

ENGINEERING
TOMORROW

Danfoss

Danfoss Turbocor Compressors

February 2023



 TURBOCOR

Overview

Presenter

Kyle Fields

Technical Product Manager
Danfoss Turbocor Compressors



- Introduction
 - Danfoss
 - Danfoss Turbocor Compressors
- The Innovation of Oil-Free Technology
 - Oiled vs Oil-Free
 - Refrigerant Landscape
- Our Products
 - Danfoss Turbocor Product Portfolio
 - Upcoming Products
- Our Community
 - Danfoss Turbocor Expansion - Project Greenfield



Danfoss Turbocor Compressor Products

The world's leader in oil-free compressor technology

Danfoss is the leading manufacturer of Oil-Free compressors and is the pioneer of the Danfoss Turbocor® compressor – the world's first oil-free magnetic bearing compressor for the HVAC industry.

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Danfoss Business Overview

Our World

40,043

Employees

Worldwide sales

in more than 100 countries

95 factories

in 27 countries

Privately held

Ownership

Nordborg, Denmark

Headquarters

Top 3 markets



We have almost doubled Danfoss in five years

2022:
~EUR 10bn

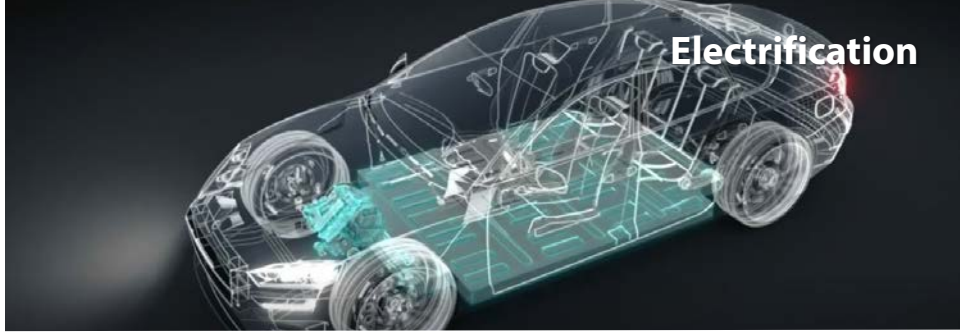
2021:
EUR 7.6bn

2017:
EUR 5.8bn

Climate Change



Electrification



Urbanization



GLOBAL MEGATRENDS

Transforming our world

Food & Water Supply



Digitalization



Power Solutions is Transforming

Leading position in mobile and
industrial hydraulics

From EUR **1.9bn to 4.9bn**

Climate Solutions is Transforming

Leading position in cooling and
heating infrastructure

From EUR **2.6bn to 3.1bn**

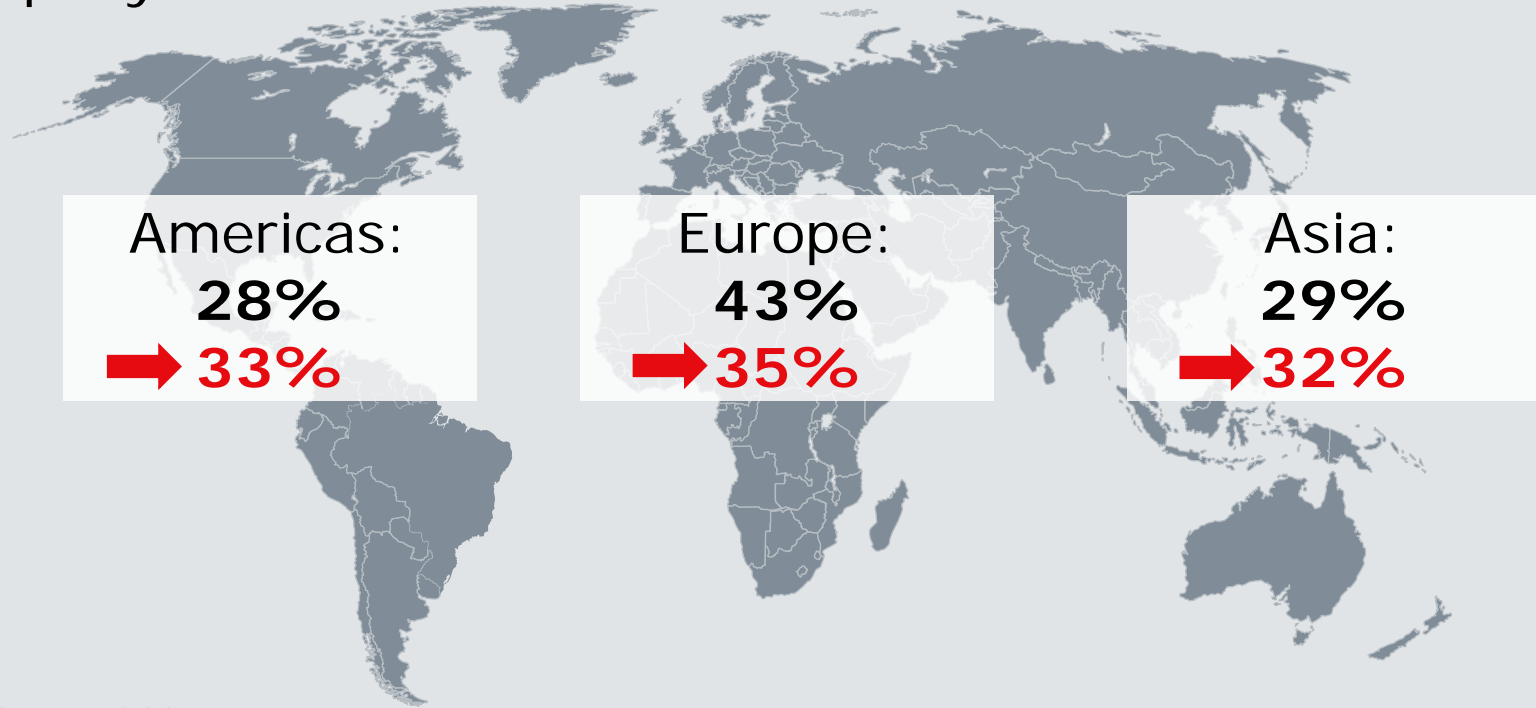


Drives is Transforming

Leading position in power electronics and electrification

From EUR **1.4bn to 2.2bn**

By strengthening our core and investing in regional high-potential hotspots, we have become an even **more global** company



Before EATON Acquisition
After EATON Acquisition

ESG

Environment / Social / Governance



We pioneer solutions for customers to **enable decarbonization**



We innovate best-in-class **circular products**



We offer a leading employee experience that values and respects **diversity and inclusion**

A photograph of a man with glasses and a young child in a field. The man is leaning over the child, and they are both holding a colorful pinwheel. The background is a bright, open field under a clear sky.

