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natural refrigerants
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LATEST ADVANCEMENTS FOR NATURAL REFRIGERANTS

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I plan to tell you about:

- Advancements in various sectors
- Discuss directions in:
  - Commercial refrigeration
  - Industrial refrigeration
  - Ammonia in HVAC
  - CO_2 in air conditioning
- Refrigerant issue in light of increasing portion of renewable energy generation (w/o CO_2)
- Possible meaning of efficiency and LCCP (TEWI) calculations for the natural refrigerants

Significant expansion of natural fluids in almost every application

- Light commercial refrigeration (small self contained units)
  - Mostly R290 but also strong R744
- Commercial (supermarkets, typically split systems like condensing units or racks)
  - Mostly CO_2 with sometimes R290 or R717 in high side with R744 in low
  - New R290 with secondary loops
- Industrial, R717 (related to charge reduction), R744
- Insufficient expansion in air conditioning
  - Attempts with R290
  - Possible R744

Light-commercial sector

- Plug-in (self contained) systems with either:
  - R290: lower cost, flammability – low charge
  - R744: nonflammable
  - Still the mail issue is the cost
- Novel systems with R290 (also in commercial sector):
  - Water loop on high side
  - Glycol loop on low side
- Regulatory: push to increase allowable refrigerant charge (R290)

Components for light-commercial

- Compressors:
  - Still mostly needed for R744
  - Good number and competitive price for R290
- Condensers for R290 – to reduce charge because they hold most of the charge
- Less soluble oils for R290 and compressors with less oil
- Needed more small compressors for R744
- HXs are opportunity to reduce both charge and cost
- Even more can be achieved in: vending machines, freezers, bottle coolers, water dispensers etc. anything small and plug n play

Supermarket systems differ a bit

- condensing units vs.
- racks

USA and Europe

Japan

Commercial refrigeration sector Supermarket systems

- Ongoing activities:
  - Make CO_2 better at high ambient temperatures:
    - Ejectors: variable flow or stages
    - Various ways to improve “left side” of the diagram: intercooling, split cycles, …
- In 2016:
  - Japan is leading in development of condensing units,
  - MHI just introduced their new 10HP
  - Panasonic launched new 30HP (20+10) and 12HP CO_2 units…
  - We see less CO_2 racks for 50-200 kW… due to regulation?

Industrial refrigeration sector

- Historically the only one with natural refrigerants continuously in use (ammonia)
- Undisputed efficiency but B2L drives:
  - charge reduction,
  - hermetic compressors and
  - indirect systems:
- Japan (mostly Mycom) quite ahead with NH_3/CO_2 secondary systems (800 units by Mayekawa and MHI)
- Very slowly staring with CO_2 DX for cold stores
- US focused on “roof top” container like low charge air cooling units

In conventional industrial refrigeration Large sizes

- Compressors
- Accompanying vessels

Big vessels = huge charges

Equipment is on the roof too

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Numerous and multiple evaporators

Important in this moment

- Recent accidents in China took several lives
- Very strong pressure for sound environmental solutions strengthens the position of ammonia
- **Are we waiting for a big earthquakes in California, Japan, to realize that not only nukes could be a problem?**

Direction: decentralization

- Multiple units - lower capacities
- Smaller sizes - reduced charges
- Safer
- Possibly less expensive (serial production)
- New markets

There are various options to fit different applications:

First step: self contained large facility

- **700 kW ammonia refrigeration package**

Courtesy of Industrial Refrigeration Service, Inc.

Another option: preassembled systems with CO_2 or other coolants

- Can be applied beyond cold storage for:
- Process industry
- Central cooling
- Sport complexes

NewTon

Courtesy of Mycom

Rooftop ammonia units are getting more popular

Courtesy of Evapco

- Cooling air
- Cold stores
- Prep rooms

Courtesy of Nextcold, Inc.

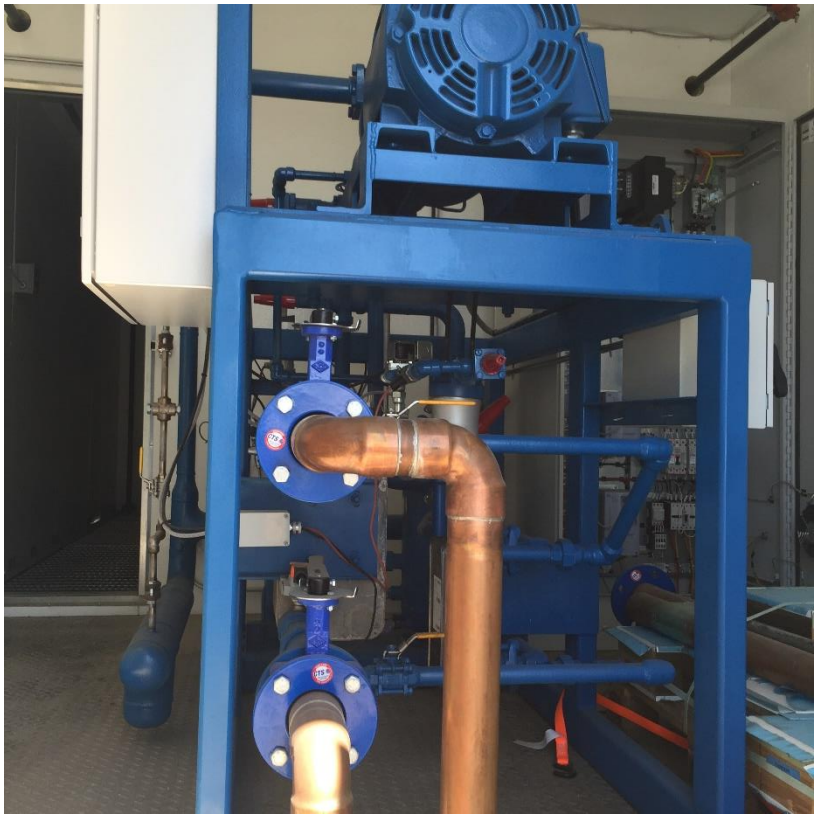
- **150-300 kW ammonia refrigeration units**

