NATURAL REFRIGEANTS GETTING A NEW BOOST

The latest technology trends in the natural refrigerants and markets

with great help from

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A brief reminder – natural refrigerants

- In **vapor compression** systems:
  - Hydrocarbons: R600a, R290, ….
  - Carbon Dioxide: R744
  - Ammonia: R717

  Became mainstream options
  - Water: R718 – low pressures and large equipment per capacity. German technology company introduced very good solution with three small centrifugal compressors
  - Air: R729 (aircrafts, low temperatures,..). A leading Japanese company has very efficient units.

  Possibly
  - Helium (Stirling) – cooling issues, niche applications
- In **absorption** systems: (niche applications, inexpensive heat)
  - Ammonia – water
- In **ejector** systems: (when steam is almost free)
  - Steam
- Other **niche refrigeration options**:
  - Magnetic, acoustic, electrochemical, …

Hydrocarbons

- Very strong increase in consideration because of the low cost
- Easing regulations for low charge
- Almost drop-in replacement for R22 replacements (R290)
  - a/c or commercial refrigeration
- Easy replacement for R12 or R134a (R600a)
  - Refrigerators are the most successful application, mostly in Europe
- Flammability mitigated by design and charge

What is happening

REGULATORY

- Discussions at IEC (International Electrotechnical Commission) level:
  - Commercial Ref Std. 60335-2-89 flammable refrigerants charge limit to increase from 150 to 500g, (1,2kg limit for A2L refrigerant - (voting July,13th)
  - A/C IEC standard (-40) larger charges not yet approved (still max 1kg of R290 under specific conditions), in US A3's are almost not allowed (114g limit in UL484).
- In US the EPA SNAP approval of 150 g limit in household refrigeration on hold, AHAM supports the change, in evolution
- California expected adopt recent HFC bans. Some other States expected to follow.
- In China debates over 1.5 kg for a/c, IEC SC61D is working on it, but it will take some time

TECHNICAL

- **Not much technically in mitigation of flammability**, main mitigation system is the air movement and use of sensors
- Some indication of search for smell tracers
- Two studies in progress for A3's risk assessment, one in UL, paid by AHRI and another one in Japan, results in this year

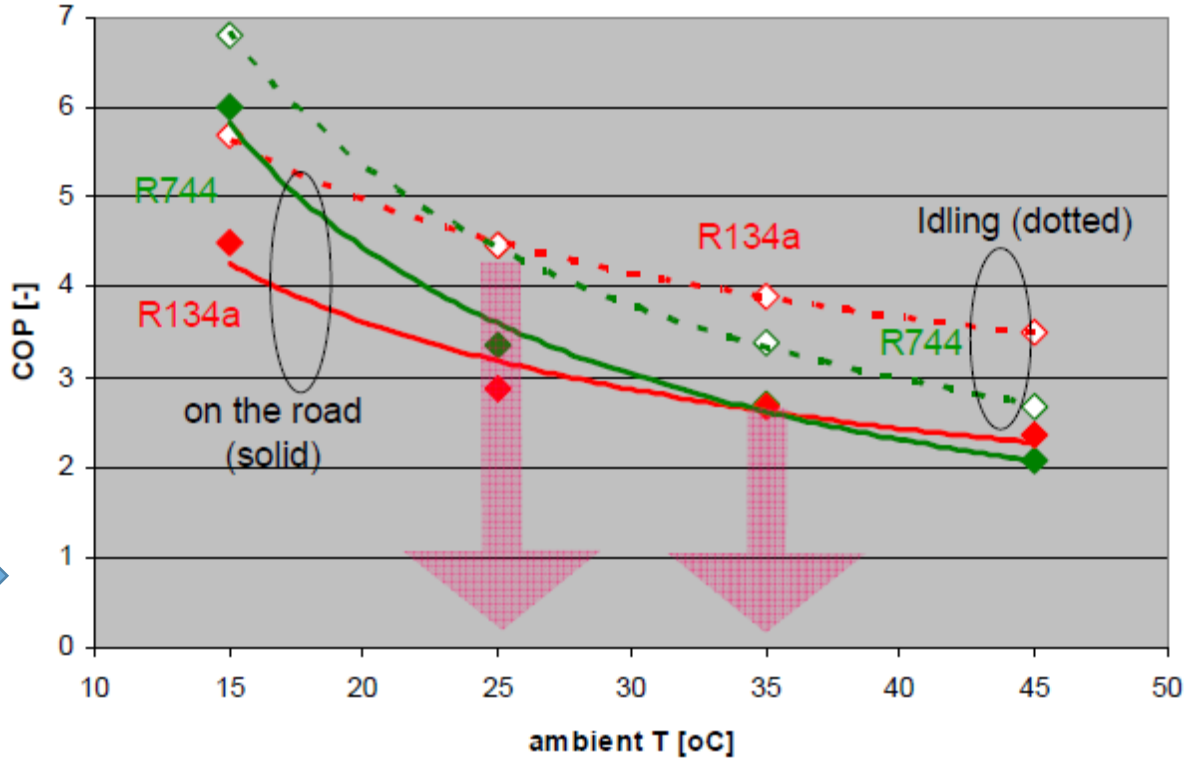
MARKETS

- Last year Coca Cola allowed use of HC's in their systems except vending machines, Pepsi does it longer time.
- In Europe used long time. China considering even in a/c system.