Our Purpose

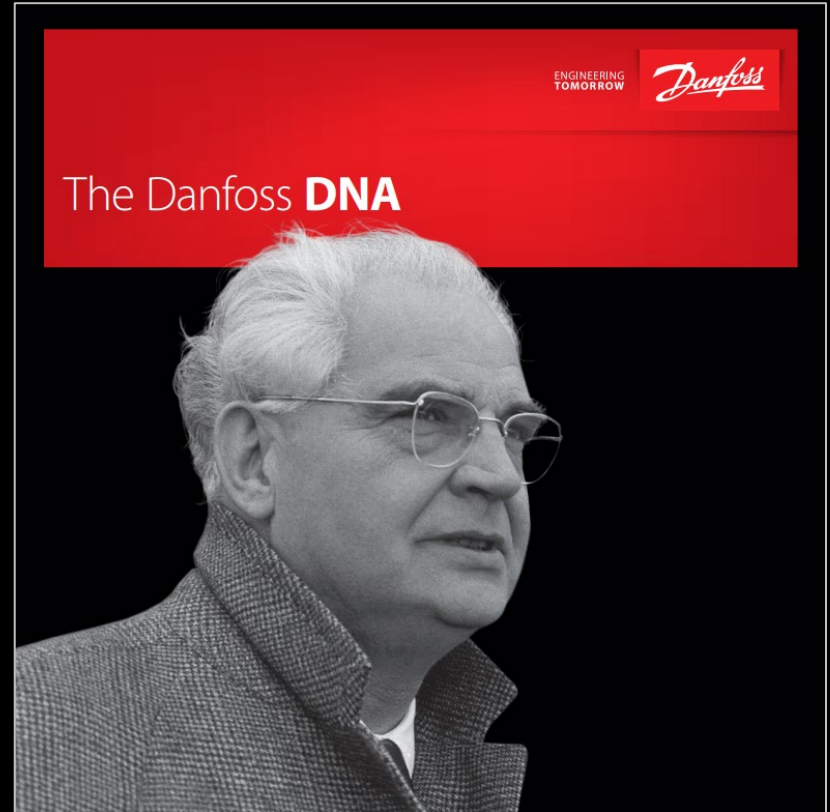
We engineer tomorrow to build a better future

**Decarbonizing
with our customers**

**Long-term
value creation**

Danfoss' long-term success is fueled by **bold investments**

The longer view,
courage and
sustainability



Our transformation is fueled by bold investments for Danfoss' long-term success

The longer view, **courage** and sustainability

The Danfoss **DNA**

Turbocor – compressors and engines of growth

Danfoss Turbocor is a compressor unlike traditional oiled compressors. To avoid the need for lubrication, the motor shaft in a Turbocor compressor levitates in a magnetic field, eliminating the need for traditional oiled bearings. The resulting oil-free design improves reliability by removing the complex oil management system. Moreover, Turbocor compressors provide industry-leading efficiency as oil is no longer present to degrade performance. And, through features such as the integral variable speed drive, Turbocor results in an efficiency improvement of up to 40 percent compared to conventional compressors. Danfoss Turbocor is the first compressor of its kind and has made Danfoss a market leader.

Background

Turbocor was the brainchild of Ron Conry, an Australian refrigeration engineer and inventor. In the 1990s, he saw the need for a centrifugal compressor. Beginning with a list of "what is possible", he embarked on a comprehensive research project which took him round the world. Amongst the points he called "almost impossible – but it can be done" was designing a motor shaft

using magnetic bearings. Today, this is the axle which performs up to 40,000 rotations a minute inside a Turbocor compressor.

Danfoss has deep roots within refrigeration, this is where the company started and has more than fifty years' experience in development and production of compressors.

When Danfoss invested in Turbocor, some perceived this as a wild technology bet. But Danfoss saw a dedicated team of enthusiastic engineers with a shared vision and a significant market potential. This was exactly the kind of project that Danfoss should invest in, even if the investment would be significant and the perspective was indeed long-term.

Conry gathered a team of experts and secured the funding to go ahead. He started in 1994 in Melbourne with 35 people, 30 of whom had completed PhDs. Three of them left the very first meeting before it had even concluded. In 2000, the Turbocor team moved to Canada because both production and living costs were lower there. Of the team's 24 participants, 20 made the

move from Australia to Canada. In 2001, Conry launched the first Turbocor onto the market. It was sold to the University of Southern California. A couple of years later in 2004, Conry and Danfoss agreed to enter into a joint venture and in 2005 Turbocor Compressors moved to Tallahassee, Florida.

In 2013, Danfoss took over full ownership of Turbocor. The acquisition cemented Danfoss' leading position within variable speed compressors and gave the group a decisive strategic advantage on the global refrigeration and air-conditioning market. Danfoss already had a strong position in the market for small and medium-sized commercial compressors; by acquiring Turbocor, Danfoss expanded the product portfolio to include very large commercial compressors.

Danfoss has a long heritage in the production of compressors. Made in Australia with parts from some of Danfoss' early compressors.

The technology

The challenges of developing Turbocor were immense. To an observer, the shaft looks simply like a rod; in fact, it is a complex assembly of 142 parts including ultra-strong magnets which are composed of masses of thin rings made from rare earth metals, equivalent to those used in the space industry. Sensors measure the position of the shaft 100,000 times a second, as it rotates up to 40,000 rpm.

The neighbors

Tallahassee is an ideal location for Turbocor. The city is the home of the National Magnetic Laboratory, one of the world's leading research institutes in the fields of magnetism, superconductors and supermagnets. Danfoss is now located in the midst of a community with very special skills and talent.

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Danfoss Turbocor Compressors

Business Overview



 **TURBOCOR**[®]

HISTORY



Turbocor moves to Montreal and establishes engineering labs and training facilities

1993

1999

2001

2004

2007

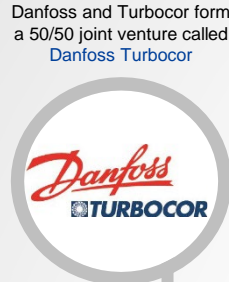
2010

2013

2014

2018

2020

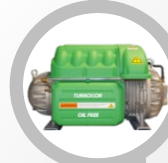


Danfoss and Turbocor form a 50/50 joint venture called Danfoss Turbocor

Full line of TT Series compressors released with up to 200 Tons nominal capacity



Introduction of the first centrifugal compressor TG310 to use Low GWP refrigerant HFO1234ze



Introduction of the TTH/TGH compressor, the world's first Oil-Free compressor optimized for high lift applications



Introduction of the VTX1600 compressor, having up to 450 Tons nominal capacity



Turbocor begins as an R&D startup company in Australia with an international team of designers and engineers

First Turbocor compressor TT300 installed in California, USA



60-90 Ton



Danfoss Turbocor relocates Headquarters to new state of the art facility in Tallahassee, FL (USA)

Danfoss acquires 100% ownership of Danfoss Turbocor Compressors



Introduction of VTT Series of Compressors having up to 400 Tons nominal capacity



Introduction of the TGS490 compressor, the world's first Oil-Free compressor optimized with low GWP, non flammable R515B

