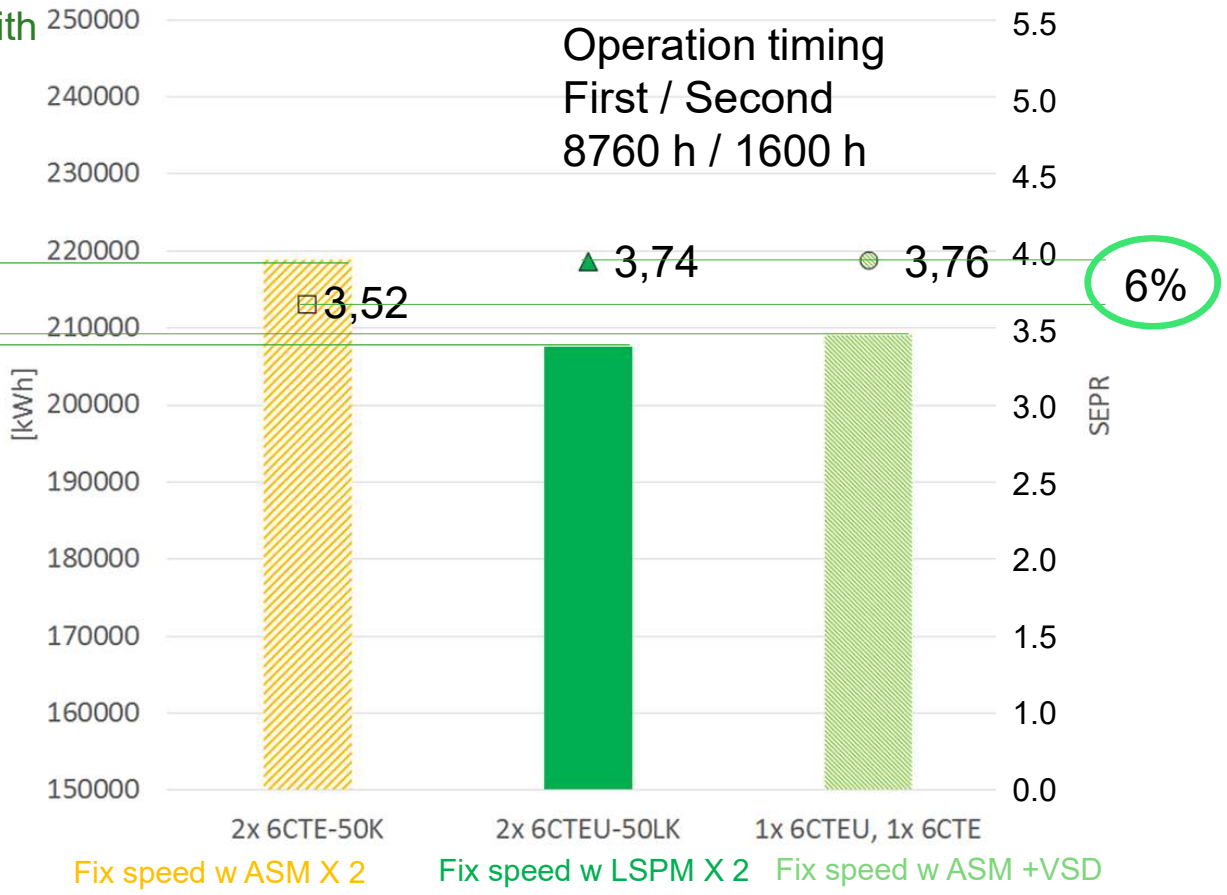
PARALLEL COMPOUND: ROI CALCULATION MUST BE BASED ON ANNUAL OPERATING HOURS

Detail calculation with Strasbourg climate with parallel system

218823 kWh/a

209012 kWh/a

207549 kWh/a



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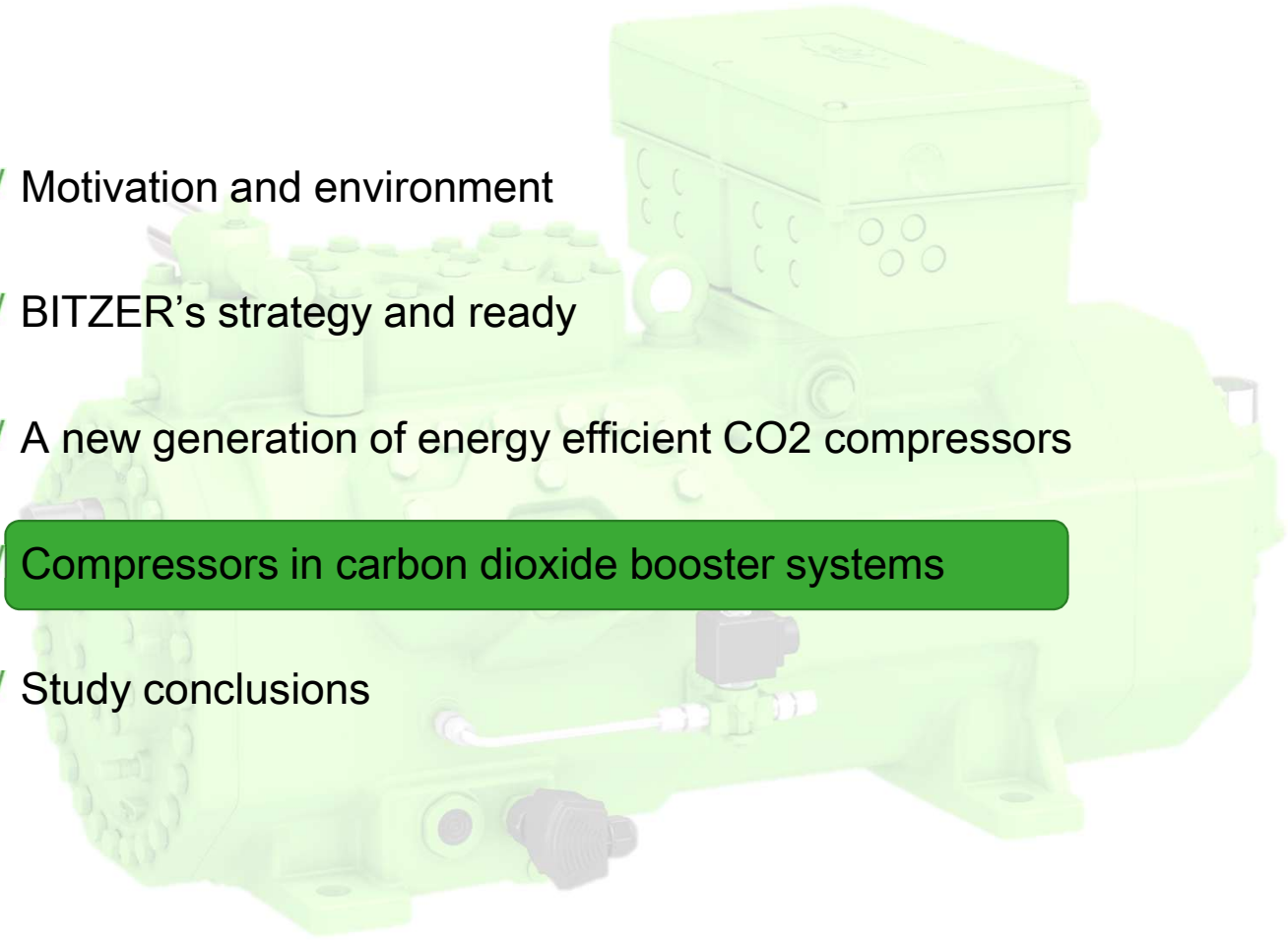
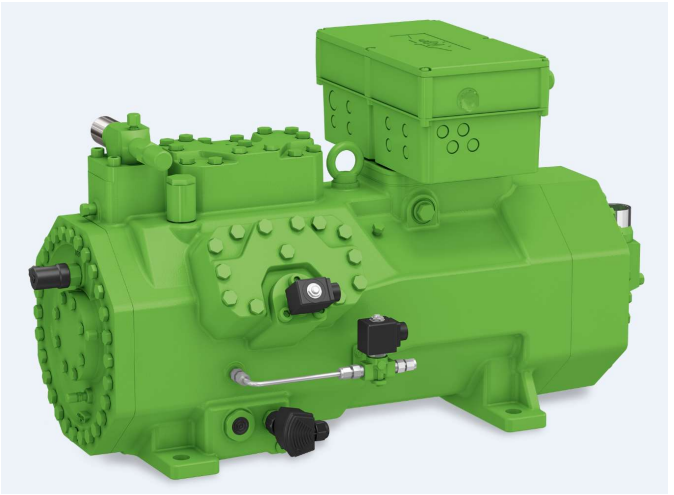


APPLICATION INTRODUCTION OF CO2 COMPRESSORS

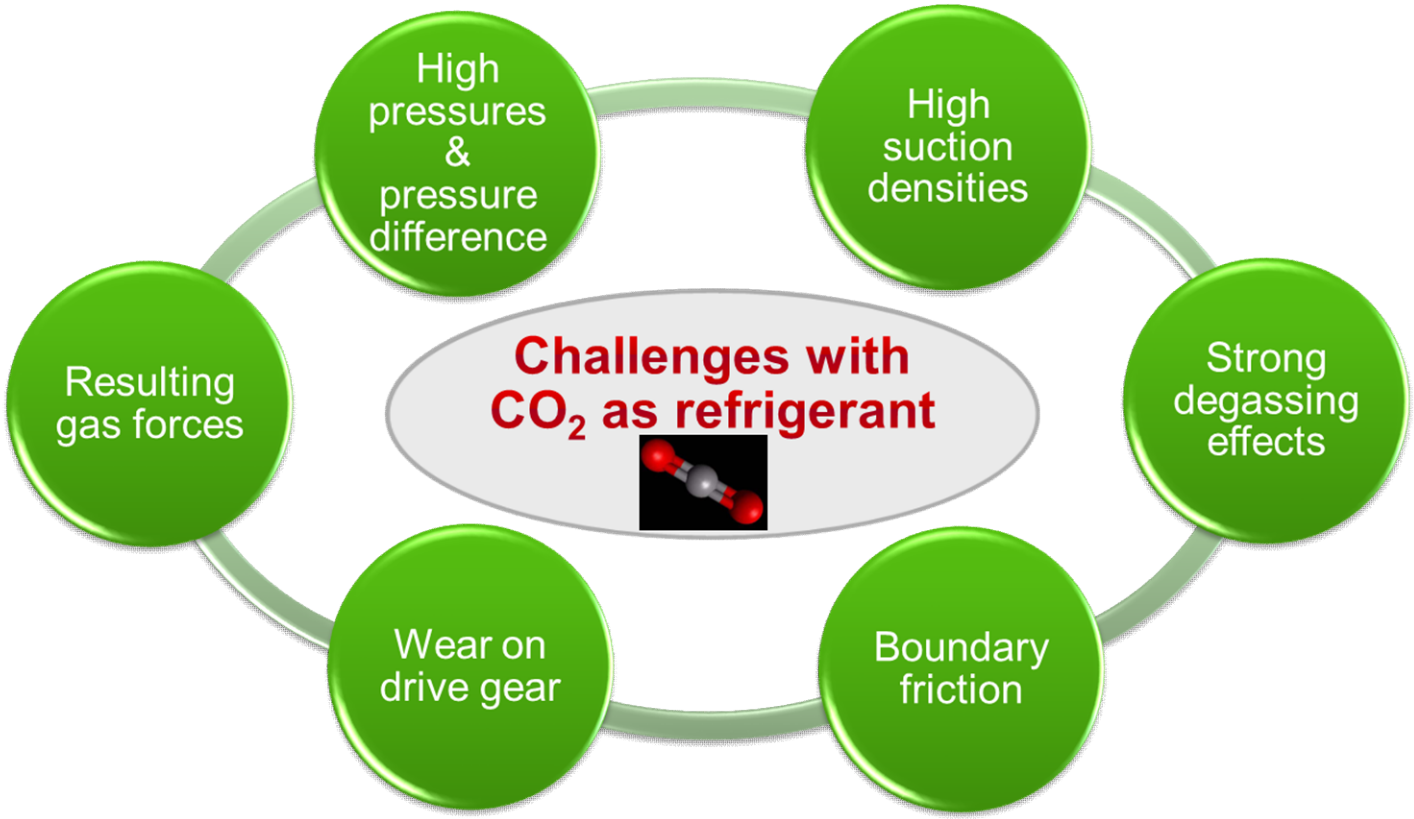
- The first prototype compressors for sub-critical CO2 applications were supplied to research institutions like the DTI in Denmark in the years 1995 to 1998.
- In the year 2000, the first commercial HFC/CO_2 cascade system was installed in Bettembourg in Luxembourg by Linde.
- The propane/CO2 cascade system was installed McDonald in Vejle , Denmark , it was designed and engineered by DTI in 2002.
- In the year 2004, Linde commissioned the first all CO2 system for trans-critical application in Wettingen, Switzerland.
- The 4th generation of CO2 compressors made by BITZER in the year 2010.
- Has sold more than 100.000 CO2 compressors by the end of February 2018.