Carbon dioxide

- Very old refrigerant
- Abandoned because of high pressures and heavy equipment;
- Besides environmental reasons **microchannel HXs and better materials** reopened the door, especially for MAC applications
- Wrongly assumed to be low efficient refrigerant – we showed for MAC
- **The ONLY A1 refrigerant with ODP = 0, GWP =1**

Summary of R134a vs. R744 in SAE MAC program
Identical capacity, same size HXs



CO_2 is still the extremely active area
R744 became the mainstream refrigerant

- HPWH – the first successful commercial application of transcritial systems:
  - Besides success in residential sector (reached stabile 0.5e6 p/a) rapidly expanding in commercial and industrial sizes
- Currently supermarkets are expanding application utilizing CO_2 as transcritical:
  - Improvements by “booster” aproach almost a game changer
  - strongest in Europe but going elsewhere (Europe > 14,000 CO_2 transcritical stores, >3,100 in Japan, 340 US, and >210 in Canada)
  - larger stores, with booster systems, heat reclaim etc….
- Convenience stores:
  - Mostly in Japan, but elsewhere too
- Bottle coolers – tens thousands p/a
  - strong push by The Coca Cola – recent acceptance R290 trouble for R744

In MAC applications

- From extremely strong beginning prospects seemed to be closed when industry selected R1234yf as a replacement for R134a
- Situation somewhat changed when Daimler published flammability results in Oct. 2012
- Currently: Increase in viability of electric vehicles pushes CO_2 because of the heat pump option
- Outcome still unknown, but way more promising
- One element is certain: we can make R744 systems efficient and low cost – demonstrated

Ammonia (R717) – I will focus on it

- The only natural refrigerant continuously in use (industrial refrigeration)
- Not appropriate for populated areas when charge is significant (B2-B2L?) but potential for upset and even panic in the case of leak is high.

So, what is good way to make it stronger and expand its use?

Keep going with what is good **but work on improving**:

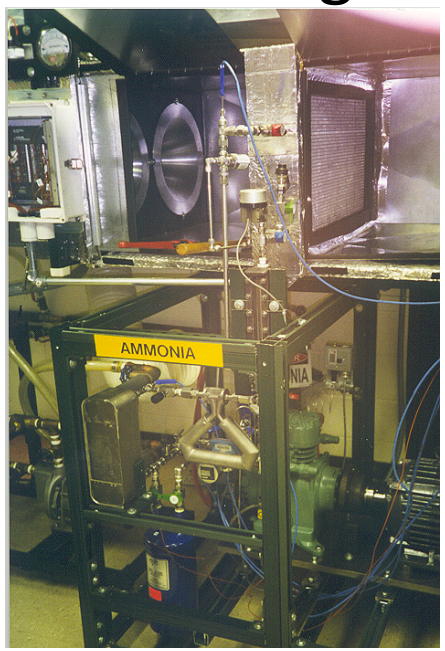
1. Ammonia **charge** should be reduced – **very strong start**
2. Instead of field erected systems, **prefabricated units**

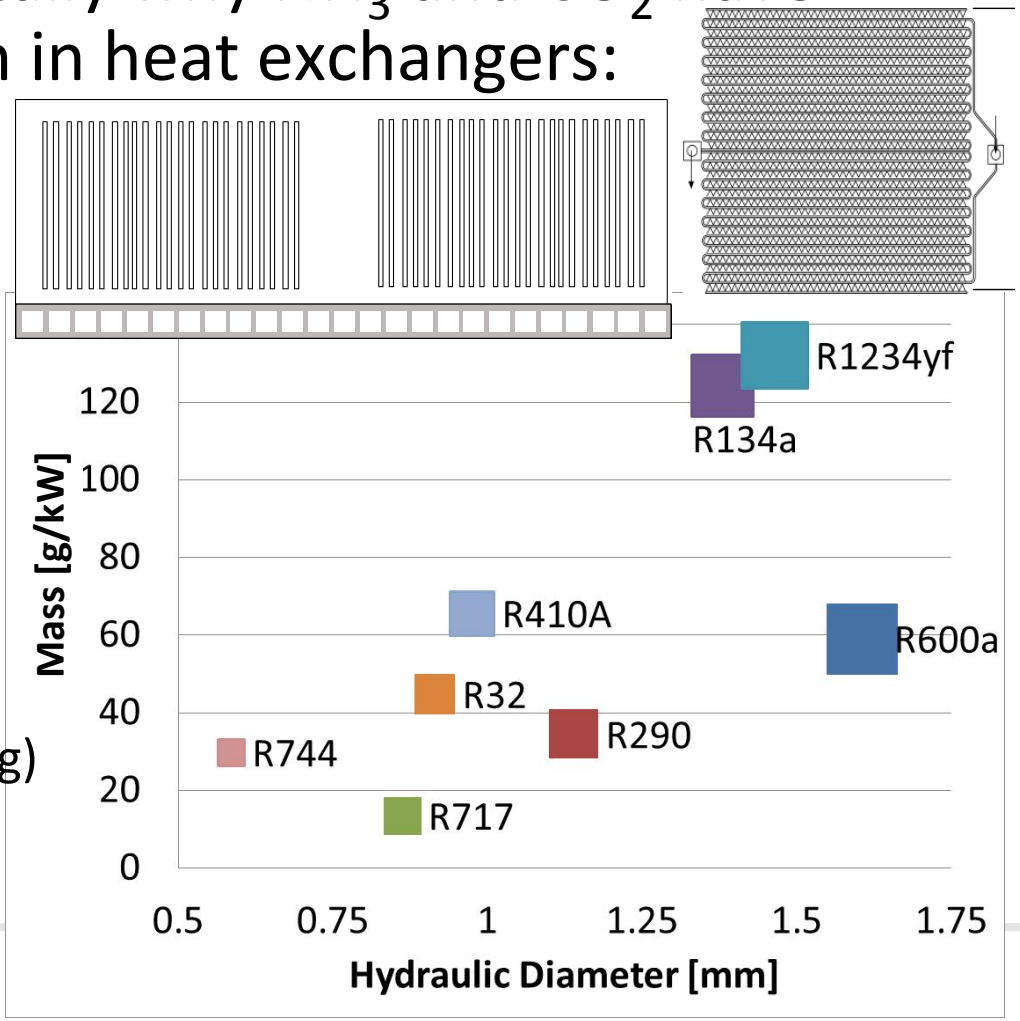
   Lower cost, better reliability, higher efficiency: **started**
3. In high stage of cascades with CO_2 (already happening)
4. Ammonia in chillers:

   Excellent but requires entering in a new area of HVAC besides industrial

1. Charge reduction – name of the game, currently

- We have explained and shown experimentally why NH_3 and CO_2 have the greatest potential for charge reduction in heat exchangers:





7-10 Ton (25-35 kW) high efficiency, **< 1 lb** (430g)

20 years ago: 2.3 oz/kW (18 g/kW).