Danfoss Turbocor®

Global Footprint

Danfoss Group

Danfoss Climate Solutions

Commercial Compressors

Danfoss Turbocor

2
FACTORIES



3
SERVICE CENTERS




337
EMPLOYEES WORLDWIDE




120,000+
COMPRESSORS INSTALLED WORLDWIDE



US: Tallahassee FL 
Plant Opening: 2007




- Main Site, all functions
- IATF Compliant
- Technology Center
- Capacity 10,000 units/year
- 10,000 m² including ADC
- 265 People

Germany: Offenbach 
Opening 2016



- European Service Center
- Better service the European OEMs
- 240 m² Office/Lab/Warehouse
- 10 people

China: Haiyan 
Plant Opening: 2017



- Assembly Line/ Service Center
- Dedicated CN and APA
- ISO 9000 and ISO14000
- Capacity from 6,000 to 13,000
- 4,000 m² + 2,000m²
- 58 people + 4 APAC employee

1933 Danfoss was founded by Mads Clausen

2013 Danfoss Turbocor wholly acquired by Danfoss

2023 Danfoss is a privately-held company and controlled by the Bitten and Mads Clausen Foundation.

Danfoss Turbocor® Market

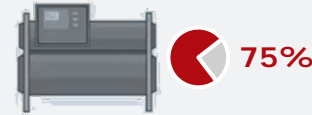
By Region and Application type

Installed Base

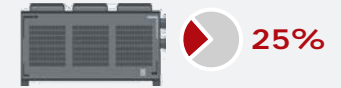
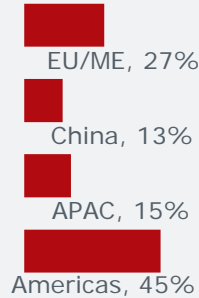
+120,000 Compressors



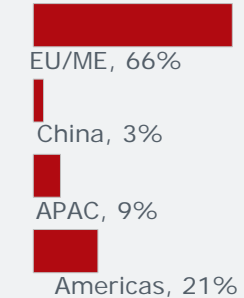
Application Type



Water-Cooled Chillers



Air-Cooled Chillers



World's largest installed base
of Magnetic Bearing Chillers



We have doubled Danfoss Turbocor in five years

**2022:
~EUR 220M**

**2021:
EUR 163M**

**2017:
EUR 109M**

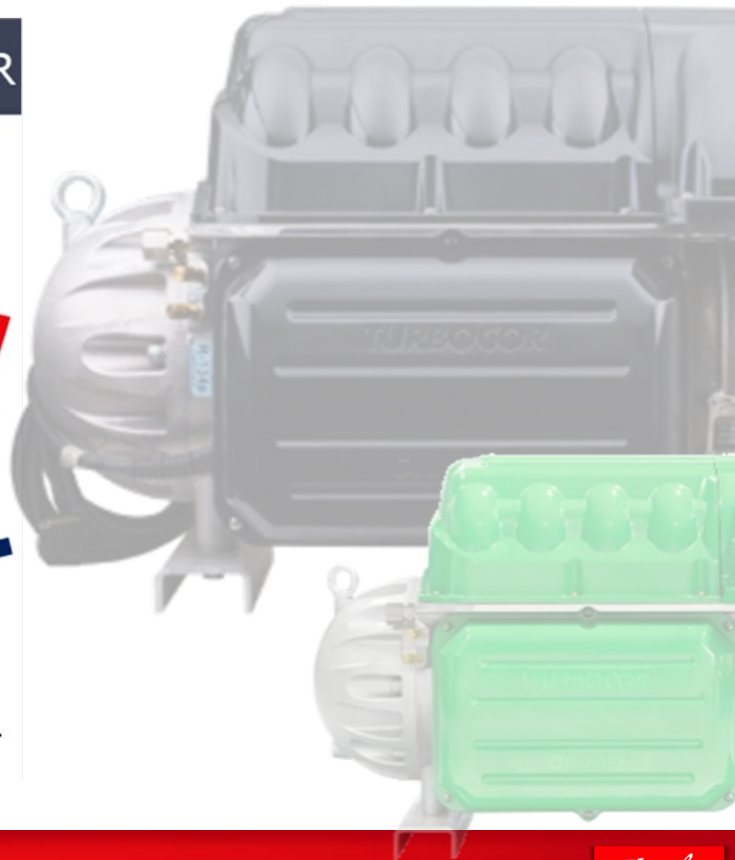
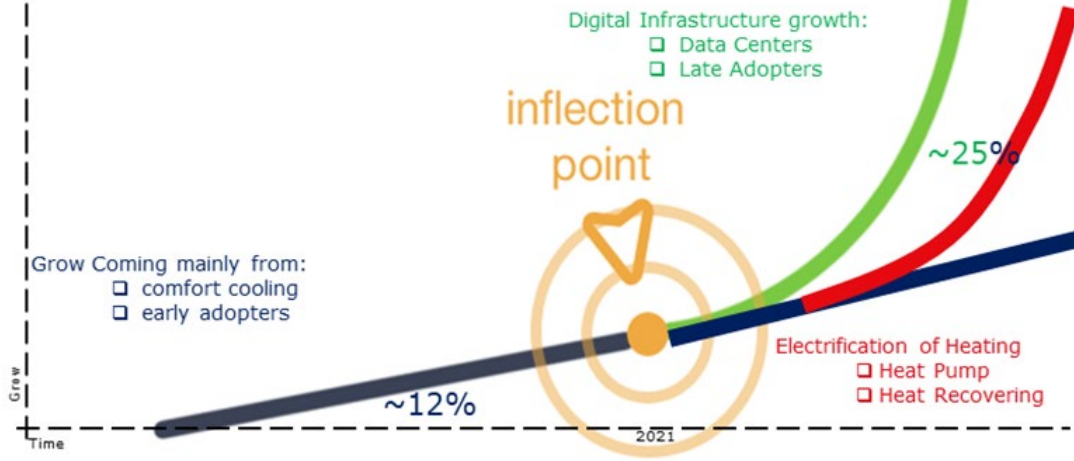
Danfoss

2027

~EUR 500M

Innovation+ Inflection Point From 12% to 20% CAGR

- 10 Years of ~12% CAGR mainly from comfort cooling
- Digital infrastructure and Electrification of Heating will add another layer to the comfort cooling demand.
- The next 5 years we will experience ~25% CAGR.



DANFOSS TURBOCOR PROMISE

We will continue to be #1 and the leader of high efficiency oil free centrifugal compressors, driving customer satisfaction within global air conditioning, heating and refrigeration.



Danfoss Turbocor & ESG

As the Leader and Pioneer of Oil Free Compressors, it is natural to make ESG an integrated part of our value proposition and culture.



