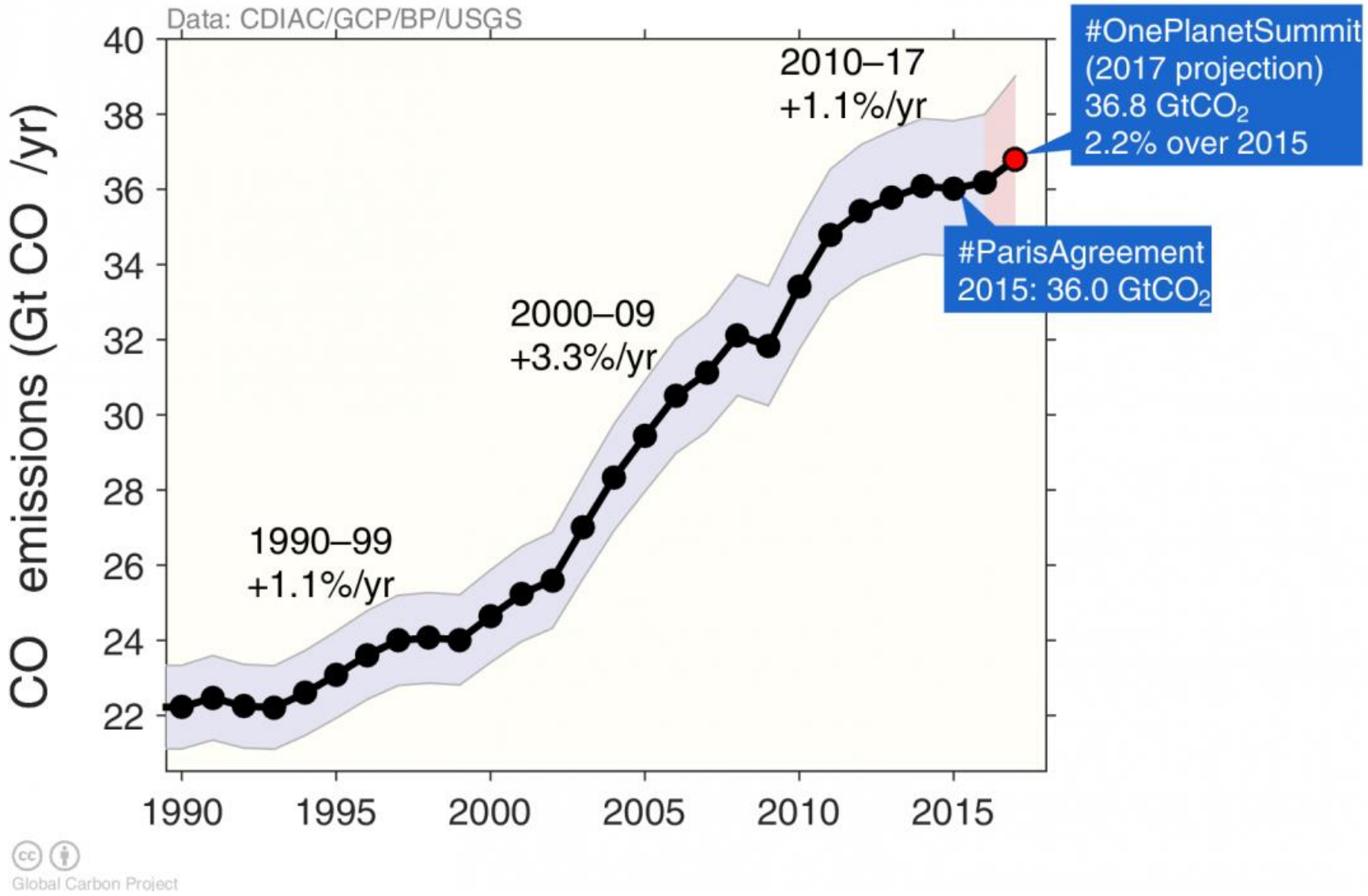
# Alternative Refrigerants for Refrigeration and Air-Conditioning sector
# Carbon Dioxide Technology.