The 4th generation of CO2 compressor of the ECOLINE+ series

CHALLENGES WITH CO2 AS REFRIGERANT

Influences on the reliability of a CO_2 compressor



THE SOLUTION — BITZER CO2 COMPRESSOR

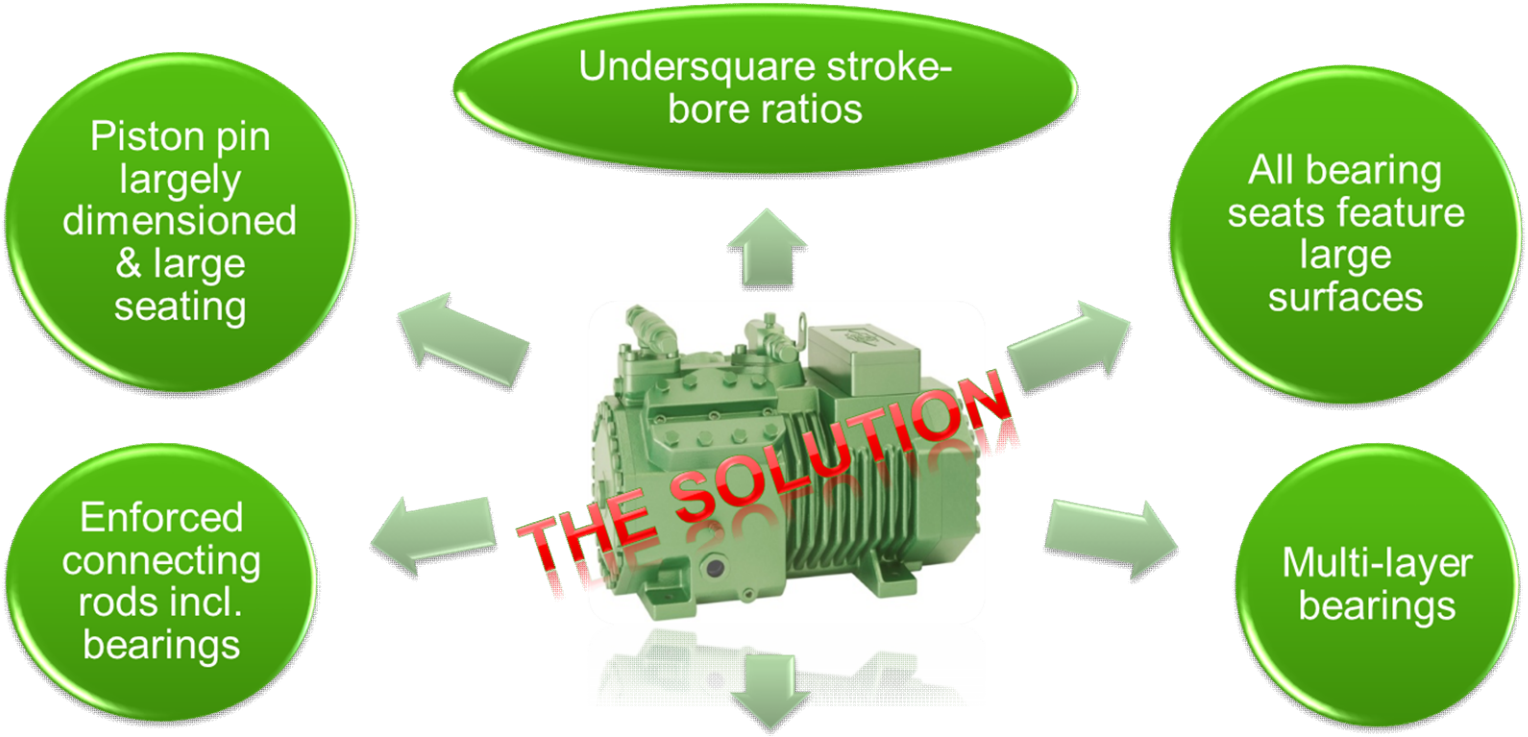
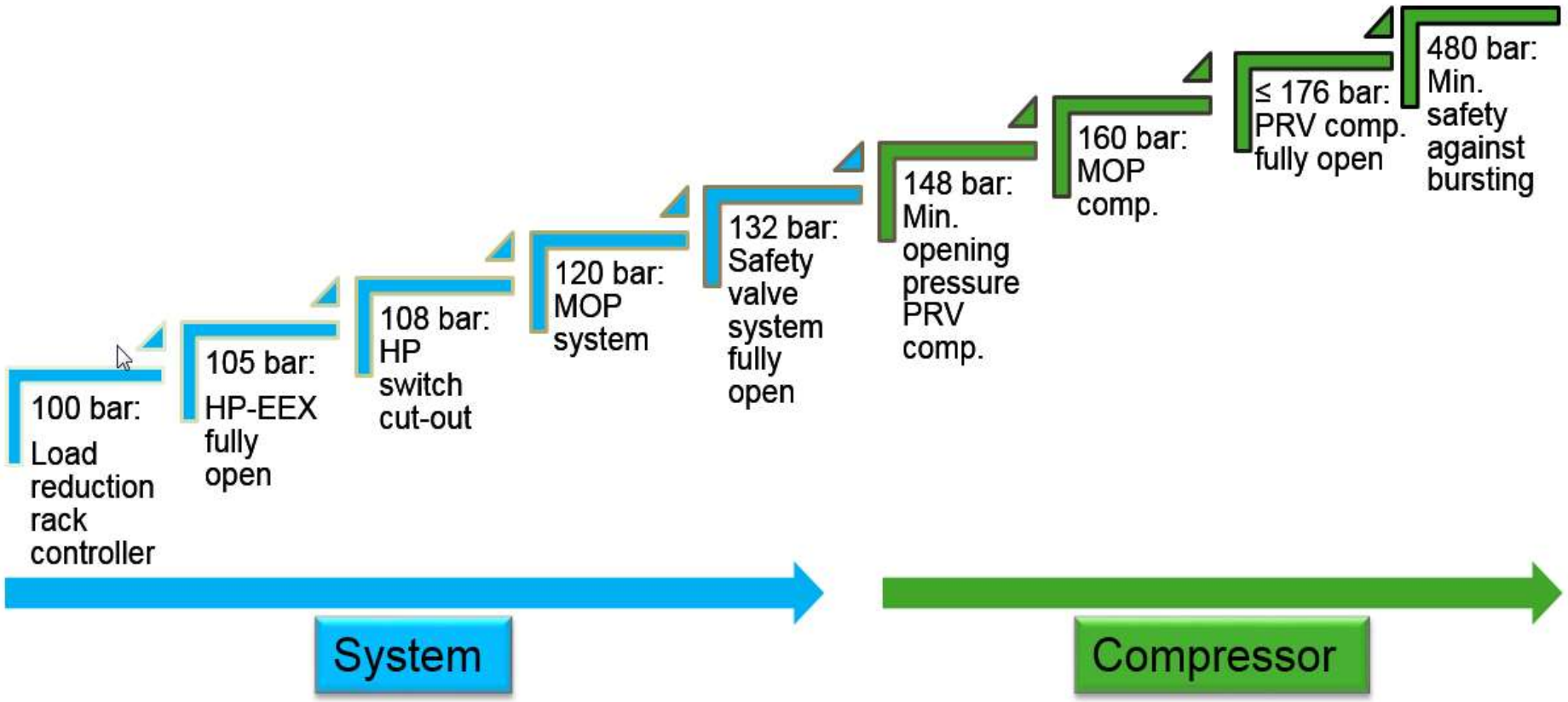
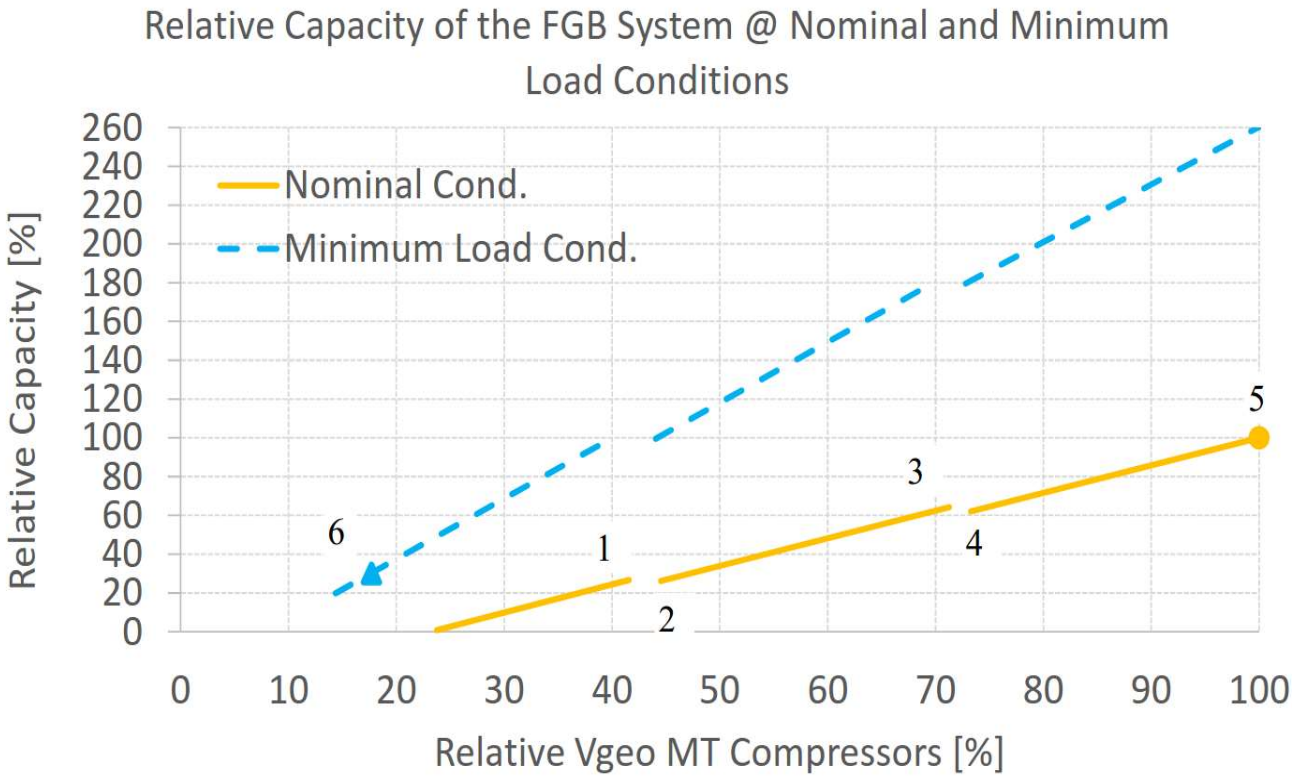