Environment



Social



Governance



Decarbonization

Danfoss Turbocor

- **Oil Free Technology (free hydrocarbons)**
- **Low GWP ready**
- **20-40% Energy Savings in HVAC**
- **The lowest carbon foot-print compressors**
 - 1/2 Weight comparing with screw
 - 399 kgCO₂e versus 1,166 kgCO₂e
 - Goal to 200 kgCO₂e by 2028
- **50% of TLH electricity is from Solar**

Circularity

Danfoss Turbocor

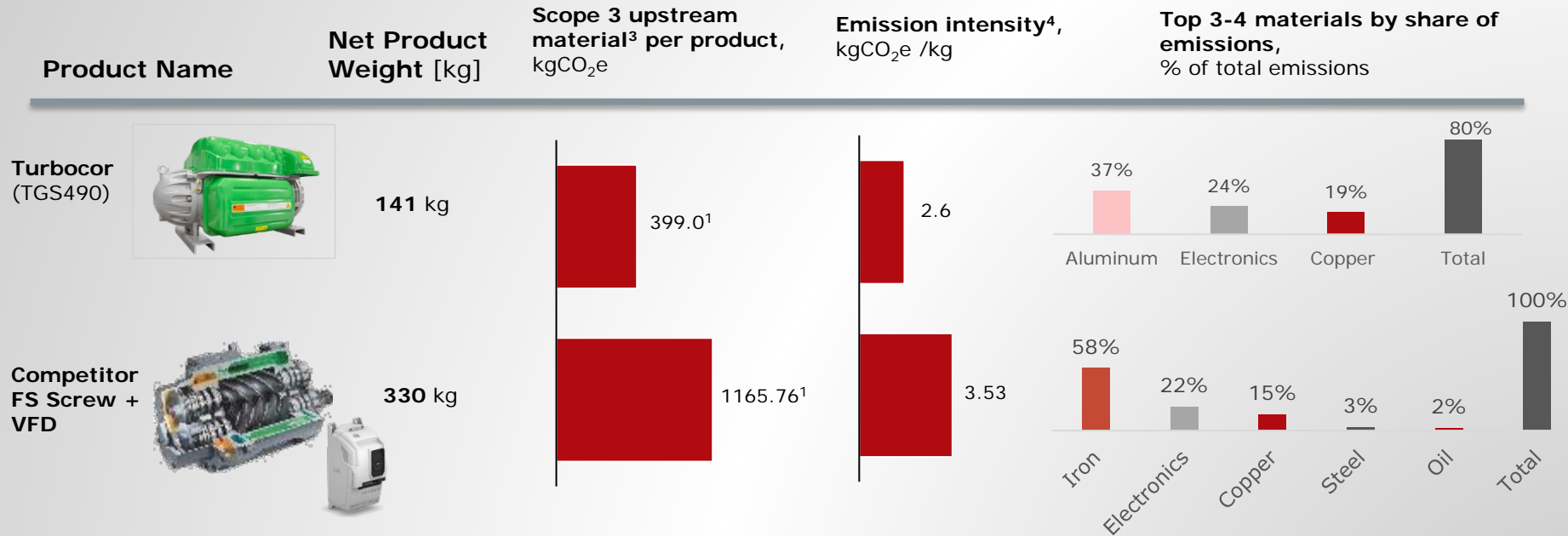
- **Compressor Exchange Program**
 - In Warranty in place
 - Out of Warranty planned
 - End Of Life planned
- **Recycling program in magnets in place**
- **Integrated in the Service Business**
- **Future design requirements**

People & diversity

Danfoss Turbocor

- **Innovation is based in diversity:**
 - 29 Nationalities in TLH
 - High Collective Intelligence
 - Entrepreneurs & Executers
- **FAMU-FSU Engineering School Program**
 - Minority and Underrepresented focus
 - Social Mobility via Education
 - 20% Engineering from FAMU-FSU
 - MOU with SDU
- **30% of the DTC Leadership is Female**

Baseline Emission Comparison [Material Intensity]



1. Aluminium recycling share updated to 75% in baseline emissions based on confirmation with product team;
 2. Steel recycling share updated to 0% in baseline emissions based on confirmation with product team;
 3. Purchased goods and services constitute category 1 of upstream scope 3 emissions, which is commonly the largest share in upstream scope 3 for the manufacturing industry. Materials are usually the main contributor;
 4. Emission factors are forward looking thereby containing the natural abatement of the electricity grid towards 2050 –
 *This comparison is not to be published as it is not fully complete and does not represent the full LCA.

Oil-Free Compressor Technology

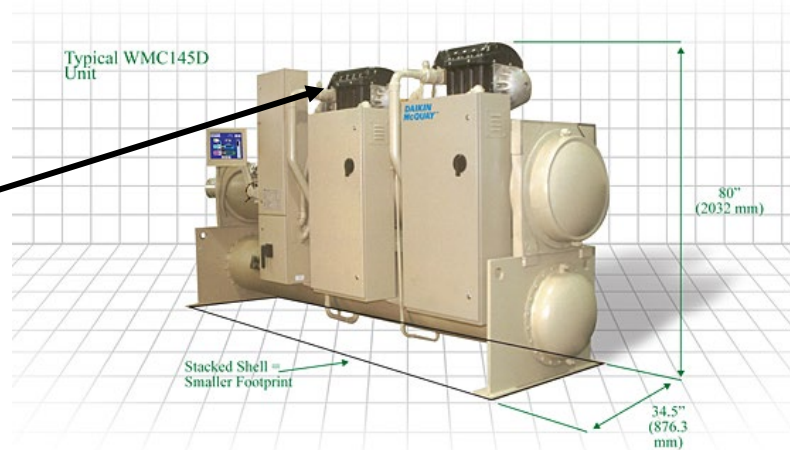


Product application

AC systems in medium to large buildings



Our Compressor...



...is the heart of a water chiller...



...which cools large commercial buildings and processes.