Ng Wen Bin

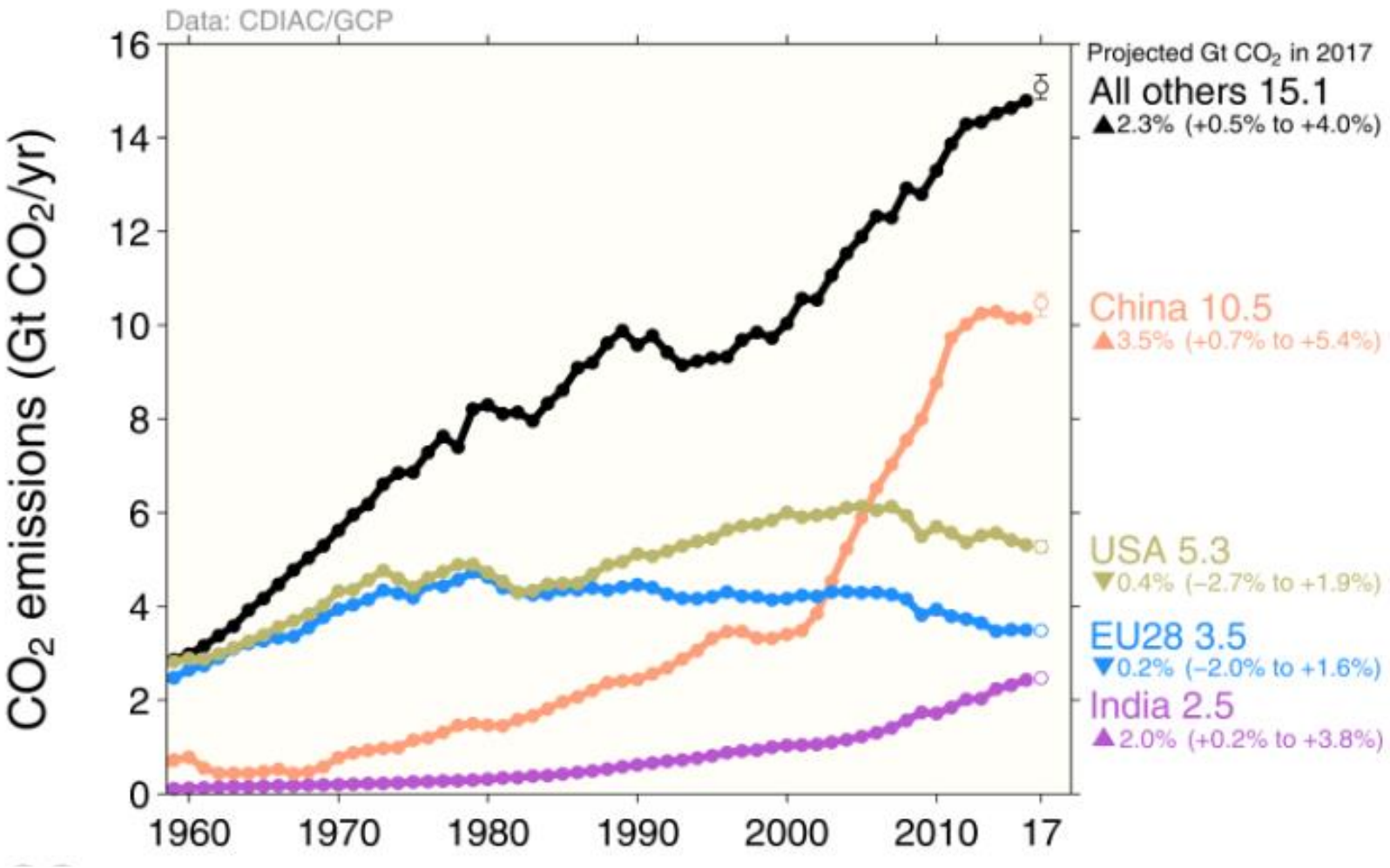
Senior Lecturer UNIKL MFI

President Elect ASHRAE Malaysia Chapter

# Global $CO_2$ emissions



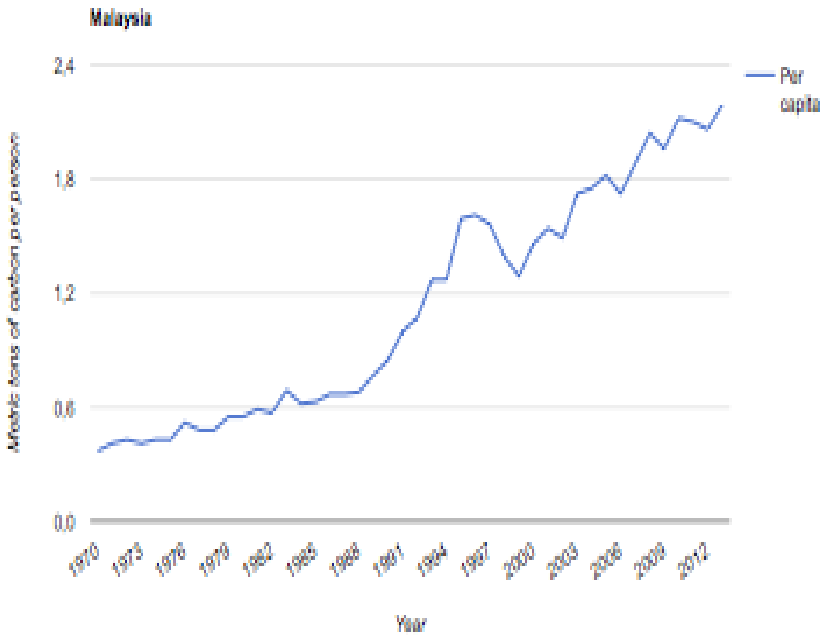