ILLUSTRATION OF AN APPLICABLE SAFETY CHAIN



RELATIVE CAPACITY OF A FGB SYSTEM UNDER DIFFERENT LOAD CONDITIONS

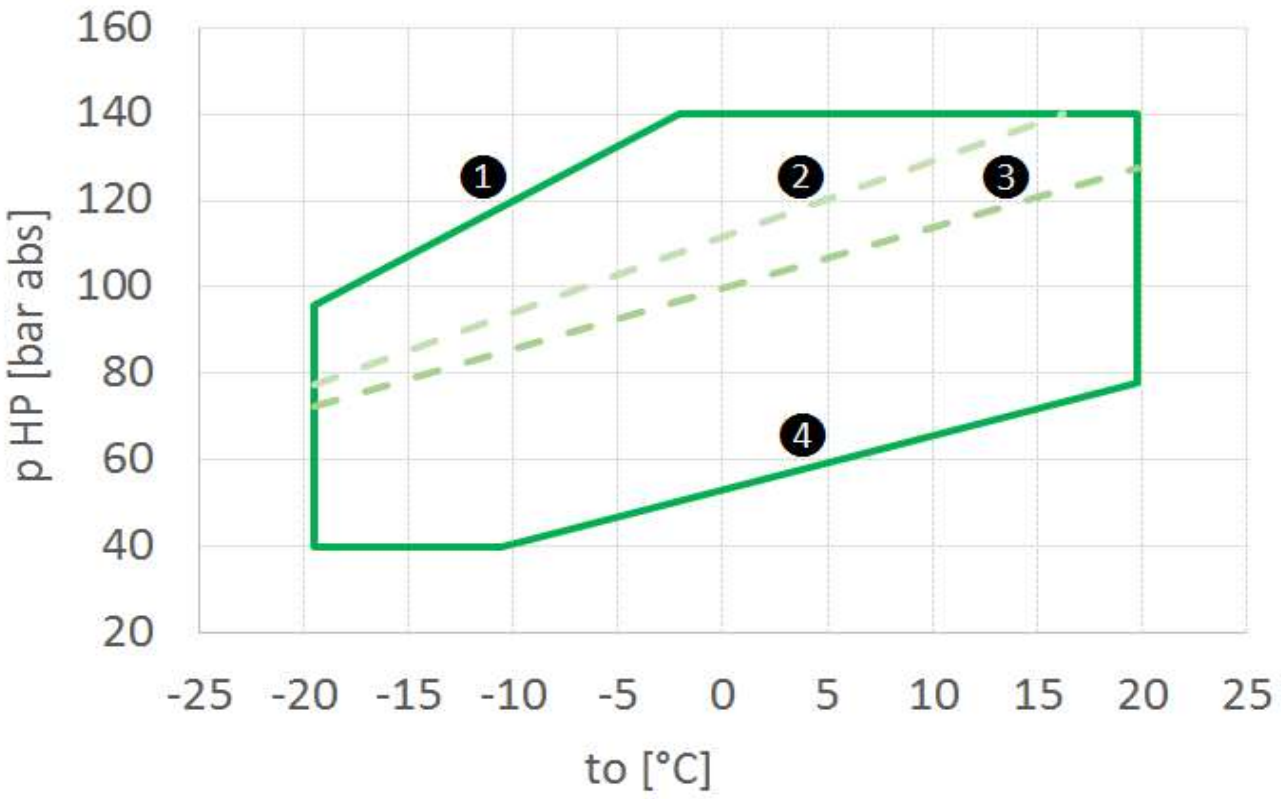
- 1 – 2: C1 70 Hz, C2 and C3 off changing to C1 25 Hz, C2 on, C3 off
- 3 – 4: C1 70 Hz, C2 on, C3 off changing to C1 25 Hz, C2 on, C3 on
- 5: All in under full load summer conditions
- 6: Minimum load conditions winter time “closed”: C1 operating with low but not minimum frequency.