Our OEM customers

Air and water cooled chillers for a wide variety of applications



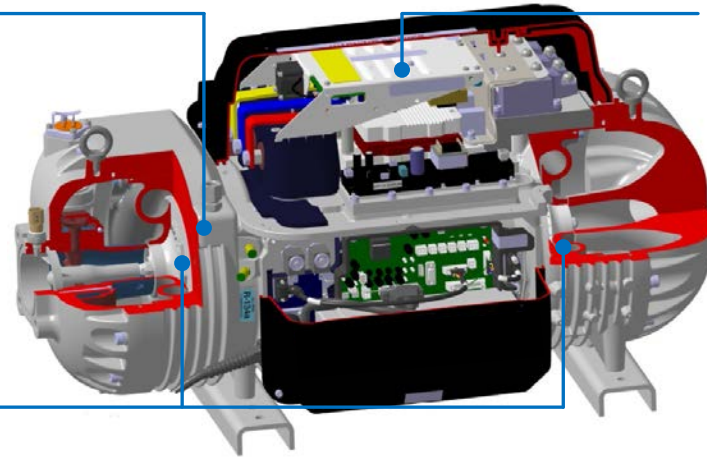
Danfoss Turbocor[®] Compressor

Oil-Free, Magnetic Bearing Technology

Oil-Free Design using magnetic bearings gives unparalleled performance

Permanent Magnet Motor
provides outstanding full
load efficiency

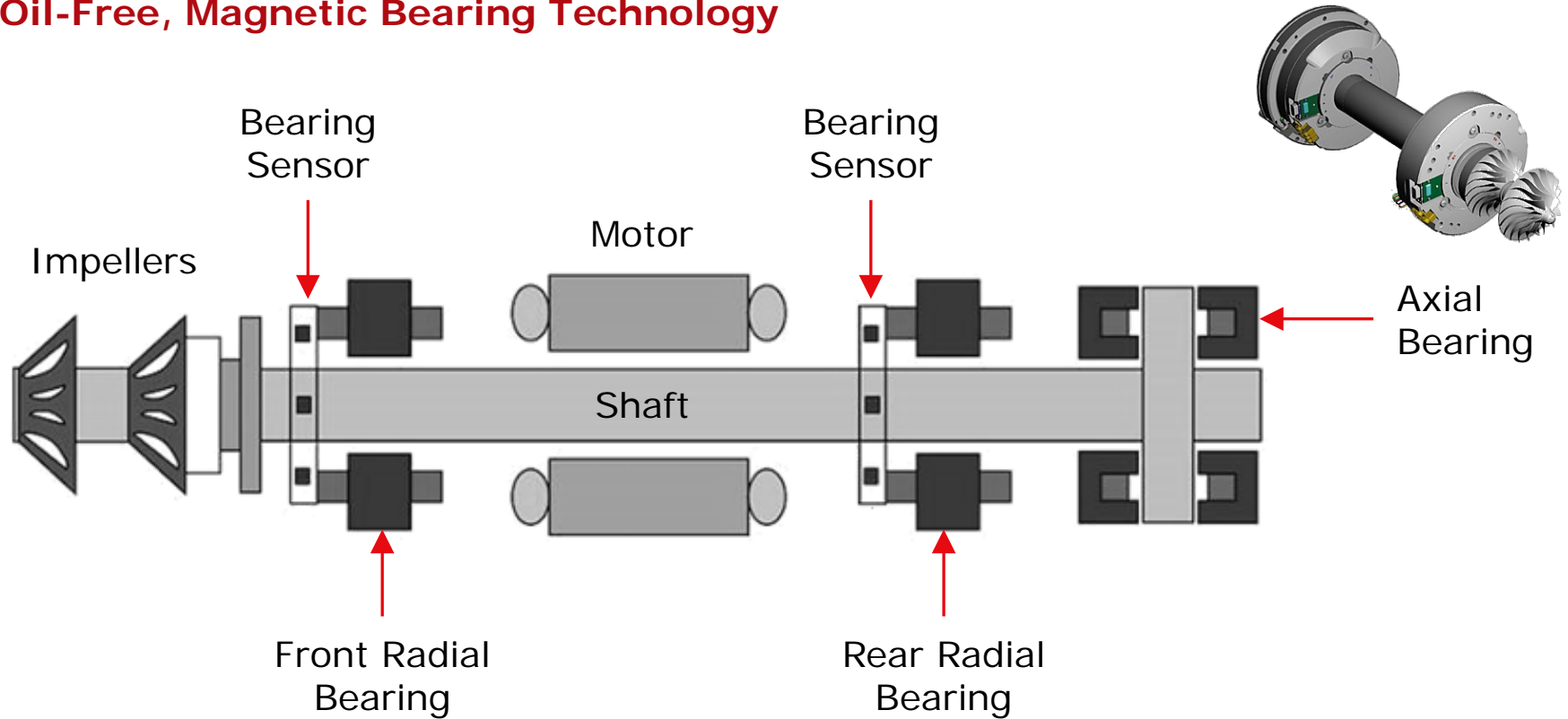
Integrated Variable Speed Drive
provides industry leading part
load efficiency



Two Stage Impeller Design
supports high lift operating
conditions

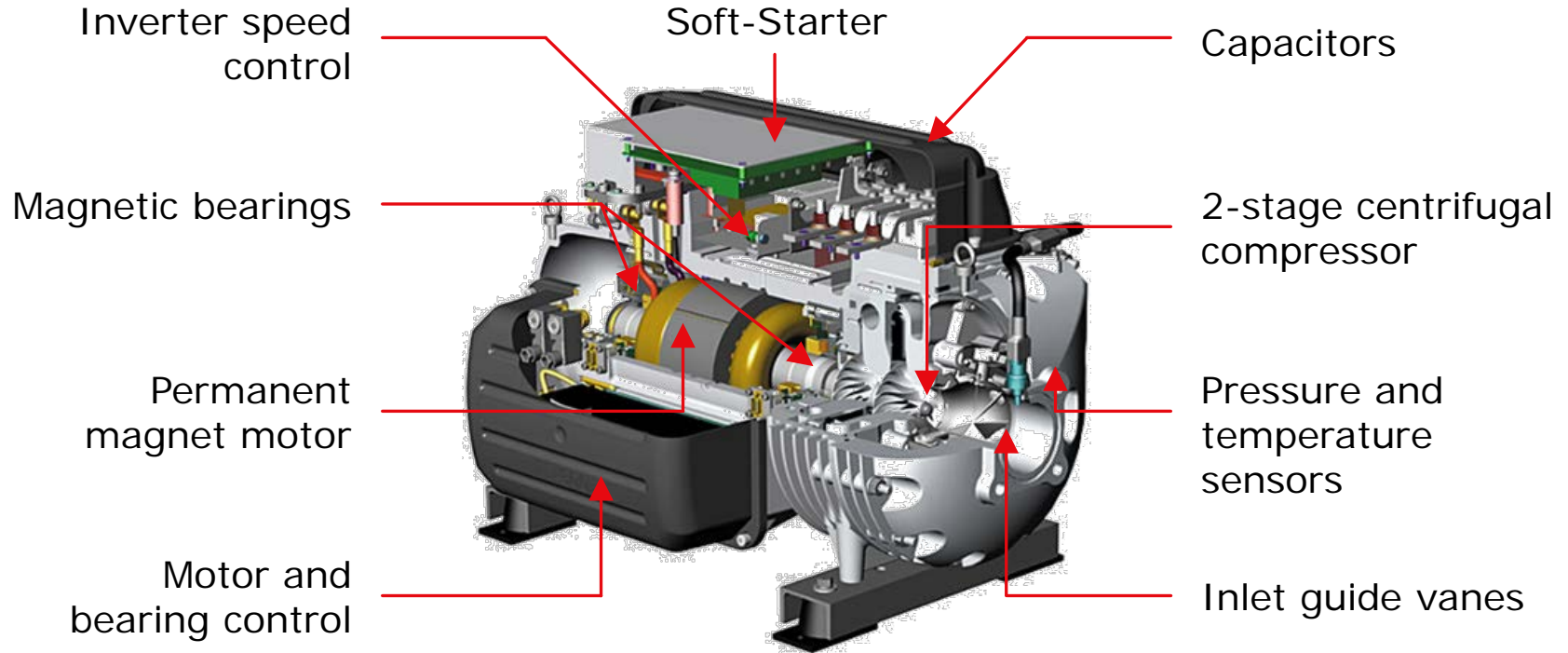
Danfoss Turbocor[®] Compressor

Oil-Free, Magnetic Bearing Technology



Danfoss Turbocor® Oil Free Compressor

Oil-Free, Magnetic Bearing Technology



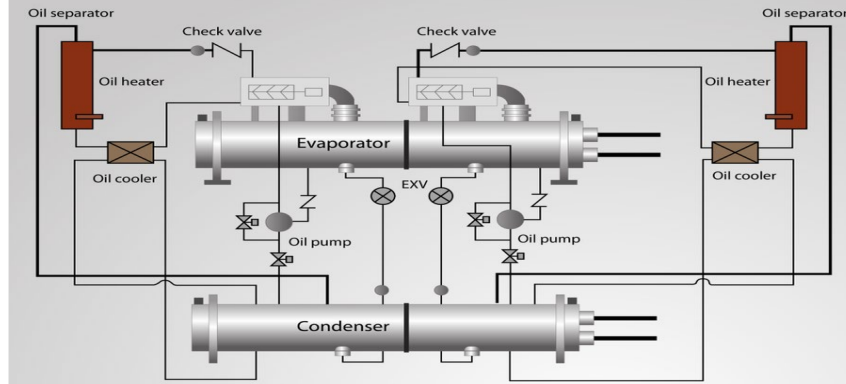
Oil-Free vs Traditional Oiled Compressors