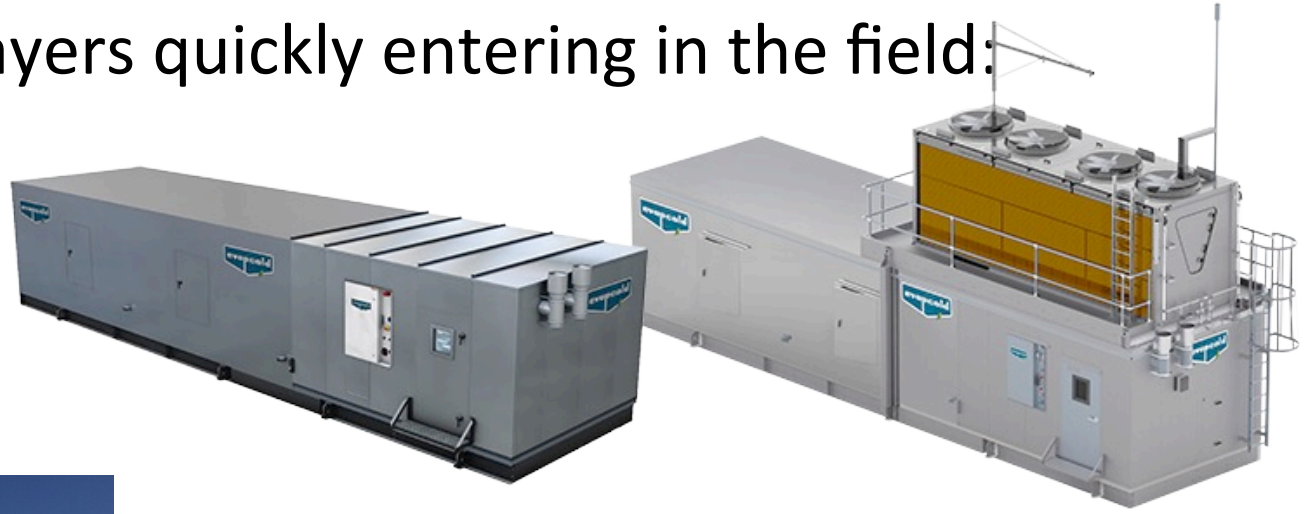
Presented first time at IIAR, Long Beach, 2001

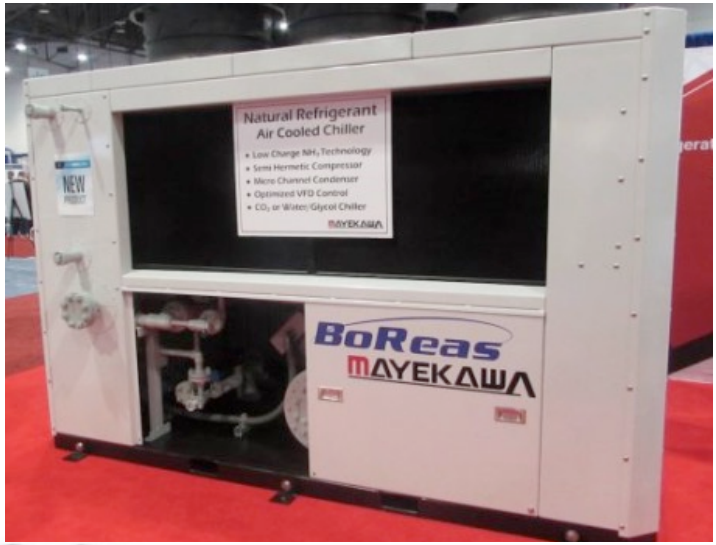
On charge

- Current charges in NH_3 units achieved orders of magnitude lower than in typical industrial installations: typically 50 – 100 lbs (100 Tons – 350 kW) vs. tens of tons (for 1- 3 MW)
- A race to call own unit low and ultra low charge
- US EPA does not require reporting a leak <100 lb (50kg)
- It would be the best to have ALLOWED charge that would not require any additional checks as UL 150 g or ASHRAE 15 used to have 6 lbs of NH_3.
- That would incentivize work on maximization capacity and efficiency and consequently move technology forward
- There is a concern that such approach would identify current industrial refrigeration charges as unsafe

2. Prefabricated units (already low charged)

Several big players quickly entering in the field:

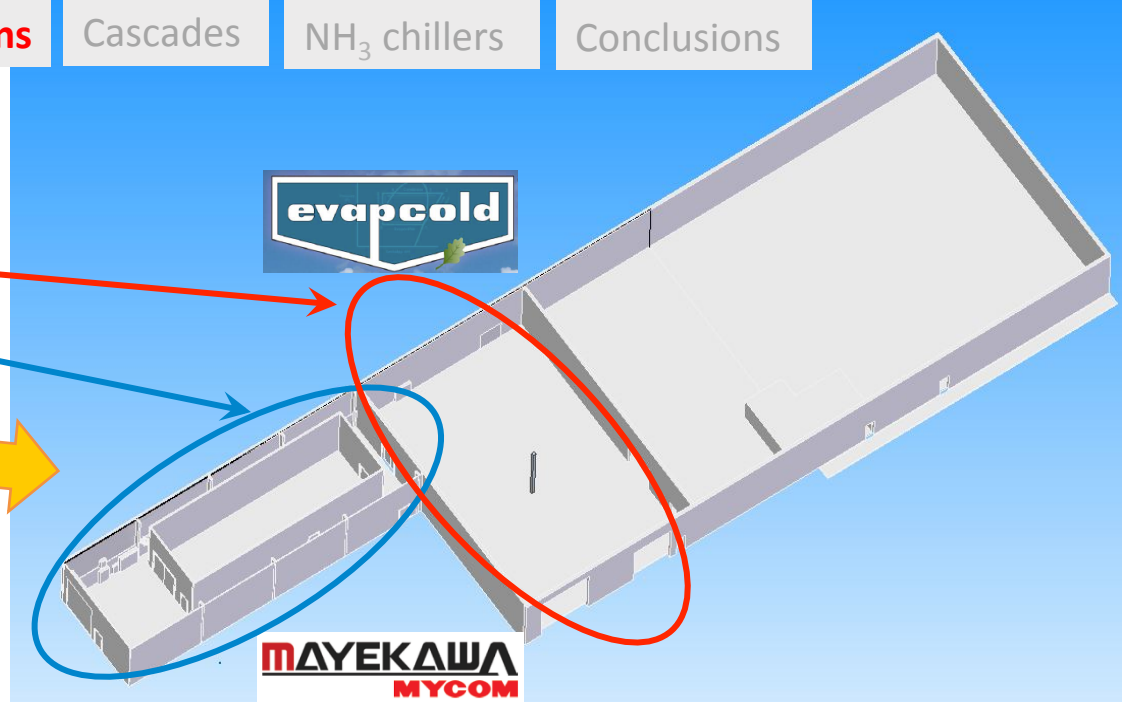


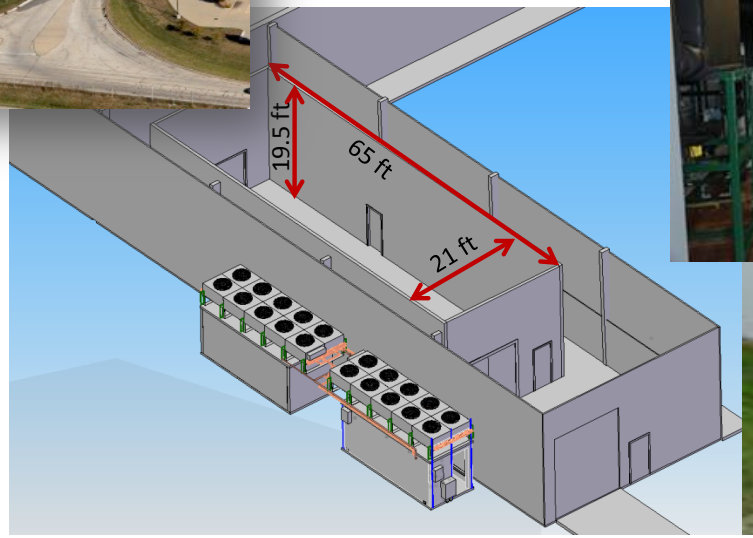


Thanks to push from California (SCE, Paul Delaney) we are working on proving the performance:

1. Evapcold – A low charge NH_3 unit with water cooled condenser (cooling capacity: 65 TR)
2. Boreas (Mycom) – A low charge NH_3 unit with CO_2 as secondary loop and air cooled condenser (cooling capacity: 31 TR)
3. Low charge ammonia package with air cooled condenser from Evapcold (cooling capacity: 65 TR)
4. Nxtcold (in line)
5. Azane (in preparation)
6. Emerson (in discussion)