SIMPLIFIED MODEL OF A LOAD PROFILE IN COMMERCIAL REFRIGERATION IN A WARM CLIMATE

Ambient temp. DB [°C]	Bin hours annual [h]	ΔT g.c. /cond. [K]	t gc out, tc applied [°C]	Bin hours OPEN [h]	Load MT OPEN [%]	Load LT OPEN [%]	Bin hours CLOSED [h]	Load MT CLOSED [%]	Load LT CLOSED [%]
-5,0	0,12	-	9,0	0,0	65,0	68,0	0,1	30,0	50,0
-2,5	3,13	-	9,0	0,7	65,0	68,0	2,4	30,0	50,0
0,0	27,84	-	9,0	7,3	65,0	68,0	20,5	30,0	50,0
2,5	79,95	8,0	10,5	23,1	65,0	68,0	56,9	30,0	50,0
5,0	318,82	8,0	13,0	95,4	65,0	68,0	223,4	30,0	50,0
7,5	510,94	8,0	15,5	174,5	65,0	68,0	336,4	30,0	50,0
10,0	957,29	8,0	18,0	374,6	65,0	68,0	582,7	30,0	50,0
12,5	916,86	8,0	20,5	403,1	66,8	69,1	513,7	30,0	50,0
15,0	1164,71	8,0	23,0	602,6	72,1	74,9	562,1	32,1	52,9
17,5	796,06	8,0	25,5	412,6	77,5	80,6	383,5	37,5	60,0
20,0	885,92	8,0	28,0	401,2	82,9	86,3	484,7	42,9	67,1
22,5	764,55	6,0	28,5	331,7	88,2	92,0	432,9	48,2	74,3
25,0	964,27	4,0	29,0	457,9	93,6	97,7	506,4	53,6	81,4
27,5	592,23	3,0	30,5	390,5	98,9	100,0	201,8	58,9	88,6
30,0	483,58	2,0	32,0	418,5	100,0	100,0	65,0	60,0	90,0
32,5	202,53	2,0	34,5	195,4	100,0	100,0	7,1	60,0	90,0
35,0	78,91	2,0	37,0	78,0	100,0	100,0	1,0	60,0	90,0
37,5	10,00	2,0	39,5	9,9	100,0	100,0	0,1	60,0	90,0
40,0	2,24	2,0	42,0	2,2	100,0	100,0	0,0	60,0	90,0
42,5	0,04	2,0	44,5	0,0	100,0	100,0	0,0	60,0	90,0

SIMPLIFIED ILLUSTRATION OF AN APPLICATION LIMIT OF A COMPRESSOR FOR TRANS-CRITICAL APPLICATIONS



LUBRICANTS

Lubricant type	Viscosity range [cSt]	Gas solubility	Tribology characteristics	Miscibility +5 .. -50°C
Polyol Ester (POE)	32 …220 dependent on lubricant, compressor type and application	High	○ (+ ①)	Yes
Polyalpha Olefin (PAO)		Medium	+	No
Poly Alkylene Glycol (PAG)		Low	++	Partly

① With special anti wear additives

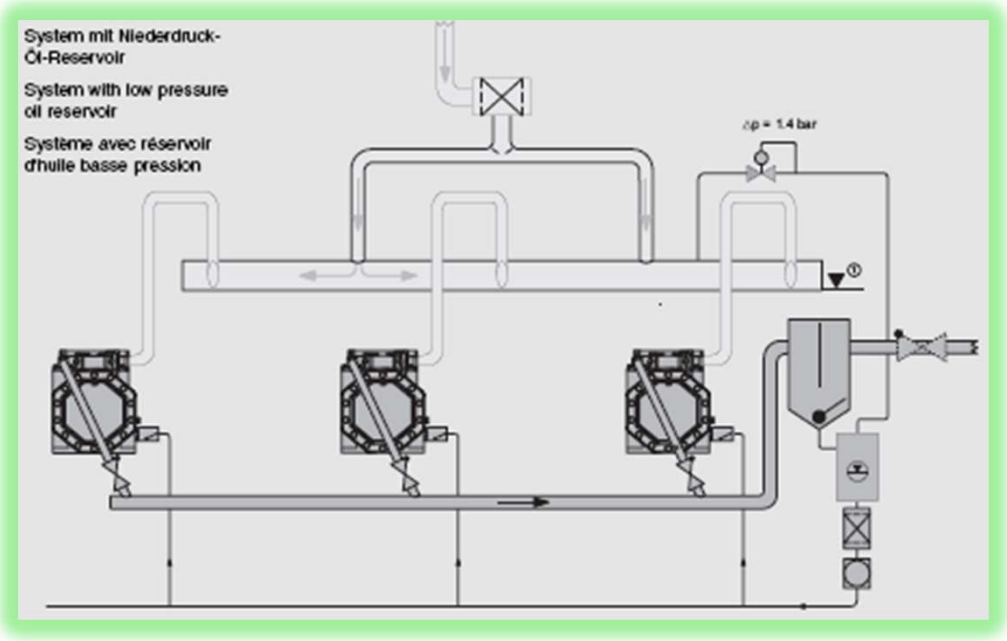
POE + Good overall properties ⇨ optimal for branched systems (oil return)
− High gas solubility ⇨ strong demands on compressor design technique

PAO + Low vapour pressure, high viscosity index ⇨ favourable with screws
− No miscibility ⇨ requires high efficiency oil separators

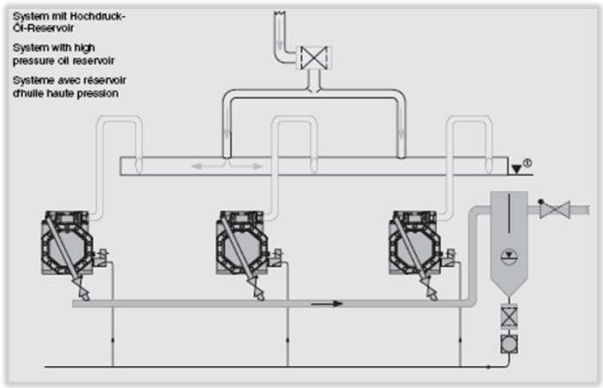
PAG + Good lubrication properties & thermal stability, no reaction with water (t < 160 °C)
− Miscibility, lower dielectric strength, conductivity in presence of e. g. Na^+, K^+