Oil-Free Compressor Technology

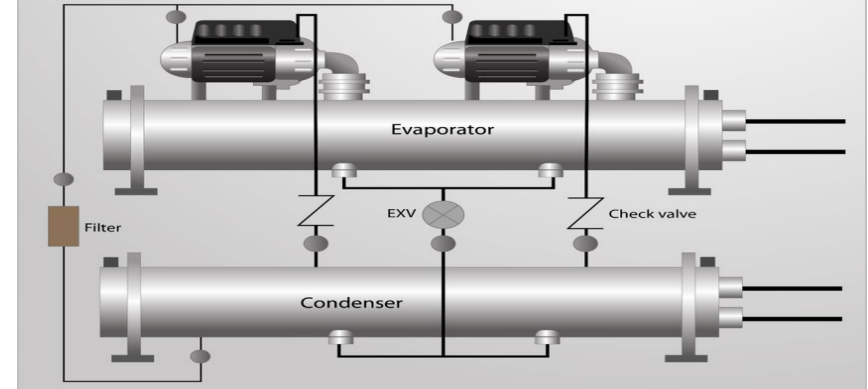
vs Oiled Compressors

Typical Oil Management System



- Oil is required to lubricate bearings which are used to support rotational and linear movement of the rotor
- Form seal to prevent refrigerant from going back to suction
- Lubricate open drive compressor shaft seal to prevent refrigerant leakage

Oil-Free System



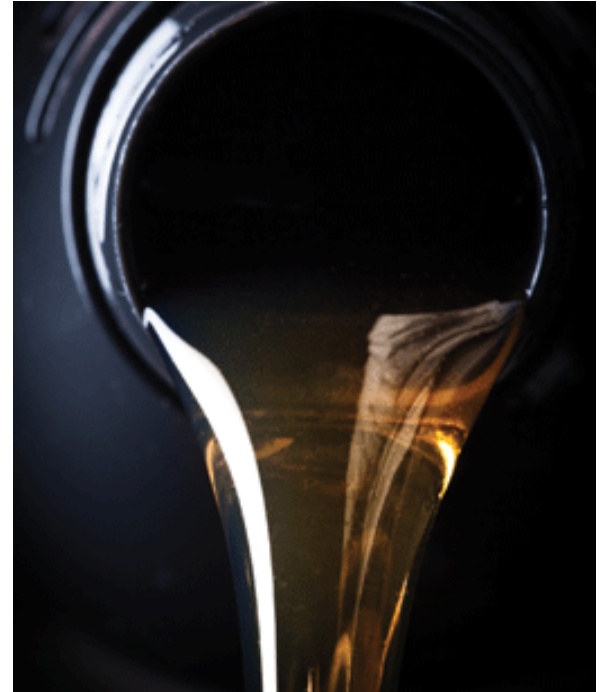
- No lubrication required
- Oil-Free, magnetic bearings provide a less complex and reliable design

Maintenance

vs Oiled Compressors

Maintenance Task	Oiled Chiller	Oil Free Chiller
Check Oil Level	Daily	<i>Not Required</i>
Change Oil	\$1,600 Annually	<i>Not Required</i>
Replace Oil Filter	\$2,000 Annually	<i>Not Required</i>
Inspect Key Components Oil pump, sump heater	Weekly	<i>Not Required</i>
Oil analysis	\$50 Annually	<i>Not Required</i>

- **Total annual maintenance cost associated with the oil management system = \$3,650**
- **Lifetime maintenance cost associated with the oil management system = \$83,950**
- Note: Based on 23 year chiller life expectancy per ASHRAE Handbook

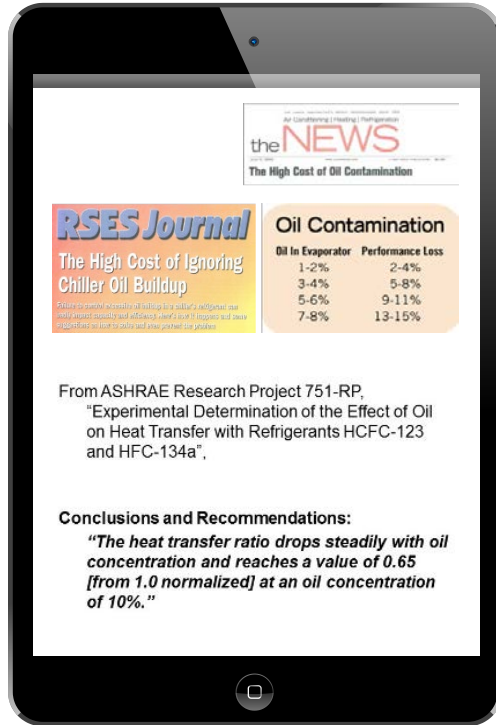


Long Term Performance Oiled Compressors



Long Term Performance

Performance Degradation due to Oil

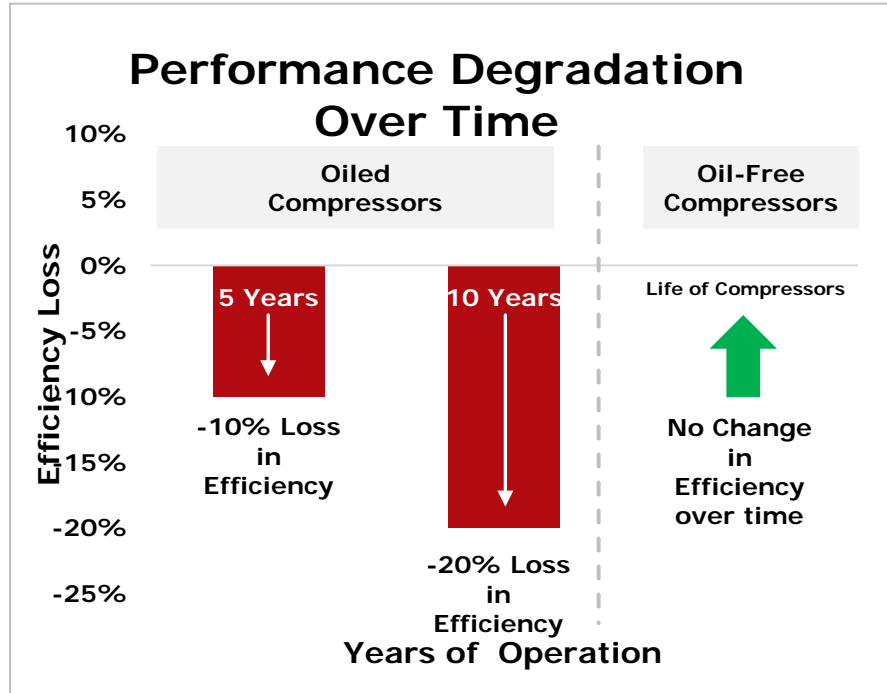


Numerous 3rd party studies have proven that ***the majority of chillers have excess oil charge***, resulting in degraded performance over time