Example: Distribution center in Long Beach

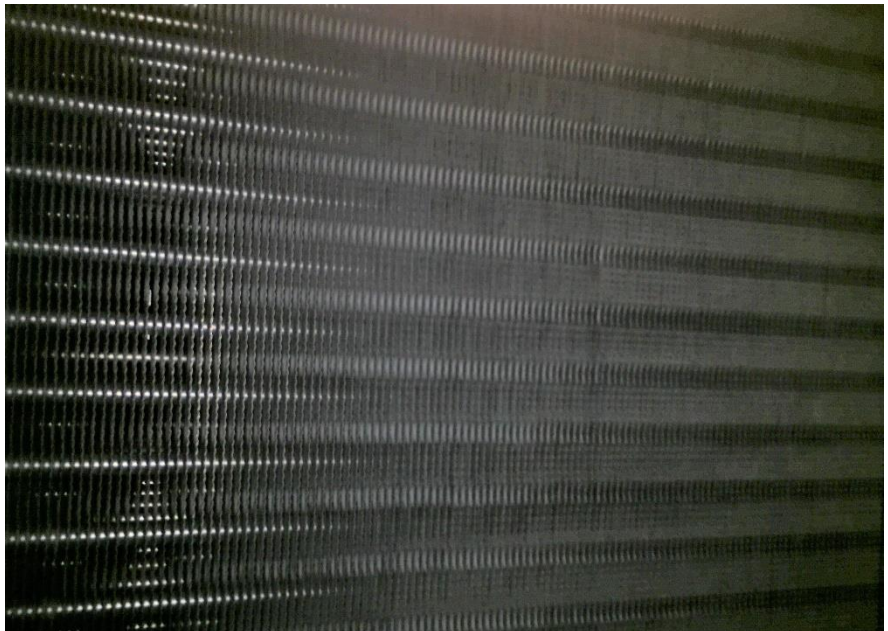
Box has condensing and evaporator part

Miniature cooling tower combined with BP condenser reduce T_{cond} and T_{disch}

Compact screw compressor, controls…



SS evaporator, wet exit



Openings in the ceiling for the units ready in 20 min

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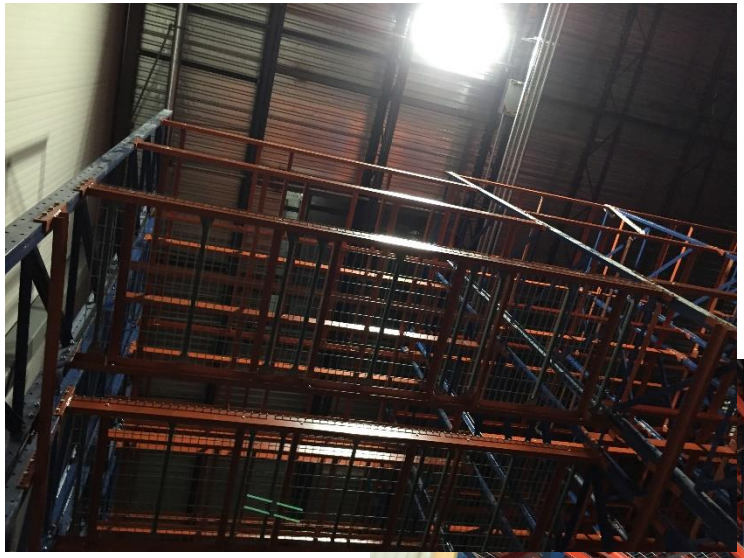
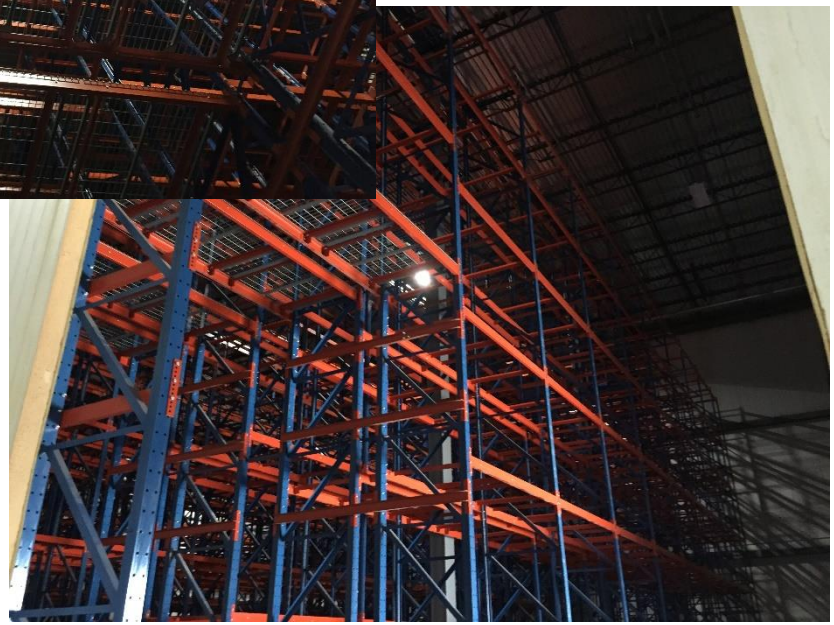
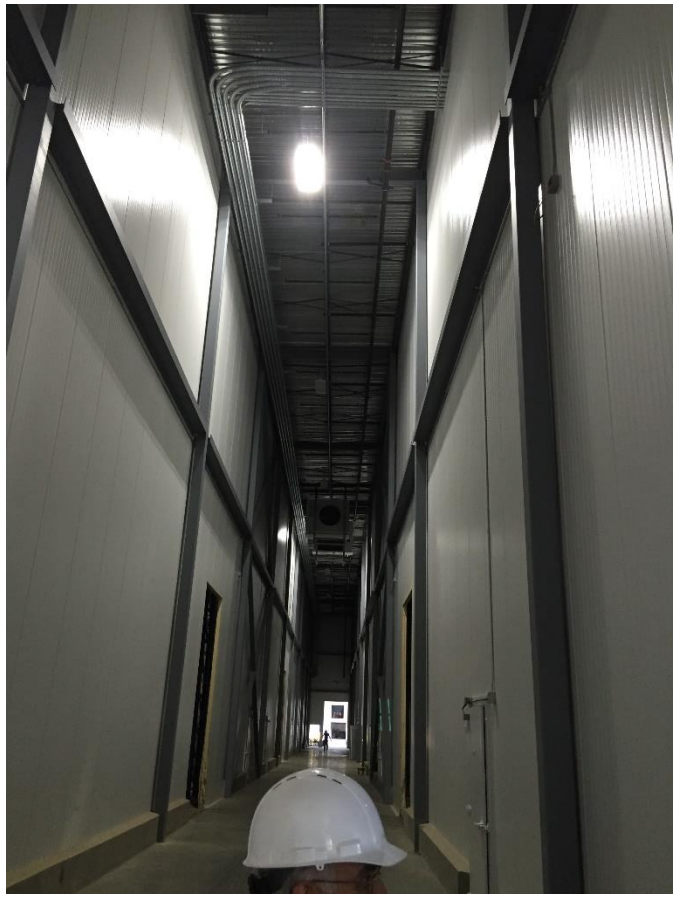
Tall chambers and corridors cooled from above