OIL MANAGEMENT

The recommended system for an active oil management: Low pressure oil reservoir



Stronger degassing effects: High pressure oil reservoir



VIBRATIONS

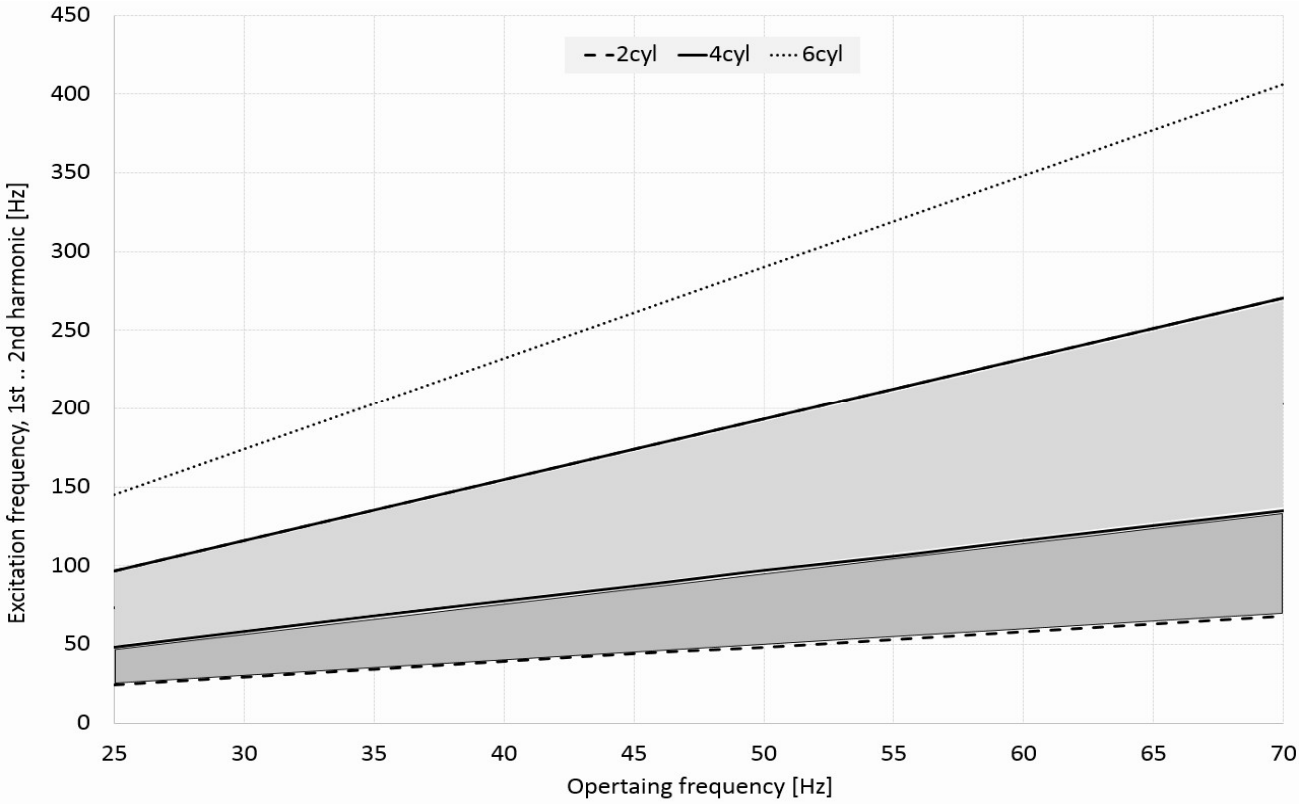
Data Input -- Refrigerant									
Refrigerant		**R744**							
HP = Discharge Pressure		**90**	bar						
DGT = Discharge gas temperature		**120**	°C						
a = Sonic speed		**283,53**	m/s						
Nominal Compressor rpm @ 50 Hz		1450	min-1						
Data Input -- Compressor									
Operating frquency of the compressor		**25**	**35**	**45**	**50**	**55**	**60**	**70**	Hz
Compressor rpm, nominal		725	1015	1305	1450	1595	1740	2030	1/min
Rotational frequency of the shaft		12	17	22	24	27	29	34	1/s
Number of cylinders / working strokes per revelution		**4**							---

Results

Fundamental frequency of the excitation	fg=n/60*N	48	68	87	97	106	116	135	Hz
	li = Critical pipe length			li = a/2*i*f	i = Harmonic number of oscillation characteristics				
Critical pipe length 1st order	**1**	***2,93***	***2,10***	***1,63***	***1,47***	***1,33***	***1,22***	***1,05***	**m**
Excitation Frequency 1st order		***48,3***	***67,7***	***87,0***	***96,7***	***106,3***	***116,0***	***135,3***	**Hz**
Range of critical pipe length	10%	*3,23*	*2,30*	*1,79*	*1,61*	*1,47*	*1,34*	*1,15*	m
1st order	-10%	*2,64*	*1,89*	*1,47*	*1,32*	*1,20*	*1,10*	*0,94*	m
Critical pipe length 2nd order	**2**	***1,47***	***1,05***	***0,81***	***0,73***	***0,67***	***0,61***	***0,52***	**m**
Excitation Frequency 2nd order		***96,7***	***135,3***	***174,0***	***193,3***	***212,7***	***232,0***	***270,7***	**Hz**
Range of critical pipe length	10%	*1,61*	*1,15*	*0,90*	*0,81*	*0,73*	*0,67*	*0,58*	m
2nd order	-10%	*1,32*	*0,94*	*0,73*	*0,66*	*0,60*	*0,55*	*0,47*	m
Critical pipe length 3rd order	**3**	***0,98***	***0,70***	***0,54***	***0,49***	***0,44***	***0,41***	***0,35***	**m**
Excitation Frequency 3rd order		***145,0***	***203,0***	***261,0***	***290,0***	***319,0***	***348,0***	***406,0***	**Hz**
Range of critical pipe length	10%	*1,08*	*0,77*	*0,60*	*0,54*	*0,49*	*0,45*	*0,38*	m
3rd order	-10%	*0,88*	*0,63*	*0,49*	*0,44*	*0,40*	*0,37*	*0,31*	m
Critical pipe length 4th order	**4**	***0,73***	***0,52***	***0,41***	***0,37***	***0,33***	***0,31***	***0,26***	**m**
Excitation Frequency 4th order		***193,3***	***270,7***	***348,0***	***386,7***	***425,3***	***464,0***	***541,3***	**Hz**
Range of critical pipe length	10%	*0,81*	*0,58*	*0,45*	*0,40*	*0,37*	*0,34*	*0,29*	m
4th order	-10%	*0,66*	*0,47*	*0,37*	*0,33*	*0,30*	*0,27*	*0,24*	m