# $CO_2$ Emissions per country



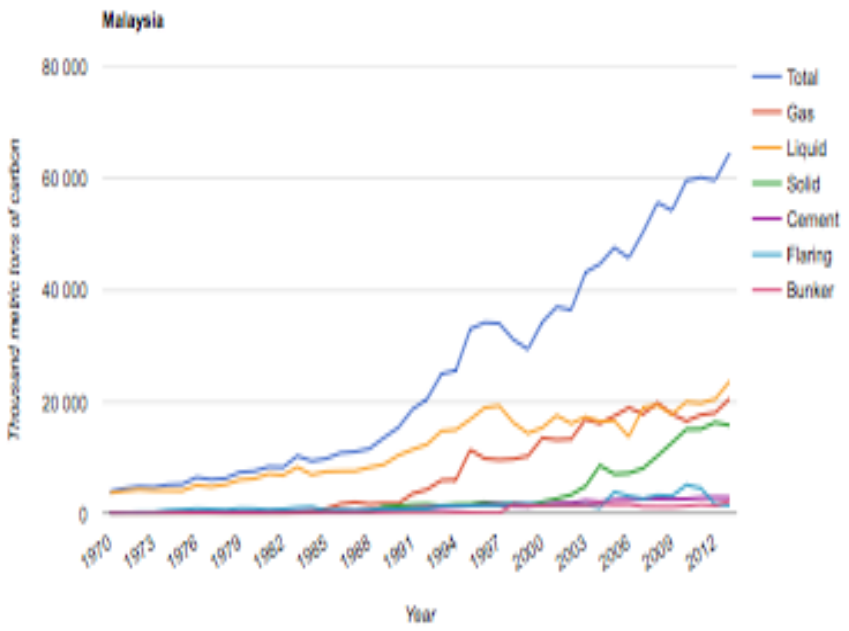
# Malaysia fossil fuel carbon emissions

source CDIAC

## Per capita



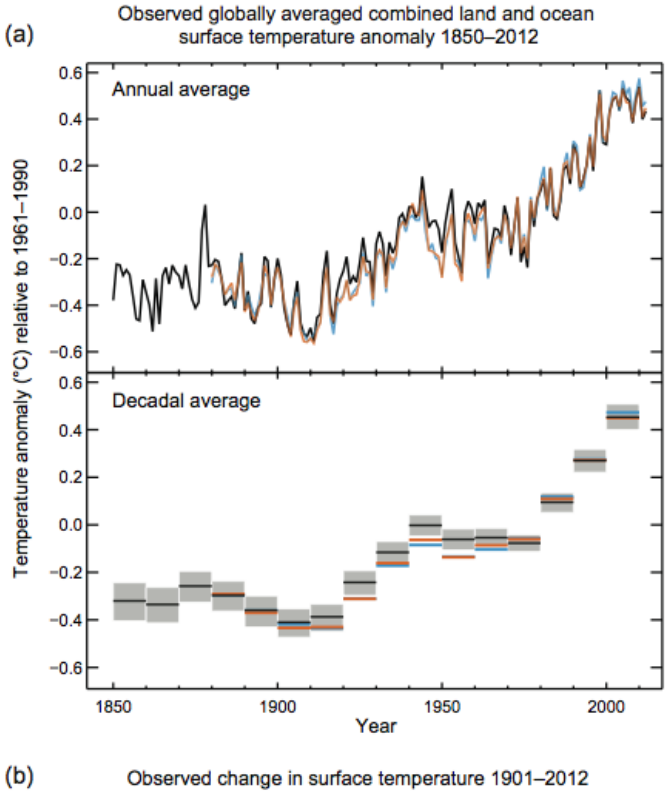

## Total, per fuel



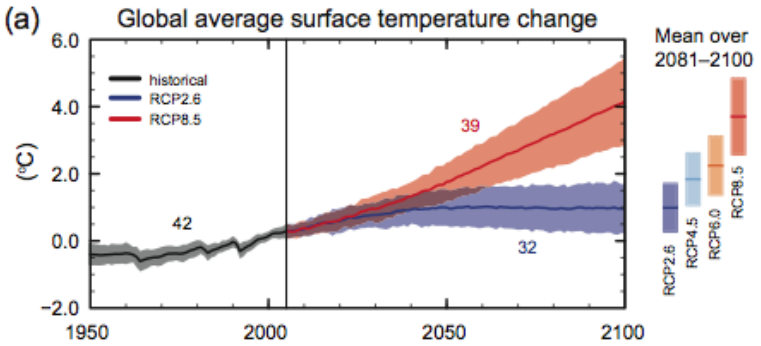