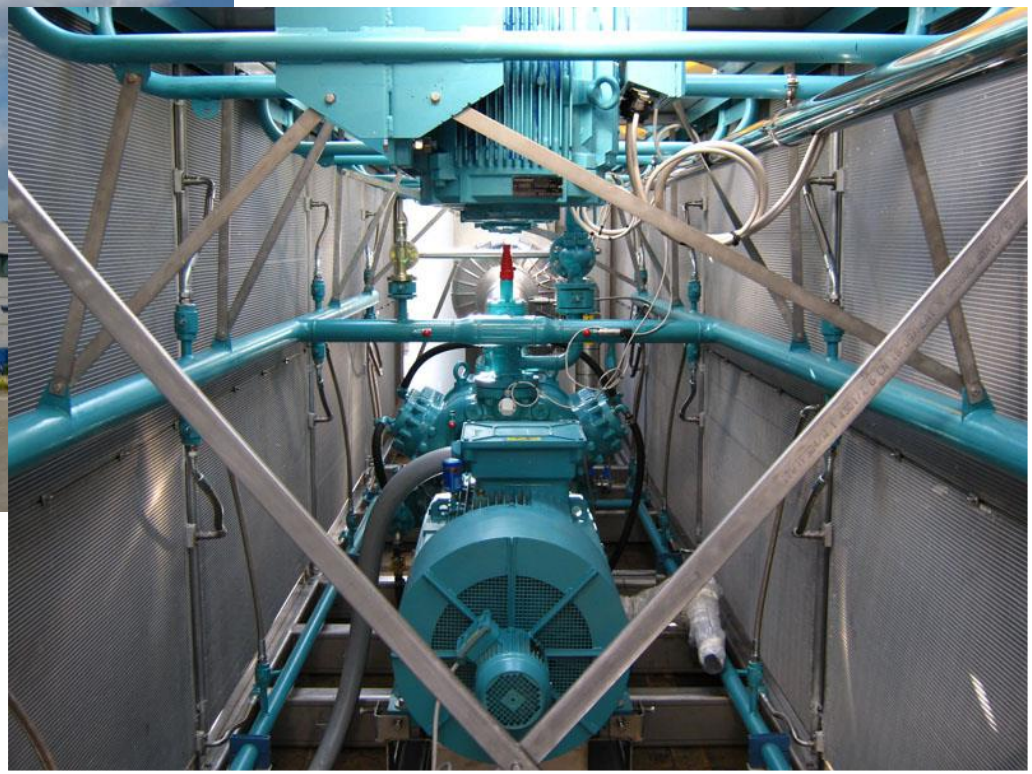






Some are not afraid of MC options

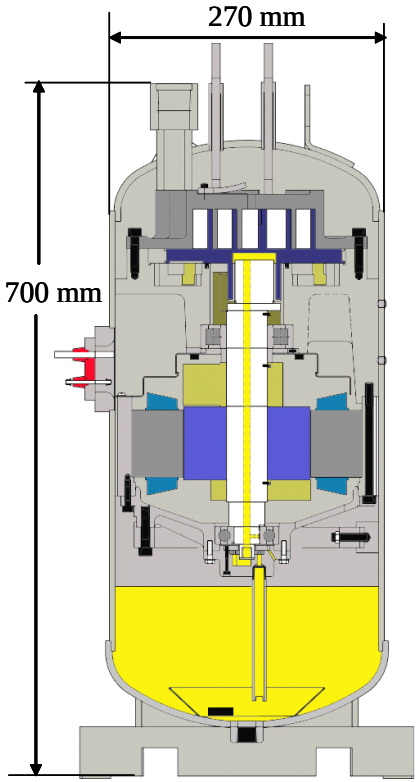
- Air cooled unit on the roof



Courtesy of Zudek, Inc.