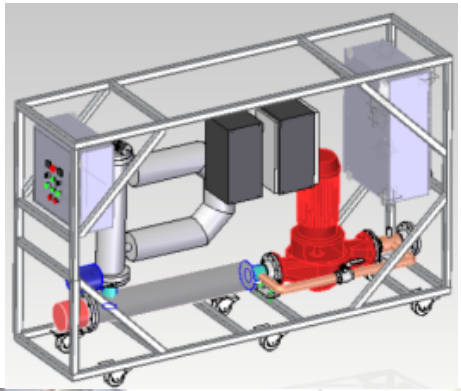
Two systems measured simultaneously



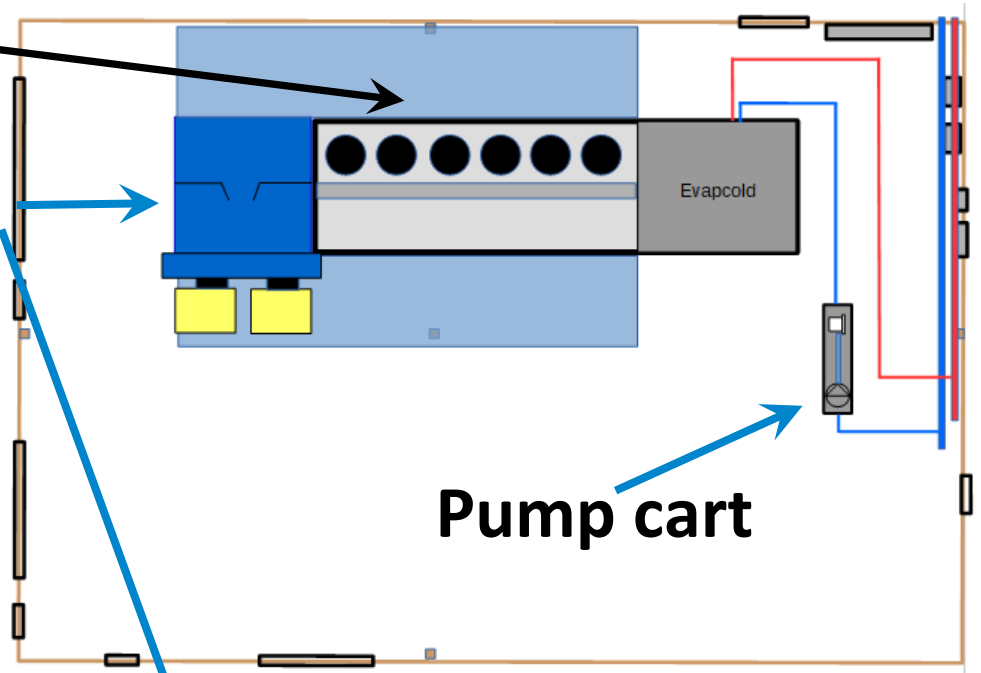


Compressors can run in parallel and cascade
Q=10-200 Ton (35 – 700 kW)
Flooded and DX
Air and liquid