# Mean global temperature

IPCC 2012 data

## Warming of 0.85°C 1880-2012




## Expected warming



# 2016 Climate change data

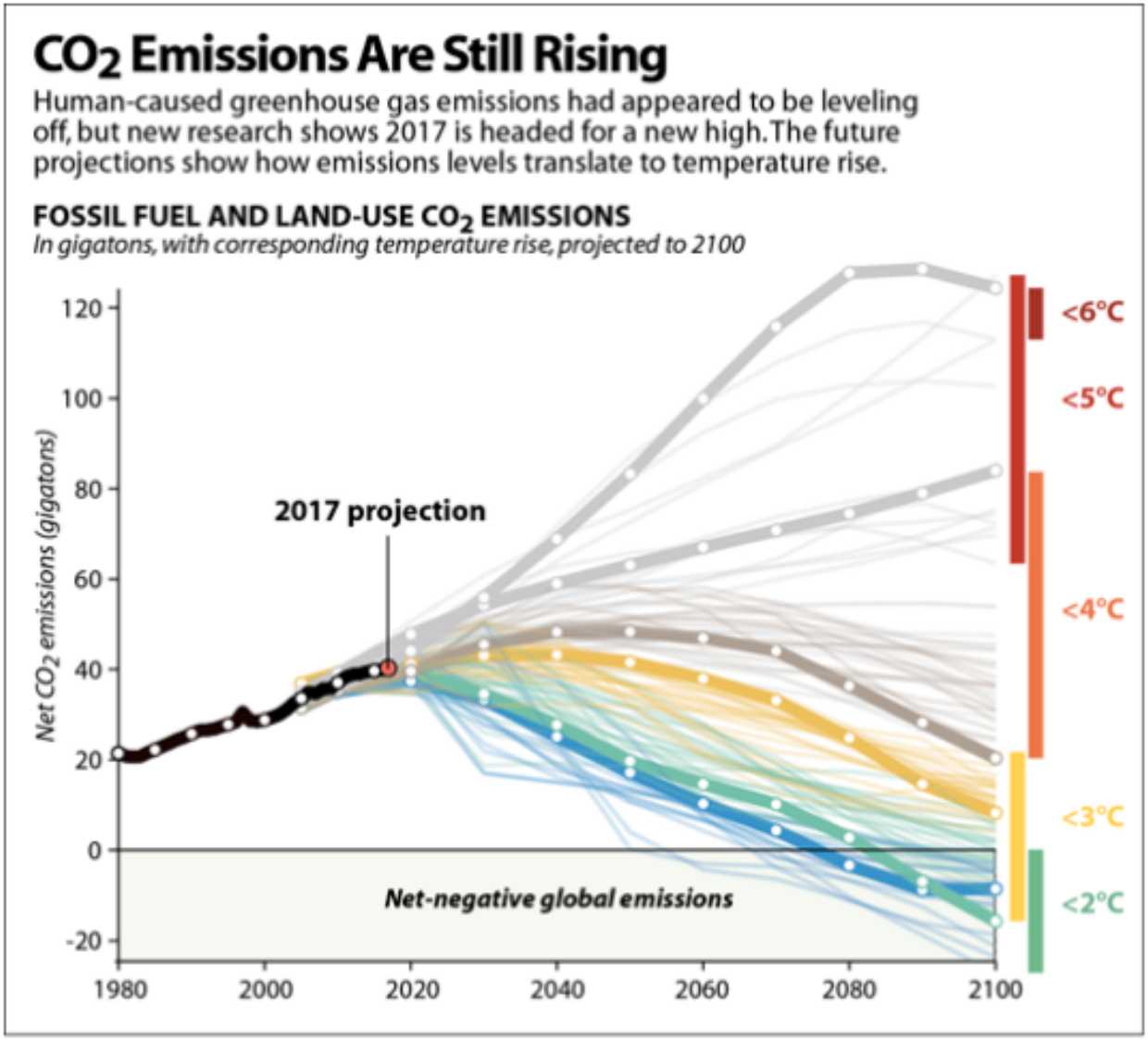
## Source (WMO)