Excitation frequencies and critical pipe length of a four cylinder compressor at specific conditions

VIBRATIONS



Excitation frequencies for compressors with two, four and six cylinders from the first to the second harmonic

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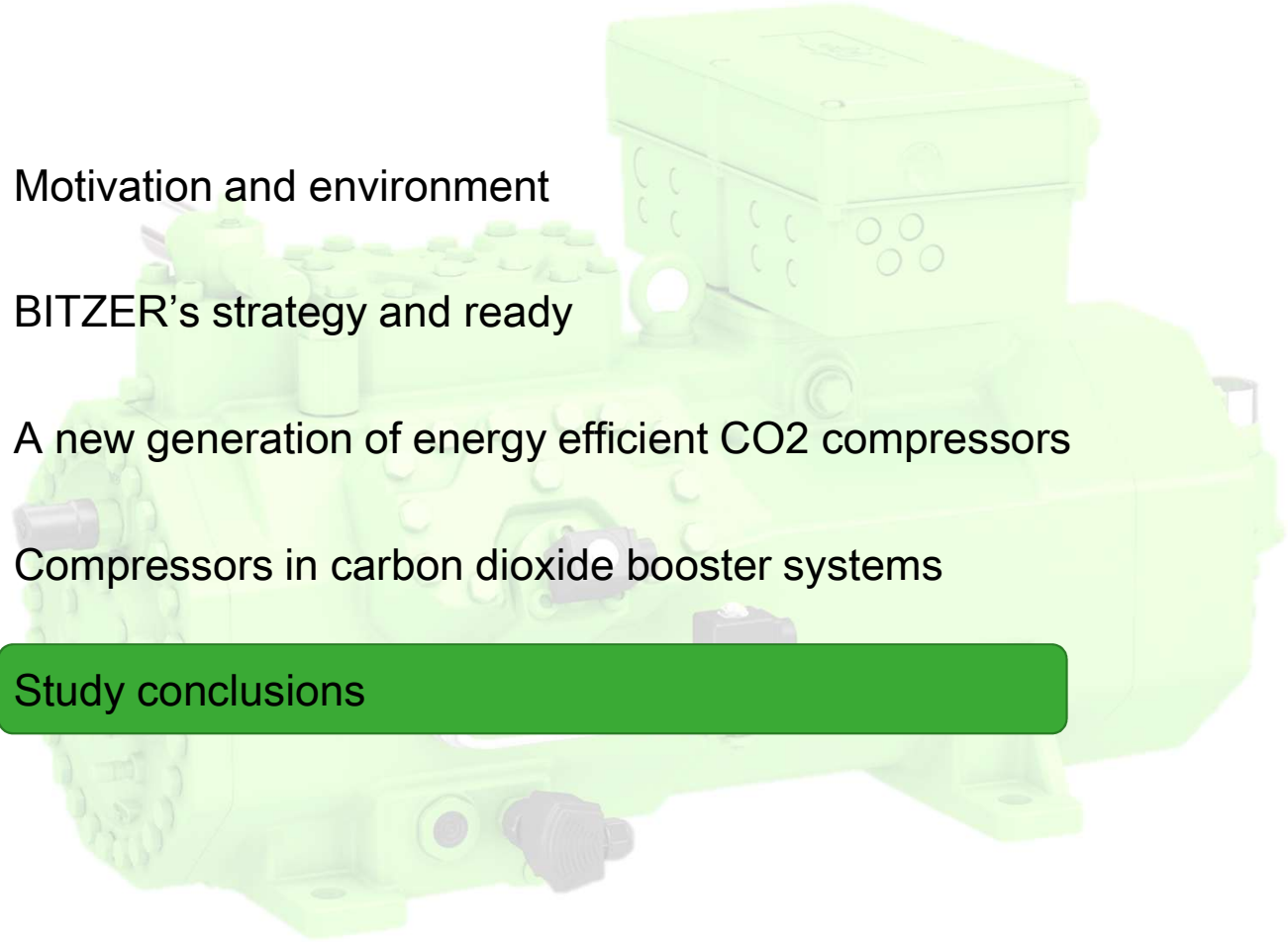

STUDY CONCLUSIONS

- Provide the schematic illustration of an applicable safety chain;
- Provide the so-called VARISTEP solution, and it can be easily combined with the efficient and well-proven concepts of rack controllers;
- Provide the simplified model of a load profile in commercial refrigeration in a warm climate;
- Analyse the factors influencing application limits;
- Polyol ester (POE) oils typically apply anti-wear additives to ensure good tribology characteristics, the design of BITZER CO2 compressors is tailored for POE oils;
- Provide the effective measure about oil management for MT and LT booster systems;
- Provide the ways about reducing vibrations of CO2 systems.
- CO2 applications require efficient compressors at full load and part load conditions together with a smart controls, system and heat exchanger design to reduce the carbon footprint of the installations.

DAS HERZ DER FRISCHE