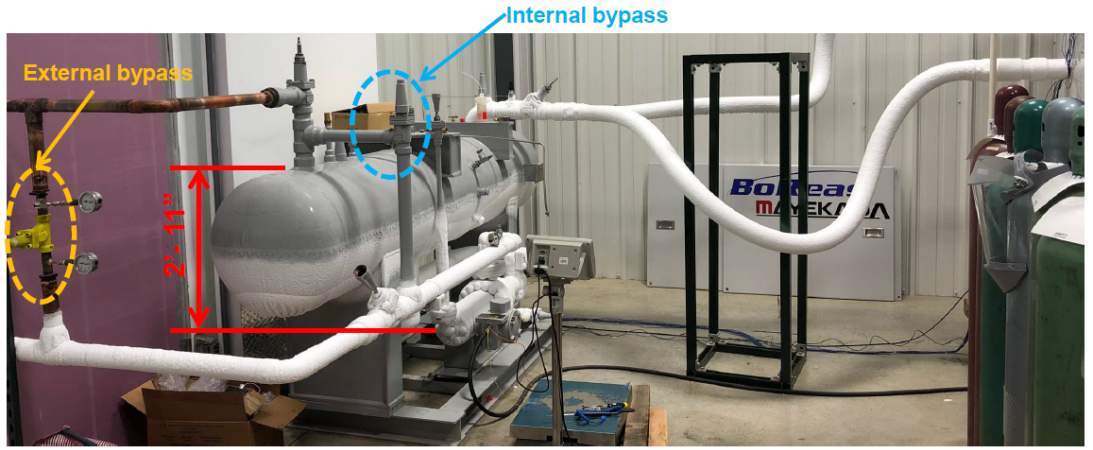
Sizes are appropriate to capacity

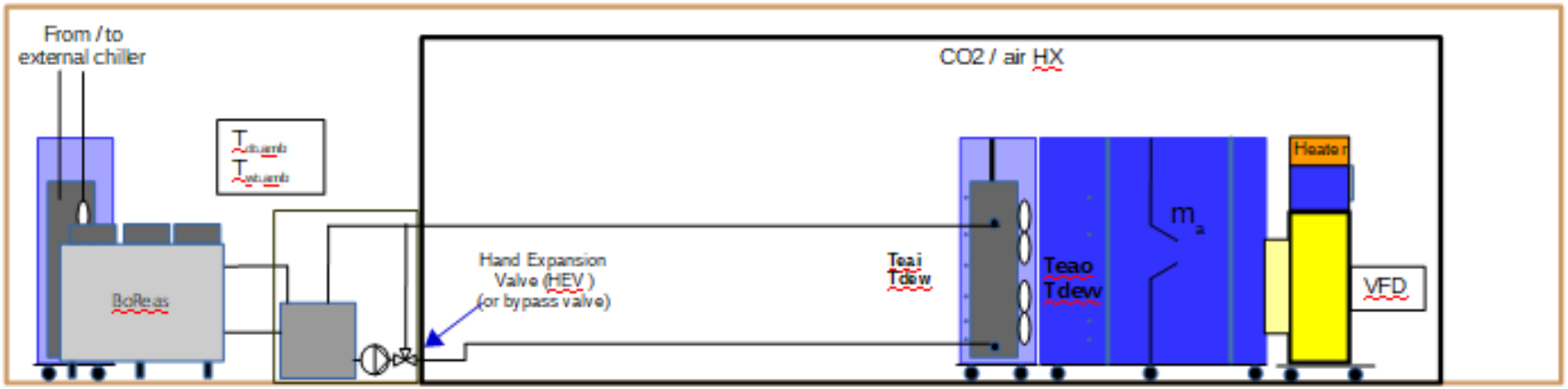


Evapcold unit broke the ice

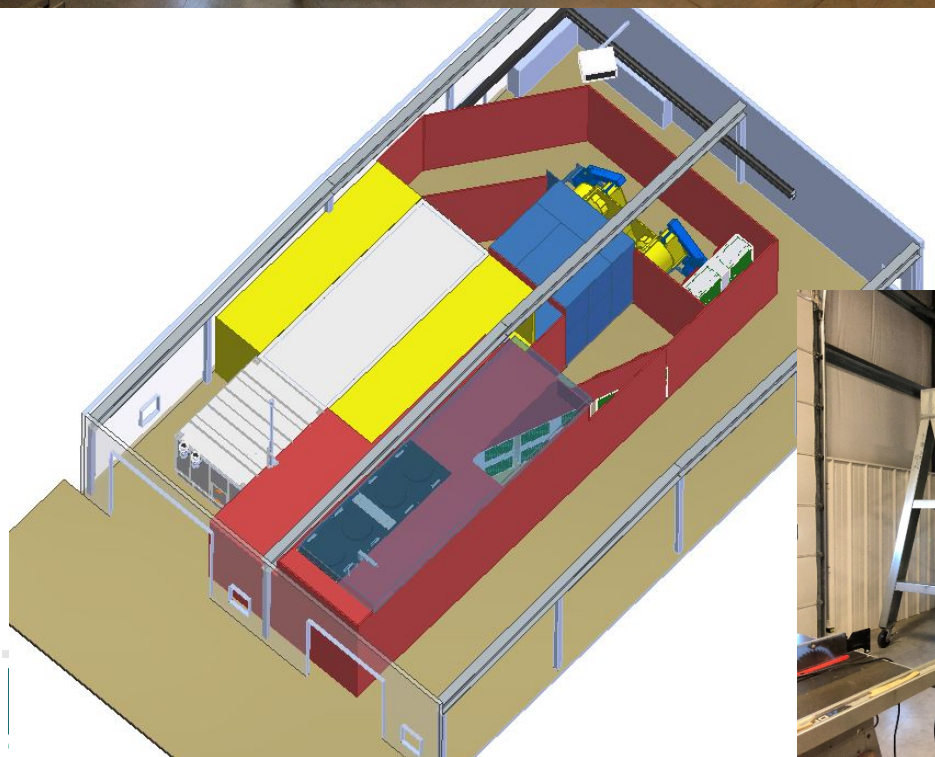


Low charge ammonia - CO_2 system





Air cooled low T ammonia unit

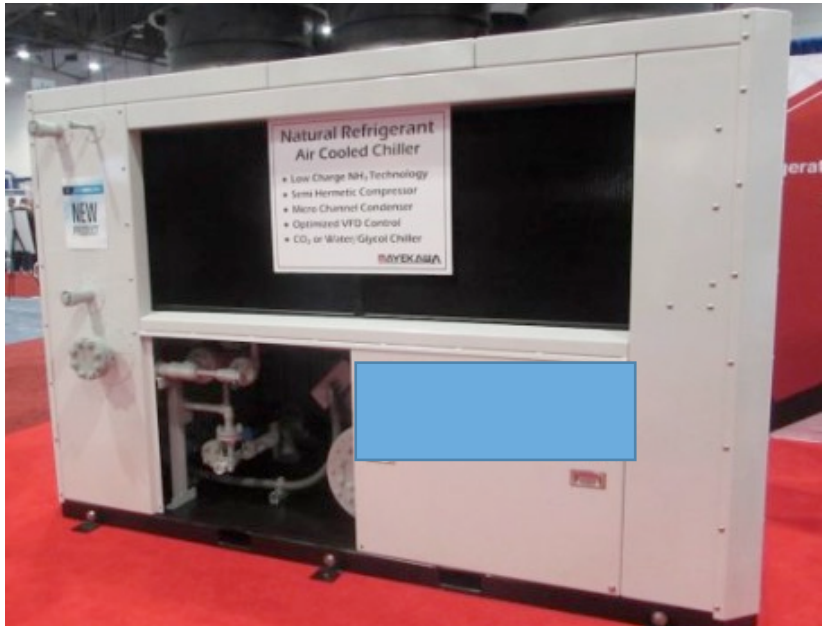


General challenges

- Measurement of the performance (capacity and efficiency) in industrial refrigeration is not common
- Technically challenging: size and capacities in particular
- We developed test procedures (based on similar AHRI/ASHRAE)
- Nothing new to CTS – we developed basis for several SAE and ASHRAE Stds.
- Even first results show very good numbers, especially compared to conventional approach, they reveal ways to improve further and realize full potentials of ammonia
- We need to talk more on the technical level!!!
- More measurements like this to avoid surprises and discredit ammonia!

3. Prefabricated cascades

- Various manufacturers
- Reduce NH_3 charge
- Increase reliability
- Should reduce cost