- ASHRAE Research Project 751
- ASHRAE Research Study 601

Long Term Performance

Performance Degradation due to Oil



2014 Tsinghua University Study

Oiled compressors incur significant performance degradation:

- 10% efficiency loss after 5 years
- 20% efficiency loss after 10 years in oil-lubricated chillers

Long Term Performance

Performance Degradation – Mechanical Wear



Mechanical wear affects performance over time

Another study found that significant mechanical wear occurs on oiled screw compressors over time that affects performance due to:

- Excessive bearing wear
- Capacity slide damage

Conclusion:

- Screw compressor wear significantly impacts performance by the fifth year of operation
- Subsequent performance degradation was found to be as high as 26 percent on average after 15 years of operation.



Source: Ying Zheng and Michael Bellstedt (Minus40 Pty Ltd). "Final Report: Compressor Degradation Assessment and Wear Mitigation Strategy."

Danfoss Turbocor Case Study Validation



Case Study Validation

Zero Performance Degradation

No Performance Degradation – Guaranteed!

- Oil free compressors incur zero performance degradation and no mechanical wear over their operational life
- Danfoss undertook a study in 2018 to validate long term operation of Turbocor compressors



TEN-YEAR STUDY
Oil-free Refrigeration Compressors
Provide Consistent Performance

By Eddie Rodriguez, Danfoss Turbocor® Compressors

► Cooling large buildings typically requires the use of air- or water-cooled chillers that produce chilled water, which then cools the air. About 39% of buildings over 100,000 square feet use chilled-water systems employing various refrigeration compressor designs.

Selecting the right chiller and compressor requires a specifying engineer to determine the building's cooling load and the proper chiller capacity¹⁴ (calculations are also done to determine the return on investment between different systems by comparing the energy

cost per ton of refrigeration along with the operational cost.

When buying a new chiller, specifying engineers and facility owners naturally focus on efficiency ratings to estimate the chillers

¹⁴ A significant factor that affects chiller performance over time is the oil used by the chiller's compressor.

— Eddie Rodriguez, Danfoss Turbocor® Compressors

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Case Study Validation

Zero Performance Degradation

No Performance Degradation – Guaranteed!

The scope of the study consisted of:

- Testing (3) compressors in operation for 10+ years in the field
 - Hershey Factory, USA
 - ABC Studio, Melbourne Australia
- Compare compressor performance results vs original test results to see if there was any deviation



Oil Free Compressor Technology

Zero Performance Degradation

No Performance Degradation – Guaranteed!

Criteria for Passing:

- Referenced **AHRI 540-2015 Performance Rating of Positive Displacement Refrigerant Compressors and Compressor Units** since no standard exists for centrifugal compressors

**AHRI 540-2015 – Region 3
(Comfort Cooling)**

5.7 *Rating Uncertainty Limits for the Verification of Published Ratings.* Published Ratings shall fall within the Application Envelope specified in Table 2 (I-P) and Figure 1 (I-P) or Table 2 (SI) and Figure 1 (SI).

Table 3. Rating Uncertainty Limits for the Verification of Published Ratings			
Published Rating	Region 1	Region 2	Region 3
Minimum Refrigerant Mass Flow, lbm/hr, kg/s	90.0%	92.5%	95.0%
Minimum Refrigerating Capacity, Btu/h, W	90.0%	92.5%	95.0%
Maximum Power Input, W, W	110.0%	107.5%	105.0%

Oil Free Compressor Technology

Zero Performance Degradation

Test results:

- All 3 compressors tested within AHRI 540-2015 uncertainty limits for
- Power kW ✓
- Mass flow ✓

Hershey PA S# 072575160					
	Suction Pressure	Discharge Pressure	Power	Mass Flow	RPM
Original Test	359.33	918.88	46.8	101.08	31905
Latest Test (cap 3 file)	362.1	919.75	48.0	103.23	30656
Deviation	0.77%	0.09%	2.56%	2.13%	-3.91%

Hershey PA S# 072605010					
	Suction Pressure	Discharge Pressure	Power	Mass Flow	RPM
Original Test	353.0	912.39	48.7	100.18	32002
Latest Test (new igbt 3 file)	354.74	914.91	49	100.33	32005
Deviation	0.49%	0.28%	0.62%	0.15%	0.01%

ABC Studio, Melbourne Australia S# 081925070					
	Suction Pressure	Discharge Pressure	Power	Mass Flow	RPM
Original Test	357.74	917.67	46.3	96.45	32016
Latest Test	358.38	917.75	47.5	95.56	32026
Deviation	0.18%	0.01%	2.59%	-0.92%	0.03%

Oil-Free Compressor Technology

Zero Performance Degradation



Oiled Screw Compressor



Oil Free, Magnetic Bearing Centrifugal Compressor

Mechanical Wear

Significant mechanical wear affects performance in as little as 5 years



No mechanical wear over the life of the compressor

Performance Degradation

Up to 20% loss after 10 years



No capacity or efficiency degradation over the life of the compressor

Danfoss Turbocor Advantages

Superior Performance and Savings over Screw Compressors

More Efficient



Up to 40%
Better Part
Load
Efficiency

Quieter



8 dBA
quieter

Smaller / Lighter



Up to 1700
Lbs / 771
kg less
weight

No Degradation



Proven 0%
Reduction in
Performance
over Lifetime

Perfect for any application where efficiency, sound, lifetime performance and size are critical

New Low GWP Refrigerant Options

R515B



What is R515B?