Hermetic NH_3 compressors help competiveness of NH_3 for smaller systems

35 kW NH_3 scroll



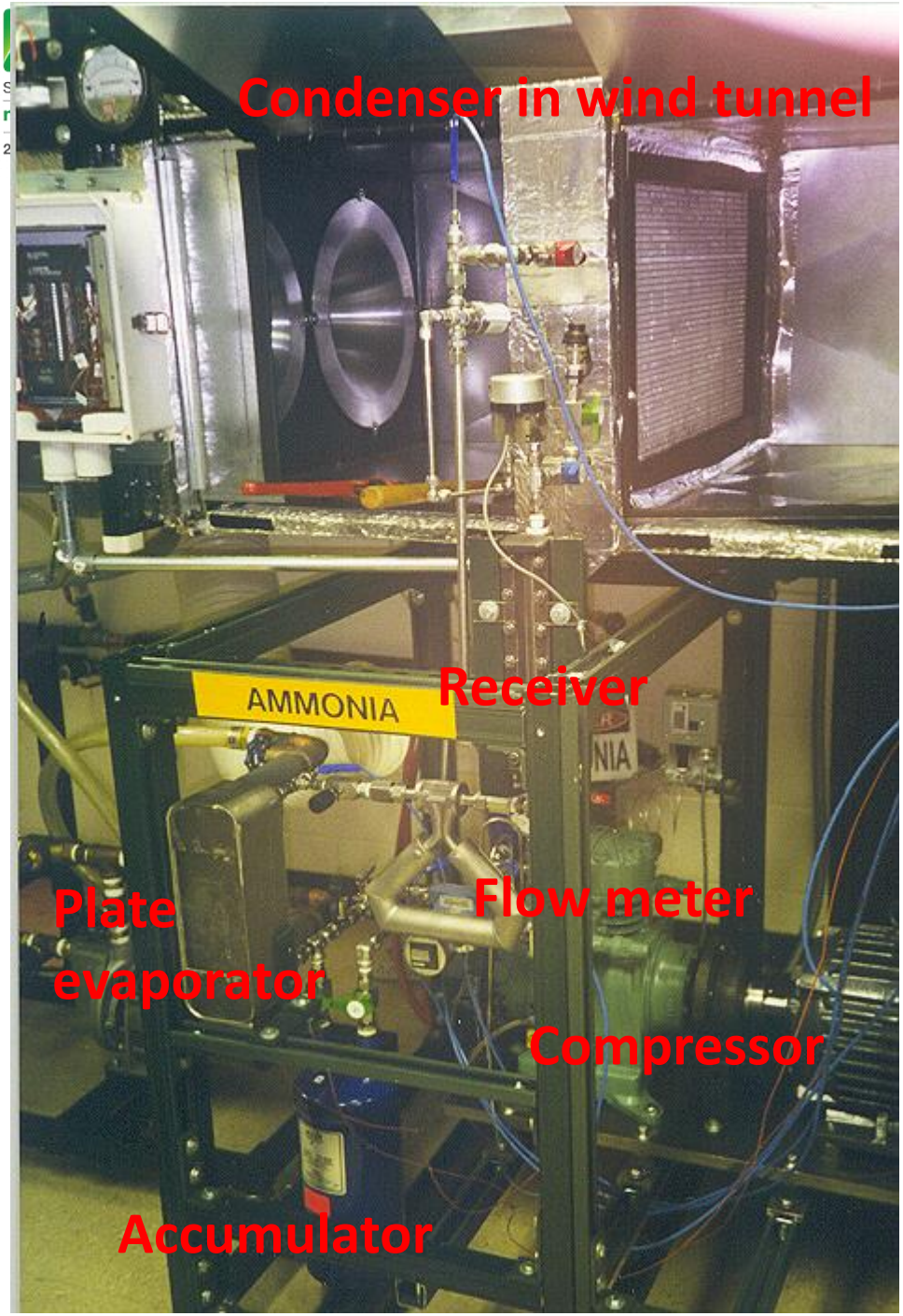
Courtesy Mycom, Inc.

The first real NH_3 chiller with hermetic compressor and MC Cd

Courtesy Mycom, Inc.

Mycom continues: Air cooled ammonia chillers with semihermetic compressors

cts

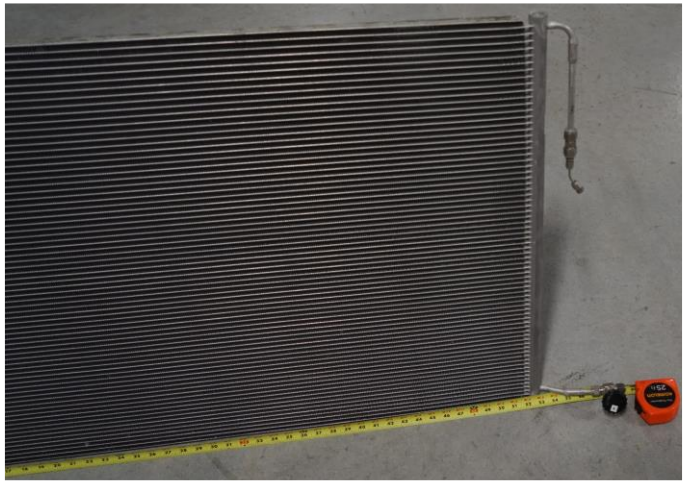


We started air cooled ammonia chillers 15 years ago

18g/kW

And continue development

Newest CTS air cooled chiller with MC Cd has excellent performance with 500g charge