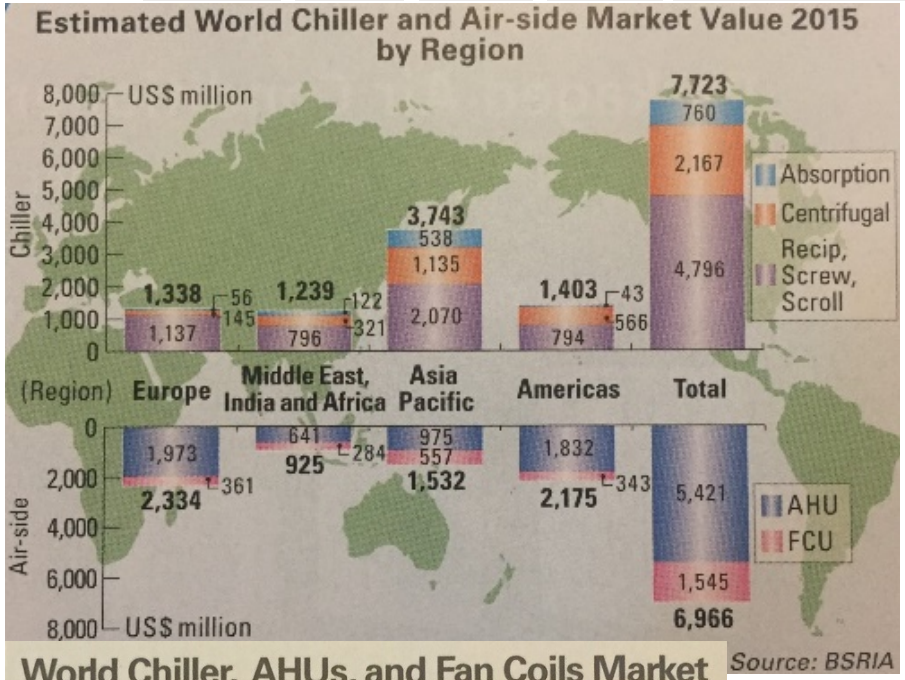


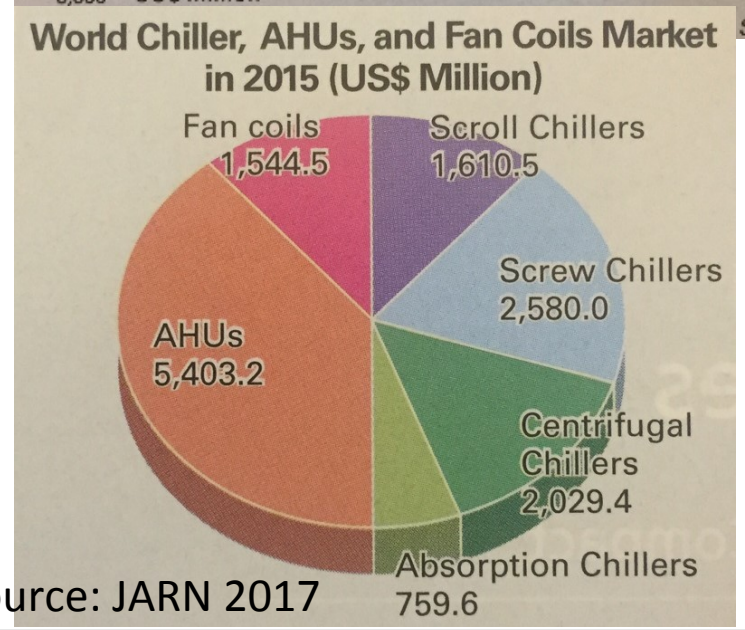
4. Ammonia chillers: opportunity for industrial, but even more HVAC

- Industrial applications with CO_2 and glycol:
  - A major Japanese company is going very strong in CO_2 (and glycols) as secondary fluid directions, with hermetic compressors, low charges – I am sure others follow

- Still missing someone big who will enter the HVAC challenge even!
  - CTS developed and made several ultra low charged (18 g/kW – 23 oz/Ton) and efficient chillers but probably a too small player to change the game
  - Some other companies (Azane/Star and others are trying