- **Global warming since pre-industrial period reaches 1.1°C**

- The target of global warming limitation at 1.5°C by 2100 seems impossible

- **Target of 2°C global warming limitation still achievable if drastic measures are applied**

# Global $CO_2$ emissions predictions



# Risks for high global warming by 2030

- **Global temperature records have been broken between 2010 and 2016 since global warming reached 0.25°C in that 6 years period corresponding to 0.4°C for 10 years**

- **Following that rythm and without drastic measures, 1.5°C global warming should be reached before 2030 and probably around 2025**

# Consequences of global warming

- Independently of the global warming, the other consequences could have dramatic repercussions:
  - **Seal level increase**
  - **Flood but also drought depending on the regions,**
  - **Typhons intensification,**
  - **Health problems (dengue, etc.)**

  It is the reason why measures to attenuate climate change have to be taken in all sectors including air conditioning and refrigeration

# Paris Agreement COP21 (2015)

- The Paris Agreement builds upon the Convention and brings all nations into a common cause to undertake efforts to **combate climate change and adapt to its effects**, with enhanced support to assist developing countries to do so.

# Paris Agreement COP21

- The Paris Agreement central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well **below 2 degrees Celsius above pre-industrial levels** and to pursue efforts to **limit the temperature increase even further to 1.5 degree Celsius.**

# 2018 situation and perspectives

- As previously said: **1.5°C temperature limitation by 2100 seems impossible.**
- **To get 2°C temperature limitation** requires limitations of the emissions as given by the models.
- **The emissions must peak before 2030**
- Then, they should decrease rapidly to be halved in the period 2070-2080