I believe it is time

- To define what is:
  - Conventional charge
  - Low charge
  - Ultra low charge
- And push for charges as low as possible to be able to make regulations same as for R290 and then make ammonia chiller look and act same as any synthetic refrigerant:
  - Hermetic compressor,
  - Light
  - Lower cost

HVAC

- The slowest growing application for natural refrigerants, in germination stage at the moment.
- R410A or R32 impose very high bar in efficiency and cost.
- Absence of good synthetic option except for the blends keeps the door open.
- I believe following directions have real chance:
  - Chillers (ultra low charged ammonia systems)
  - Mini splits:
    - R744 – because no flammability
    - R290 for smaller, self contained and separated systems

CO_2 for air-conditioning:

- Not that many trials:
  - Daikin recently presented (at Purdue conference) a try to reach high COP
  - I will show you for the first time partial result of the work we did ten years ago.

We tried CO_2 in a typical a/c unit

A reasonably efficient R410A system (Q=3.5kW, COP=3.5) used as a baseline:

- Round tube HXs
- Rotary compressor

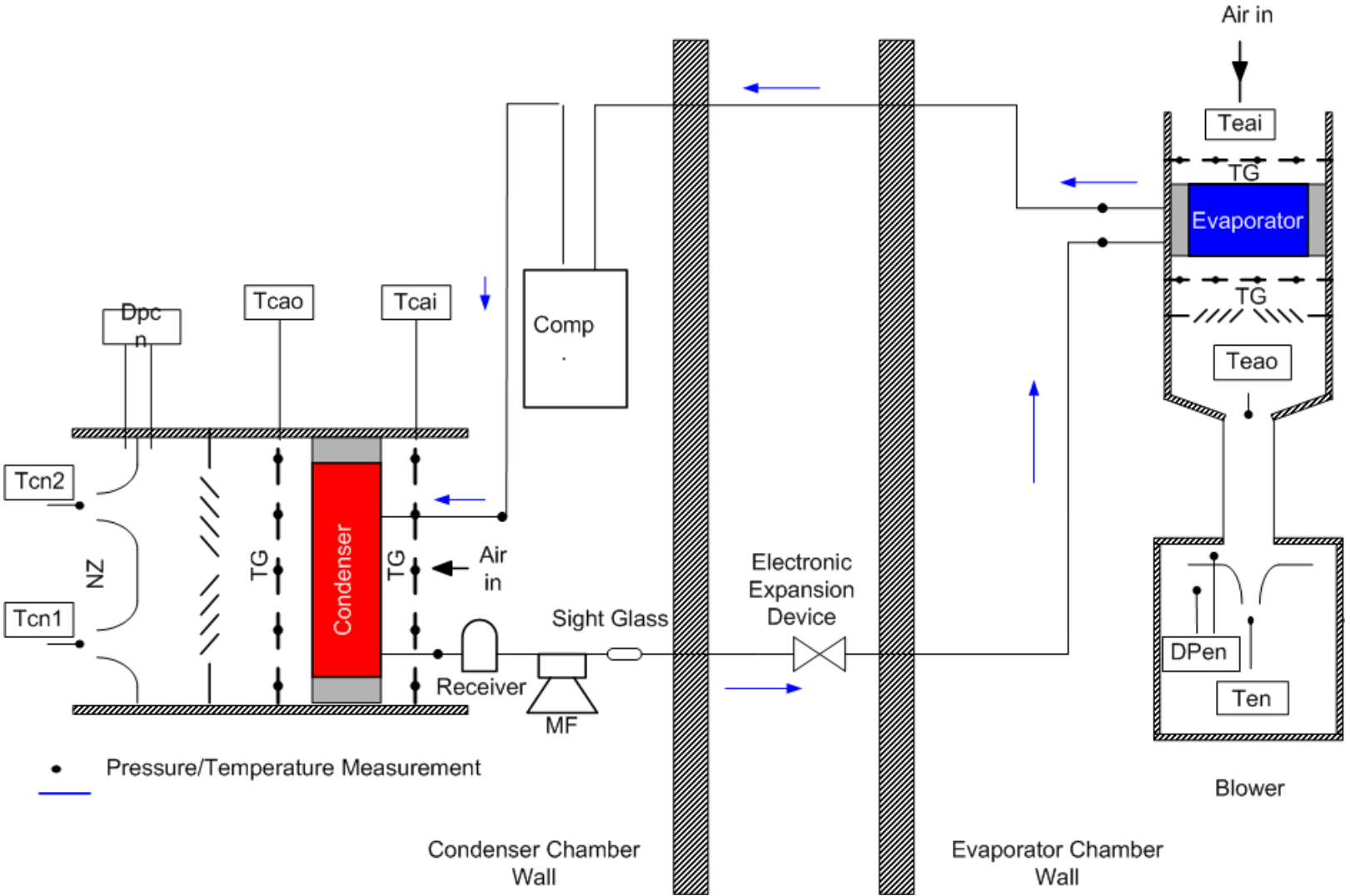
CO_2 system assembled:

- Microchannel HXs
- Same R410A evaporator
- IHX and intercooler added
- Rotary compressor with permanent magnets

Framework

- Start: Measured unit as is
- Components removed and placed in a breadboard system
- Results confirmed validity
- R744 components arranged in a system with same characteristics
- Results analyzed for various sizing options