Market is huge, compared to industrial refrigeration

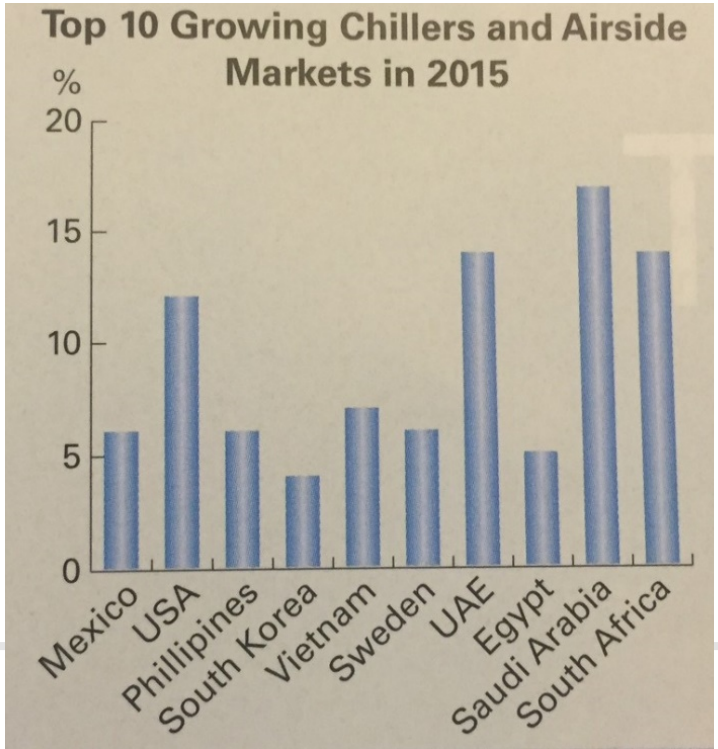


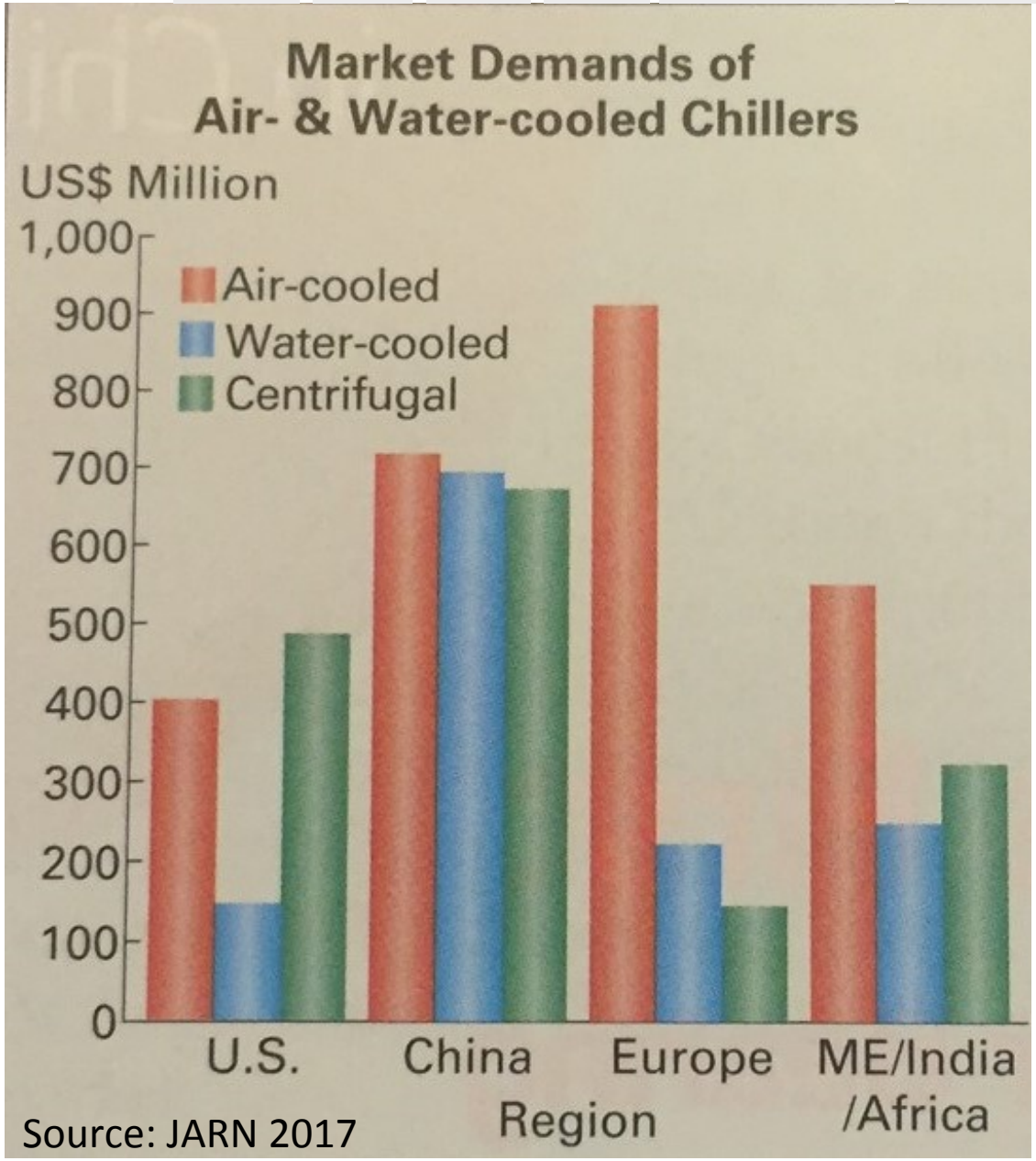


Source: JARN 2017

- 5 billion US$ per year, positive displacement compressors only
  - 1.7 b $US – scroll
  - 2.6 b $US – screw
  - 0.5 b $US - recips
  - And growing →

Source: JARN 2017

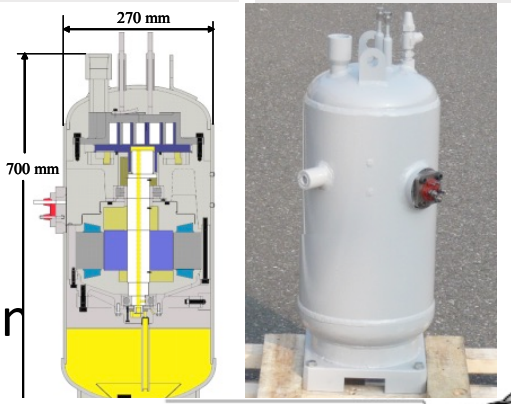


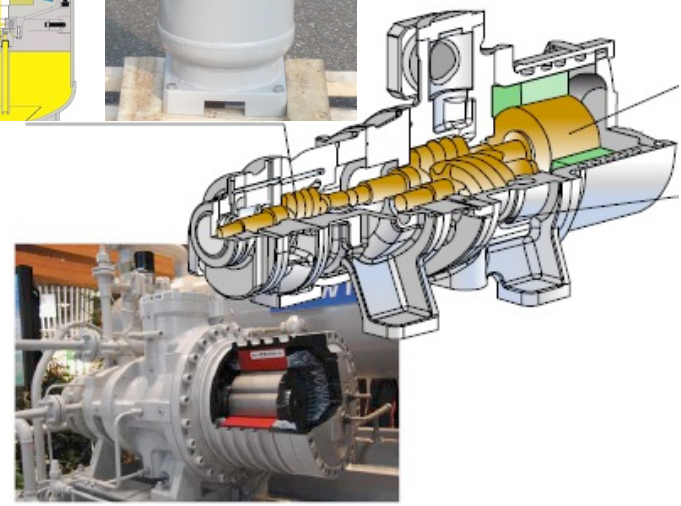


Regionally

- Air cooled dominate more in cooler areas (excellent for MC condensers)
- Water cooled also excellent for ammonia (BPHEs) – ultra low charges

Challenges in HVAC direction





- Technical:
  - Make the system look, feel and cost similar as the competition
    - Hermetic compressors – already existing but need more
    - Reduced weight
    - Increased and measured performance in the same way as competition
- Support:
  - Educate engineers and technicians
  - Reduce initial resistance
- Marketing:
  - Selling to new customers other than well known ammonia users, and HVAC market is different than industrial
- Internal to the group:
  - Someone will gain (new, creative, competent companies)
  - Many may loose or will need to shift – find them a role to avoid internal confrontation instead of making them obstructive losers

Conclusions

- Applications for natural refrigerants continuously expanding
- Dominant positions : CO_2 HPWH in Japan, supermarkets in Europe and elsewhere, R600a refrigerators in Europe and NH_3 in industrial refrigeration
- Small commercial units, LC ammonia units, MAC, … on a good trajectory
- MAC is back to the proving arena
- Ammonia chillers for HVAC – need some support
- When treated with understanding each of the main alternatives is excellent and competitive.
- Still to work on overcoming initial higher cost when advantages of natural refrigerants are clear and desirable