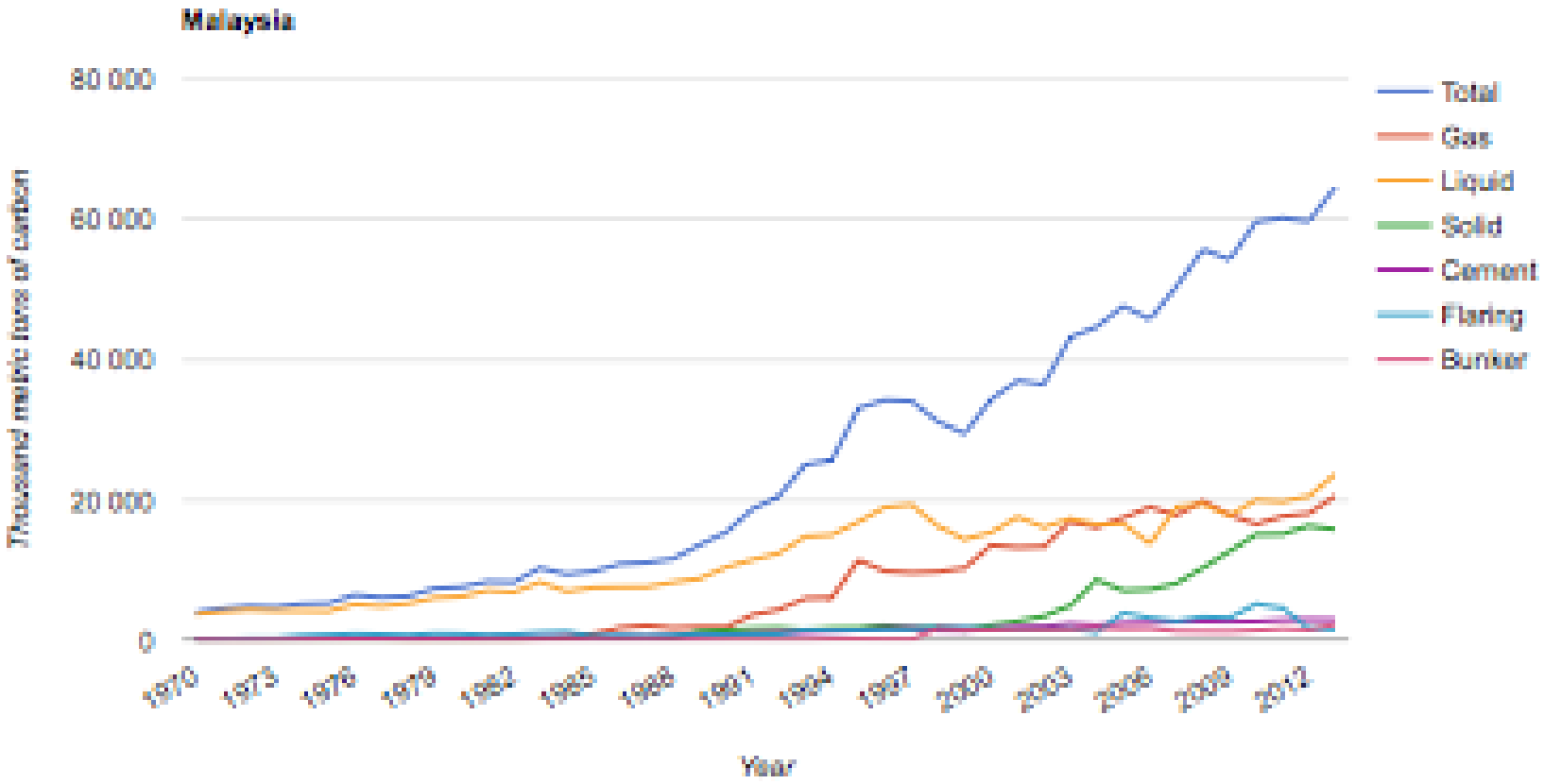
# Malaysia contribution to COP21

**source: INDC Malaysia's document**

- **Malaysia intends to reduce its GHG emissions intensity per GDP by 45% by 2030** relative to the emissions intensity per GDP in 2005. This consists of **35% of an unconditional basis** and a further **10% is condition upon receipt of climate finance.**

- **Malaysia's emissions intensity per GDP has been reduced by 23% between 2005 and 2015.**
- The extra effort should then be **12% unconditional reduction (and 22% conditional reduction) between 2015 and 2030**

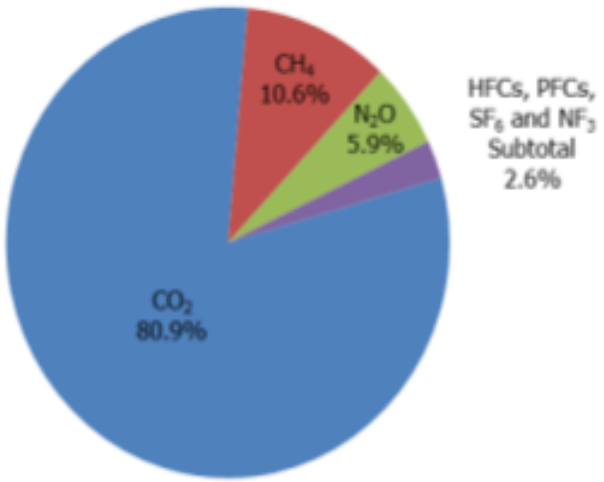
# Malaysia emissions



# Refrigerants contribution to greenhouse gas emissions

**US HFCs emissions: 2.6%**

**World-wide HFCs emissions: 5%**




- Contribution of refrigerants to GHG emissions is still low (5%) but is increasing due to the development of the cold chain. If no measures are taken, **HFC emissions will reach 10-15% of the total by 2050**, that is too much.
- **In Malaysia, A/C and refrigeration correspond to more than 50% of electricity consumption**

# Why are HFCs so harmful?

- The emission of **1kg of standard HFC corresponds to the mean emission of 2000kg $CO_2$** (about 1400 for R-134a & 4000 for R-404A)
- It is impossible to have cooling units without leakage
- It is the reason why a phase-down of those substances is scheduled.

# 2016 Kigali Agreement

- The Kigali amendment to the Montreal Protocol could **prevent 0.5 degree Celsius of global warming by 2100**.
- **Developed countries** take the lead on phasing down the refrigerant greenhouse gases starting with a **10% reduction in 2019 and a 85% cut in 2036**.

# Kigali agreement for developing countries

- Developing countries will get more time for phasing down the HFCs.
- We will have to **freeze the consumption by 2024 with the first reduction in 2029**.
  - **That means that the present refrigerating systems will be obsolete in developed countries within a few years and at most within 10 to 15 years in developing countries.**

# Alternatives to HFCs

- The consequences of this phase-down is that alternatives have to be found.
- Right now three categories of alternatives do exist:
  - Replacement of HFCs by **other chemicals (HFOs) with low GWP**
  - Replacement by **natural refrigerants**
  - Development of **green refrigeration technology**

# History of environmental constraints on refrigerants

**Before the ozone layer issue**

- The environmental

constraints on the refrigerants concerned only local environment:

**toxicity**

**flammability**

**After the ozone layer issue**

- Now, the environmental constraints concern mainly global environment:
  - **No impact on the ozone layer** (Montreal Protocol)
  - Soon, **nearly no impact on global warming** (Kigali Agreement).

But the constraints concerning local environment (toxicity & flammability) still exist but are being modified.