Simple schematics



HXs in wind tunnels and they in environmental chambers

Controls and DAQ

Expansion valve/Accumulator

Condenser chamber

Evaporator chamber

Components

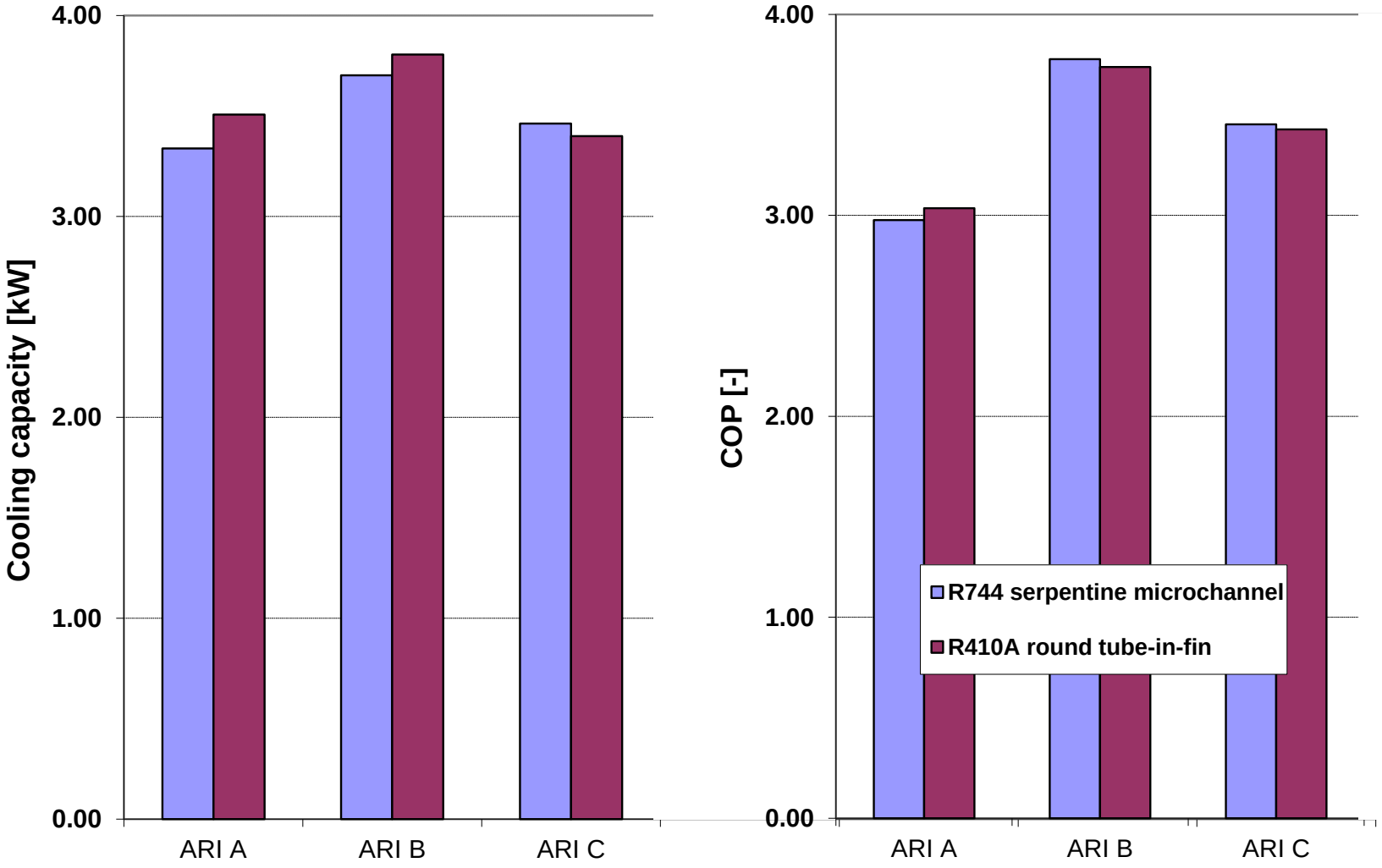
Evaporator was the same: R410A and CO_2

Condenser – round tube-in-fin
face area 3260cm^2

Gas cooler – microchannel cross-counter flow
face area 2900cm^2 plus smaller intercooler

Additional info:
CO_2 system had internal HX and intercooler

Extremely close performance



Still a challenge

- Start against all odds
- Very strong other options:
  - R32
  - Mixtures
- R290 options for many, especially China. Easy to use, economic option, but concerns related to flammability. Maybe regulations would allow higher charges.
- Development of many flameless connecting technologies
- Difficult to go to high efficiency with R744 at competitive prices at this moment
- But eventually we will probably come to CO_2