Refrigerant	R515B
Composition	R1234ze (91.1%) and R227ea (8.9%)
ODP	0
AR5 GWP	299
ASHRAE Safety Classification	A1
Glide	OR / OK

New Low GWP Refrigerant Options

R515B

R515B addresses the following regulatory issues



■ ASHRAE A1 Safety Classification:

- Current code regulations do not permit the use of A2L refrigerants



■ Provides solution to the following:

- California - Ban on use of HFC134a and R410A in new chillers as of January 1, 2024
- Canada - GWP limit of 750 for chillers on January 1, 2025

Danfoss Turbocor® Compressors

Product Portfolio Optimization 2023+

Primary Optimization Targets

Data Centers

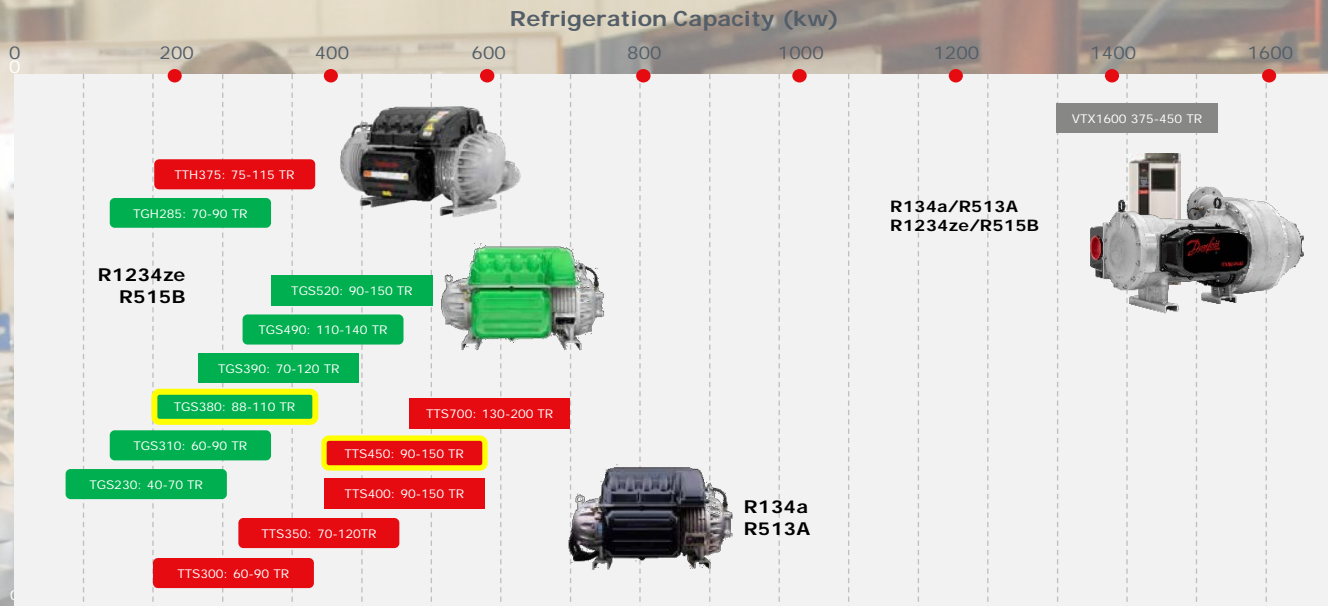
- High Suction Temperature
- Low Lift
- Drive Through Voltage
- Redundancy
- Connectivity & Monitoring

Medium Temp Refrigeration

- Ice Rinks
- Food Process & Storage
- Brewery & Beverage

Electrification of Heating

- High Discharge Temperature
- Patent electronic thermal management
- Heat Pump
- Heating Boosters



Product Optimization Opportunities

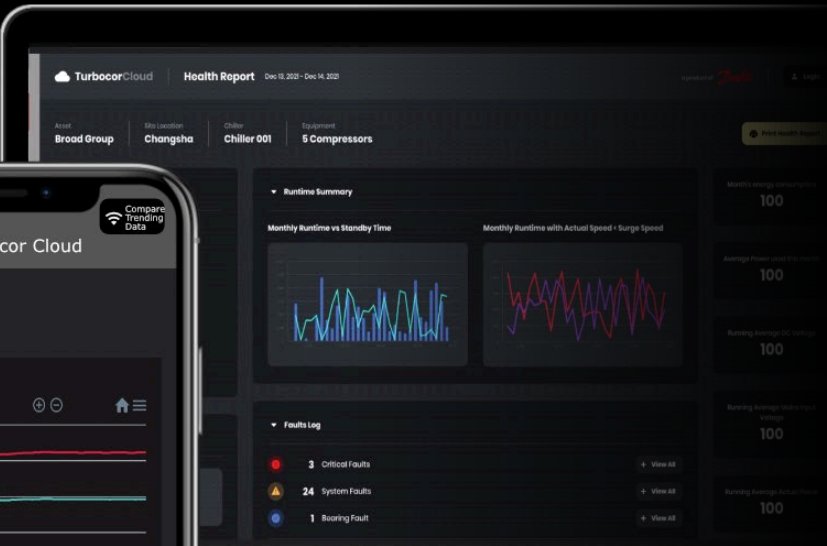
Specific Applications

Operating Envelope Expansion

Refrigerant Optimization

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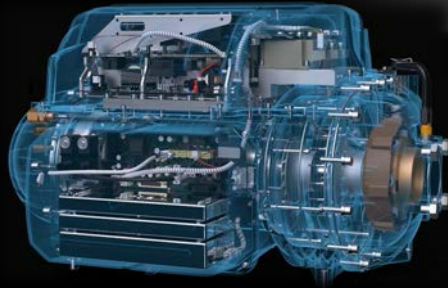
Danfoss Turbocor Digital Products

 **TURBOCOR**[®]

Turbocor® Cloud Monitoring

Turbocor Cloud Monitoring Platform

New service for compressor monitoring, leveraging more than 50 different sensors & inputs onboard Turbocor® compressors.



Data Logging

- Store events and faults to assist in troubleshooting
- Dashboard for real-time compressor monitoring and historical trending

Alerts

- Compressor information is relayed to the Monitoring Software and Chiller Controller
- Critical conditions are presented as alarms and or faults
- Information conditions are presented as alarms only

Smart Prognosis

- Condition based monitoring of internal components with compensation or warning for replacement

Timing for Release – Currently Expected 2H2023

Support for aftermarket through exchange and fixed price



DTC Product Store

Turbocor Product Store

- Configure compressors and easily identify associated spare part parts
- Net pricing and part number visibility
- Create quotations, view order history, order status & tracking info.
- Delivery note and invoices documents available
- Easily find all product literature including spare parts instructions with pictures

Future store features:

- OEM can create their own price list (price book)
- Ability to place orders via store



TurboTool® Mobile App



NEW – Q32023

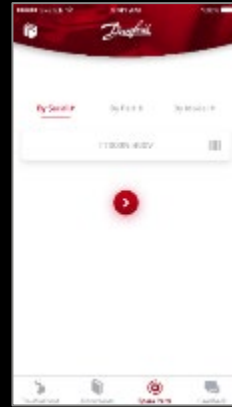


Troubleshoot



The TurboTool® app makes it easy for technicians to troubleshoot issues on Danfoss Turbocor® compressors.

Spare Parts



A quick scan of the compressor serial # using your smartphone camera or entering the part # or model # and the app will display potential spare parts kits.

Cloud Commissioning



The tool for Turbocor Cloud Services commissioning. The app allows technicians to test and verify cloud connectivity and data transfer all while onsite, in front of compressors

Documentation



Service manuals are available at your fingertips on your smart device.

DTC Tallahassee Greenfield Factory



DTC Tallahassee Greenfield Factory – Site View



Tallahassee Expansion - Greenfield

12,500 SQM – Enhanced Manufacturing





**ENGINEERING
TOMORROW**

Need Assistance?

For more information please contact your Key Account Manager or our Product Support group at turbocor.ps.na@danfoss.com.