# **Natural refrigerants** without significative direct contribution to GHG emissions

**Conventional one**

- **Ammonia** has been used from the beginning of refrigeration. Very long experience but it is **toxic & flammable** so that it must be handled with care.

**New ones**

- **$CO_2$ is not toxic neither flammable** but present properties that are not usual
- **Hydrocarbons are not toxic but are flammable.**

# History – $CO_2$

1. 1835 - Thilorier produces solid $CO_2$, usage of dry ice for laboratory purposes
2. 1869 - 1885 Windhausen develops concepts for refrigeration with $CO_2$
3. 1881 – A $CO_2$ refrigeration system was developed by Linde
4. Since 1887 – Riedinger (Augsburg), Haubold(Chemnitz), Hall(England) build $CO_2$ plants for reefer ships
5. 1894 – Mollier develops his diagram for $CO_2$
6. Since 1900 – usage of $CO_2$ large scale refrigeration plants, reefer ships, AC domestic systems, dry ice for mobile refrigeration.

# History – $CO_2$

7. Around 1900 – 37% of all reefer ships were equipped with cold air refrigeration systems. All others were equipped with compression cycles (37% with Ammonia and 25% with $CO_2$ as refrigerant).
8. After the ammonia cycle was significantly improved in the 1930s, carbon dioxide lost its importance as a refrigerant .
9. Bäckström reports in 1950 that 60% of the reefer ships and 10% of the stationary systems are operated with $CO_2$ as refrigerant.
10. In the 1960's $CO_2$ nearly ceased as refrigerant due to the easier to handle FCKW. Only dry ice remained as permanent application.
11. Revival of $CO_2$ due to awareness of ozone depletion and greenhouse effects caused by CFC/ HCFC/ HFC/ HBFC as refrigerant.