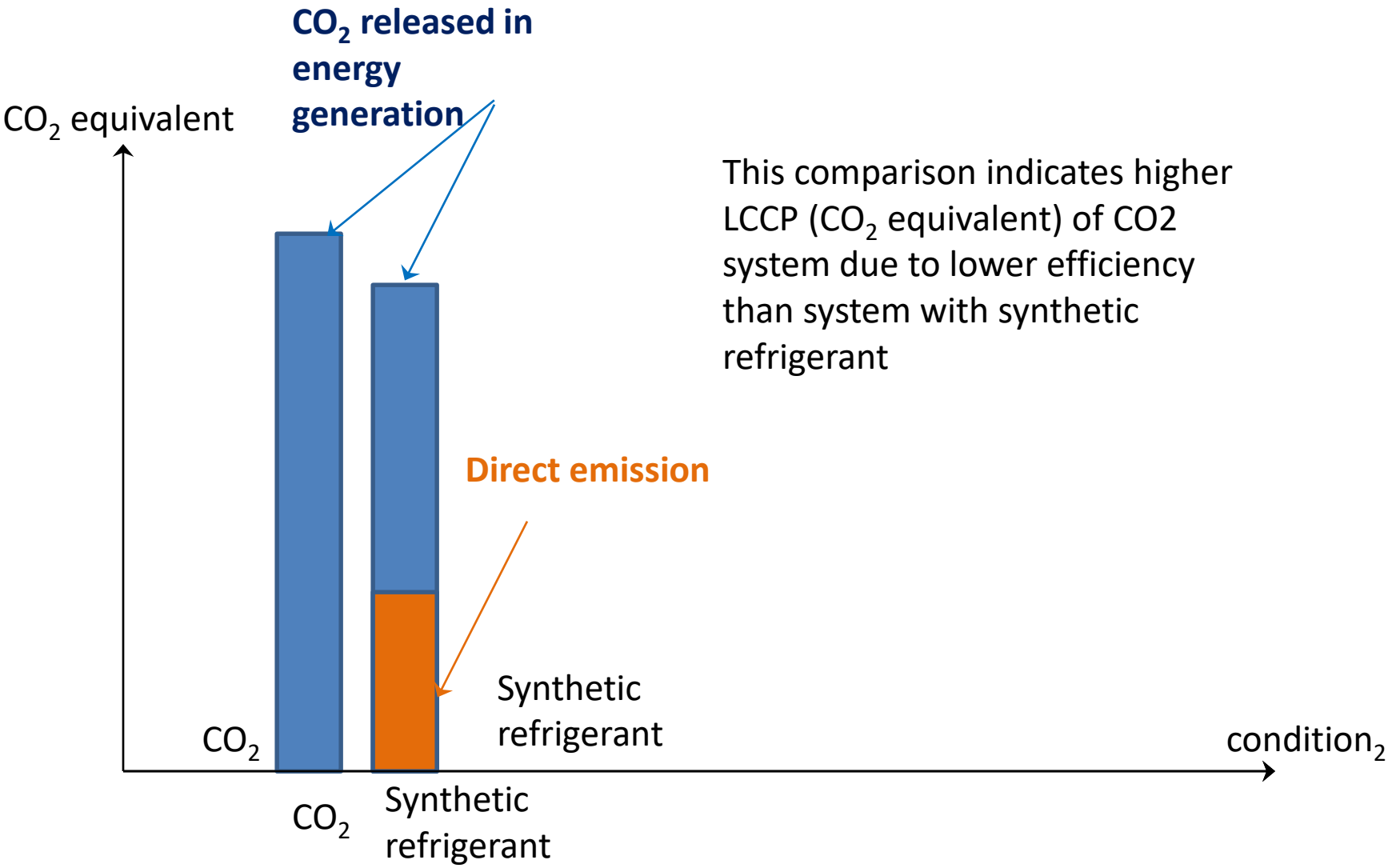
Efficiency is important but sometimes used as an obstacle: Is it really so paramount?

- Was R134a more efficient when it replaced R12?
- Was R404A more efficient when it replaced R502 or R22?
- Was R1234yf more efficient when it replaced R134a?

- Why are we imposing so high efficiencies and the same cost for R22 in air conditioning applications?

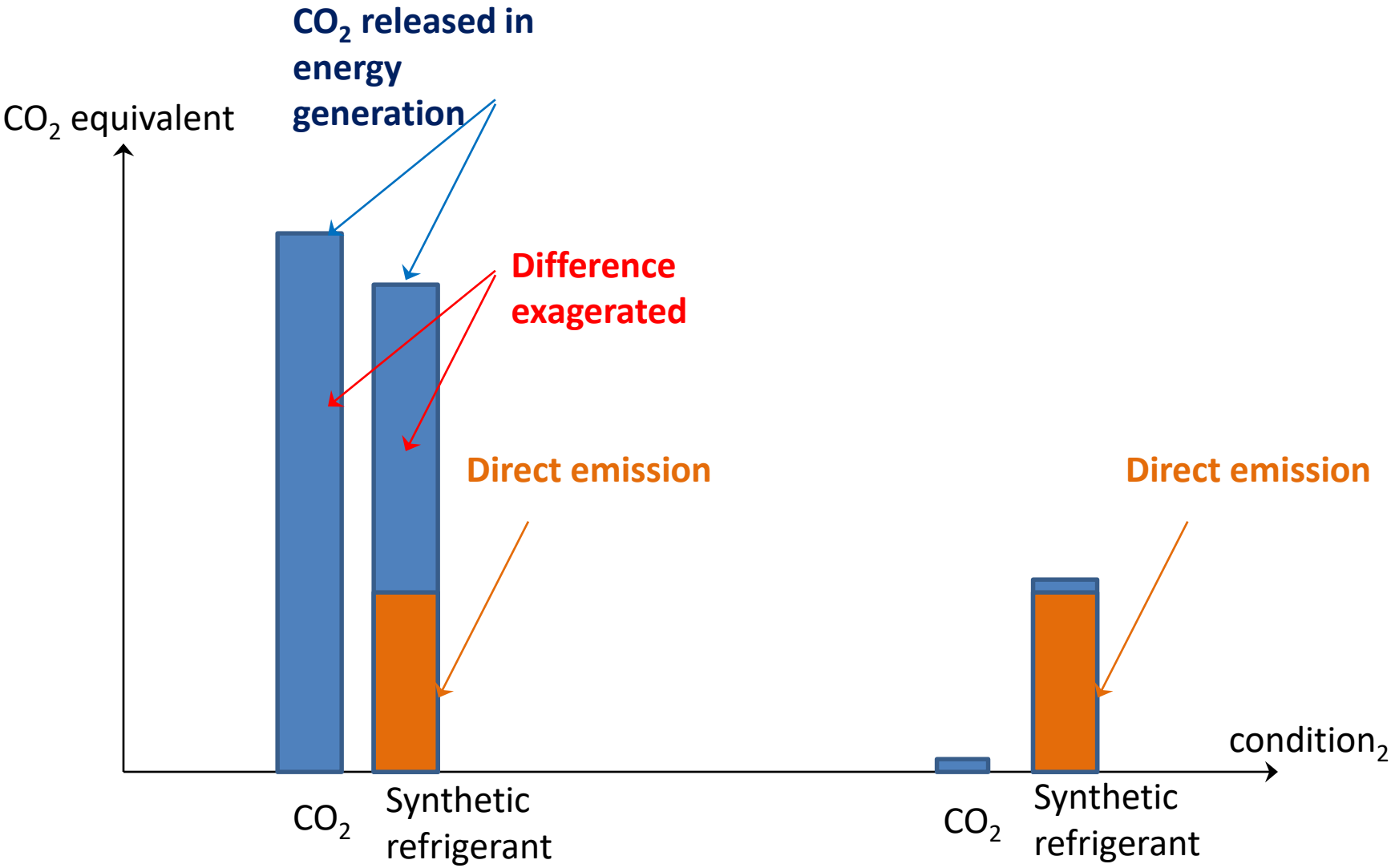
- Maybe because we are told to look in TEWI or LCCP and we see:

Typical result from LCCP or TEWI looks like



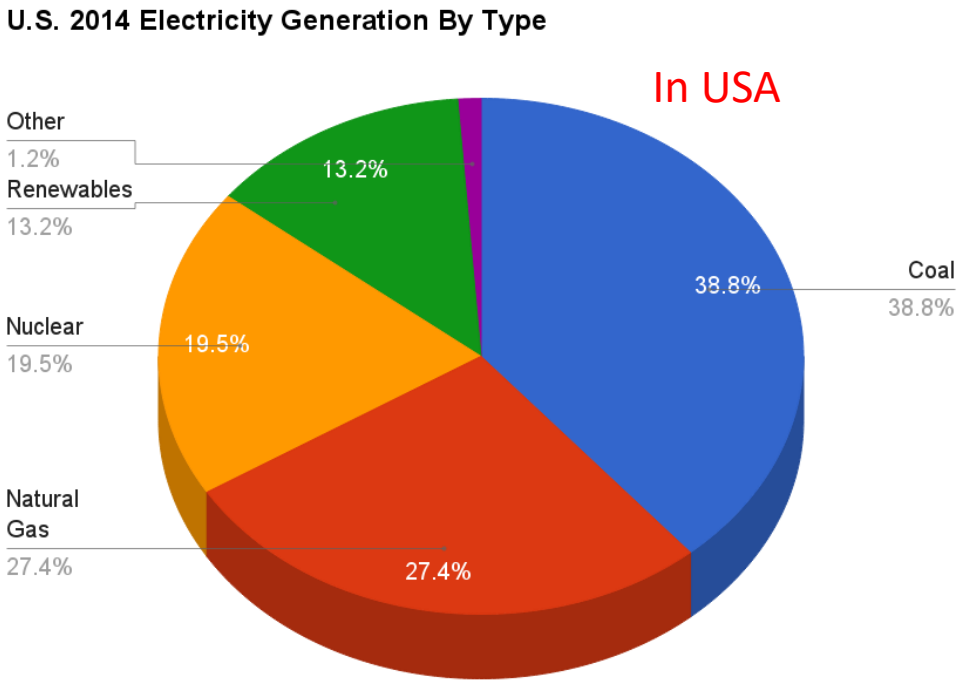
This comparison indicates higher LCCP (CO_2 equivalent) of CO2 system due to lower efficiency than system with synthetic refrigerant

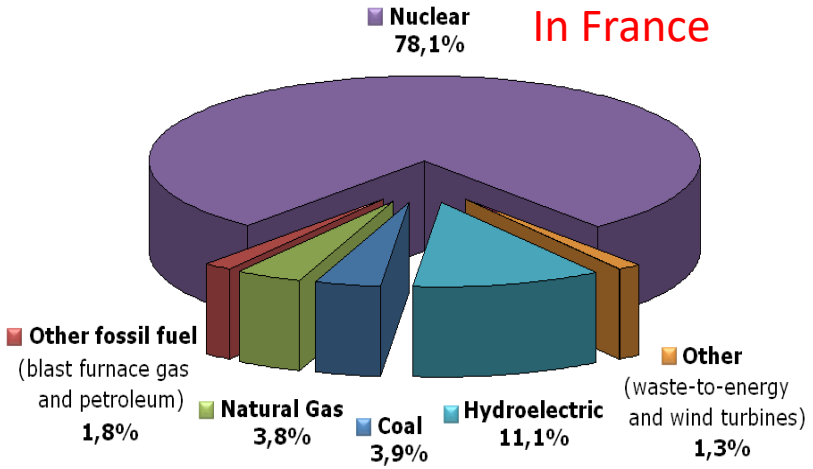
How would it look like if electricity is from almost non CO_2 generated sources



And what is reality?

Production of electric energy is increasingly CO_2 free!





1/3 non-fossil fuel

Less than 10% fossil fuel

Enormous new wind and solar capacities

Denmark, Sweden, Germany: 40% wind energy and growing

China leads in volume of wind power utilization

So,

when production of electricity becomes CO_2 free (and we are moving fast there) only direct refrigerant emissions will matter.

That is a strong argument for natural refrigerants.

As a conclusion

- Many excellent steps were made
- Significant achievements
- Much is left to be done
- More to be presented next year