For the production and storage of ready meals for air passenger catering, the Frankenberg GmbH, domiciled in the German city of Würselen near Aachen, needed a new building for production, storage and administration. The refrigeration and air conditioning equipment for the new facilities was selected in close cooperation with the company York Deutschland GmbH. Together, they developed a refrigeration concept in which CO₂ is used as refrigerant for production frosting and deep-freeze storage and R507 is used in the area of production cooling.

In order to develop an economically reasonable and at the same time environmentally friendly equipment for the new facilities of the Frankenberg GmbH, the company firstly con-
ducted conversations with different refrigeration plant engineers and discussed different solutions based on the following consumption scenarios: To find a long-term reliable solution, the company developed a concept comparison between the different refrigeration concepts in cooperation with YORK Deutschland GmbH. Apart from the technical requirements, there were other conditions to fulfill in addition to the target of an exceptionally cost-effective investment. Thus, the company wanted:

- maximum waste heat utilisation / heat recovery and good overall COP-value
- production frosters should have pump circuits, refrigerant NH₃ or CO₂
- no NH₃ coolers in processing rooms / workplace regulation
- no refrigerating system that is subject to authorization in accordance with BImSchG (federal law for the protection against emissions)
- cost-effective investment

**Comparison of system concepts**

During a joint project cooperation of three to four months, the overall concept was examined from different angles. This approach was mandatory, as the refrigerating system plays an important role in the scope of the necessary investment (approx. 15 % of total investment) as well as in the current operating costs; besides, it was intended for a period of use of 20 to 30 years. Three different refrigeration concepts were compared in detail:

- NH₃ system, two-stage, with brine system for processing
- NH₃/CO₂ cascade refrigerating system with brine system for processing
- R₅₀₇/CO₂ cascade refrigerating system with R₅₀₇ direct evaporation in processing

Moreover, in the scope of these concepts, the use of reciprocating compressor aggregates and screw compressor aggregates respectively were examined and compared with regard to investment requirements and maintenance costs as well as sound emissions.

**Decision pro cascade refrigerating system**

Finally, it was decided to use an R₅₀₇/CO₂ refrigerating system, as it is an economically as well as ecologically wise solution. CO₂ is a common and established refrigerant and can be used in refrigerating systems in many areas of food refrigeration and deep freeze storage. The cascade refrigerating system with SABROE reciprocating compressor aggregates includes the following main components:

- 3 CO₂ reciprocating compressor aggregates
- 2 CO₂ condensers
- 1 CO₂ receiver
- 1 CO₂ pump separator
- 3 R₅₀₇ reciprocating compressor aggregates
- 1 R₅₀₇ separator
- 1 R₅₀₇ HD receiver
- 1 evaporative condenser
- 1 R₅₀₇ plate heat exchanger for condensation
- 1 horizontal R₅₀₇ pressure gas desuperheater
- 1 air-cooled R₅₀₇ condenser
- 1 R₅₀₇ heat exchanger for brine cooling of continuous pass-through cooking machine
- 3 froster valve stations for CO₂ pump operation
- 13 deep freeze storage coolers CO₂-DX-operation
- 22 room coolers R₅₀₇-DX-operation
- 1 air conditioning water chiller plate heat exchanger

**Equipment with many advantages**

The decision to use this equipment was based on numerous advantages:

- good partial load behaviour due to use of reciprocating compressor
- high total COP-value: 1.42 (incl. pumps/fans and auxiliary drives)
- in comparison to NH₃ two-stage or NH₃/CO₂ cascade system, more favorable investment by about 100 - 150 thousand
In addition, this solution made it possible to reconstruct without problems an existing Samifi production froster for CO₂ pump operation.

Successful operation

After a construction period of 5 months, the new Frankenberg plant has been in continuous operation since the beginning of March, and during the summer, it has already proven itself at exterior temperatures of +35 °C.

Frankenberg: "Warm meals for specific needs"

The Frankenberg GmbH, domiciled in the German city of Würselen near Aachen, specialises in developing, producing and distributing ready meals for air passenger catering. These "hot meal" and "ready meal" products depend on supreme quality and availability. As a business partner of many international airlines, particularly the smooth and flexible production is an important cornerstone of the company's success.

Refrigerant CO₂

Carbon dioxide has been used as a refrigerant since 1850 and has a long tradition in refrigeration engineering. Considering the process to
abandon the production and use of CFCs and the associated mounting relevance of so-called natural refrigerants, the economic advantages of using CO₂ in refrigerating plants are being rediscovered, too. Some important characteristics are:

**Environment:**
- low greenhouse warming potential (GWP = 1)
- nontoxic at low concentrations – ambient air = 330 ppm
  - limit of comfort = 1.000 - 1.500 ppm
  - MAC = 5,000 ppm (0.5 %, equals 9,000 mg/m³)
  - exhalation = 3-4 % vol.
  - IDHL = 40,000 ppm (4.0 % vol.)
  - benumbing effect at concentrations above 10 % vol. in the breathing air
  - instantaneously lethal at concentrations above 30 % vol.
- non-flammable (used as fire extinguishing agent)
- heavier than air

**Refrigerating system**
- high volume flow-related refrigerating capacity (5 to 7 times higher than ammonia)
  - low compressor cubic capacity + piping cross sections
- high refrigeration figure of merit at low temperatures
- low viscosity
  - low pressure losses
- pressure losses entail only small drops in temperature
- high operating pressures (e.g. 40 bar bei +5 °C)
- low pressure relations
  - high process efficiency of the compressors
- high overall heat transfer rates during evaporation and condensation (up to 60 % above that of HFC)
- good compatibility with common materials and machine oils for refrigerating systems
- triple point at 5.18 bar and -56.6 °C
- low critical temperature 31.05 °C
- max. condensation temperature 10 - 15 °C in 50 bar-systems

**History of CO₂ as refrigerant**

1866/69  application by LOWE (dry ice)
1877  condensation by RAYDT (begin of use as technical gas)
1881/90  Design and construction of refrigerating systems by LINDE and WINDHAUSEN respectively
1887-90  strong development in refrigerating systems, especially in Great Britain and in the U.S.A.
1895  First vapor chart: MOLLIER
1904  first pressure-enthalpy-diagram by MOLLIER (TH Dresden)
1929  detailed p,h-diagram with solid phase: PLANK, KUPRIANOFF
1932  NH₃-CO₂ cascade systems for temperatures of down to -50 °C
1950  60 % of all refrigerating systems used on vessels and 10 % of all fractional and multiple horsepower refrigerating plants
1960-65  CO₂ is no longer used (‡ 0 %)
1989-93  rediscovery and first suggestions regarding plant design (LORENTZEN et al.)

**CO₂ – a bonus for the environment**
Carbon dioxide is primarily used in the beverage and food industry, for cooling during transportation, in water management, in metal processing and for fire fighting.