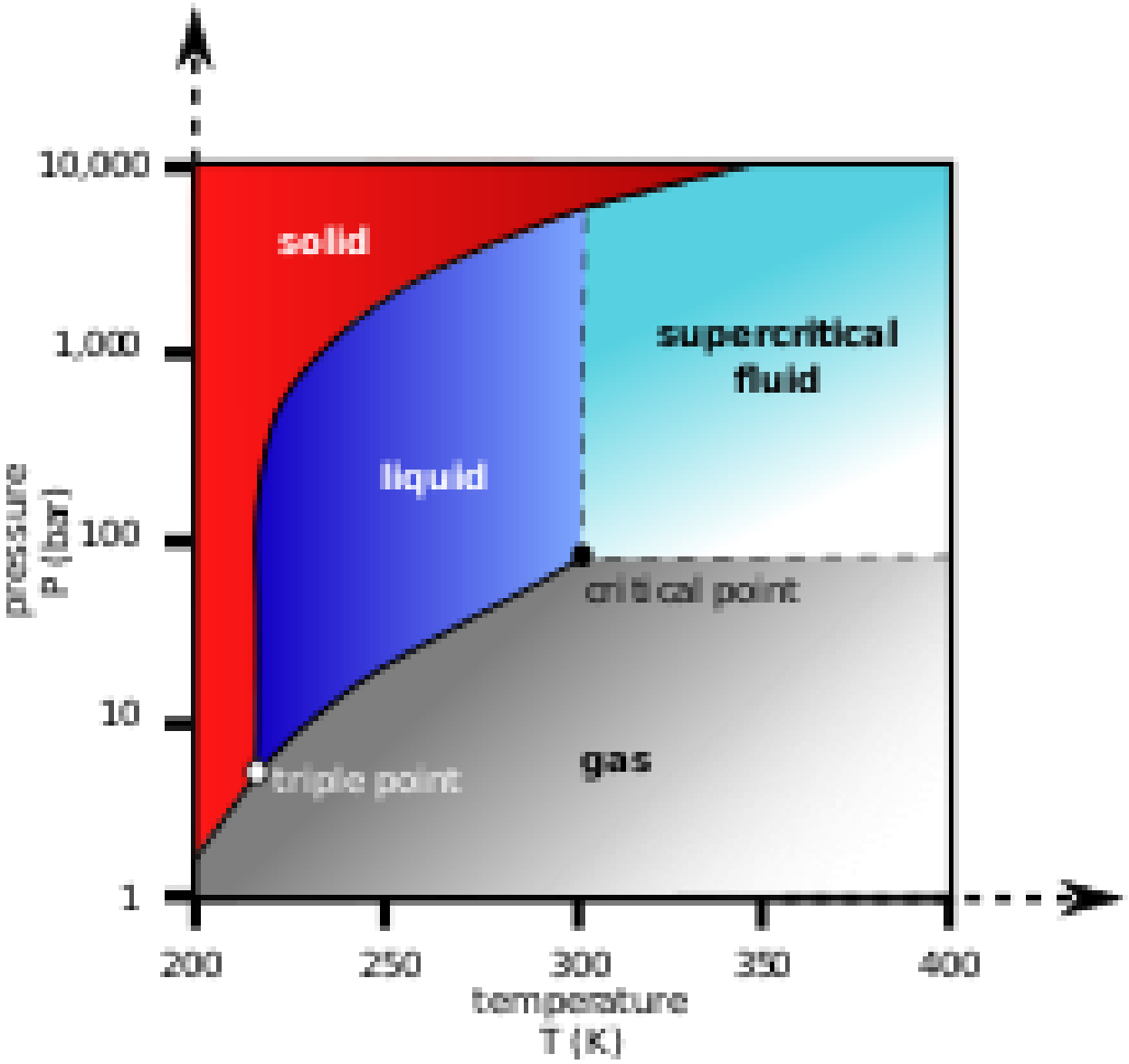
# Properties of Carbon Dioxide

1. Chemical formula : $CO_2$ (covalent bond O=C=O)
2. Mole mass : M = 44.011 kg/kmol (Refrigerant number = R744)
3. Standard density : 1.977kg/m3 (0ºC, 101.325kPa)
4. Density ratio $CO_2$ / Air = 1.529
5. Critical temperature = 31ºC
6. Critical pressure = 73.83 Bar
7. Sublimation point : t = -78.9ºC at 0.981 Bar
8. Triple point : t = -56.6ºC at 5.18 Bar
9. Decomposition temperature from 1200ºC

# Properties of Carbon Dioxide

11. Colour of the vapour : Transparent
12. Reaction to fire : incombustible
13. Reaction at atmospheric condition : stable
14. Aroma : not perceptible
15. Taste : Neutral
16. Toxicity : non toxic,
17. MAK- value : 5000 ppm
18. Danger at high concentrations:
    - Irritation of the respiratory centre from 30 000 to 50 000 ppm (3 to 5 vol%)
    - Unconsciousness at 70 000 to 100 000 ppm (7 to 10 vol%)

# Properties of Carbon Dioxide



# $CO_2$ as refrigerant

| Refrigerant | GWP |
|---|---|
| R22 | 1810 |
| R404A | 3922 |
| R134a | 1430 |
| R507A | 3985 |

Advantage

1. No ODP
2. Low greenhouse warming effect GWP =1
3. Chemically stable, non toxic
4. Cheap and available
5. No necessity for recycling or decommissioning
6. Very high volumetric refrigeration performance (5 to 8 times higher than R22 and ammonia, which leads to small parts and machinery)

# $CO_2$ as refrigerant

Disadvantage

1. Misfortunate thermodynamic properties for standard atmospheric conditions
2. Very high pressure conditions
3. Transcritical constructions for single stage systems necessary
4. Less economic than a classic refrigeration cycle with complete condensation

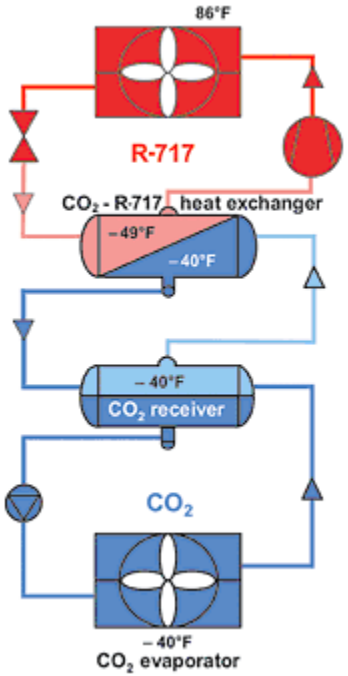
# $CO_2$ as refrigerant- usage

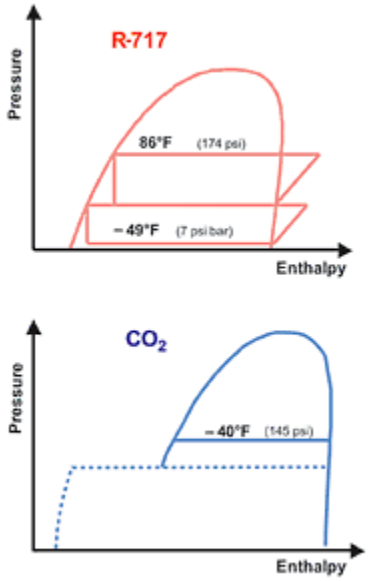
1. Dry Ice

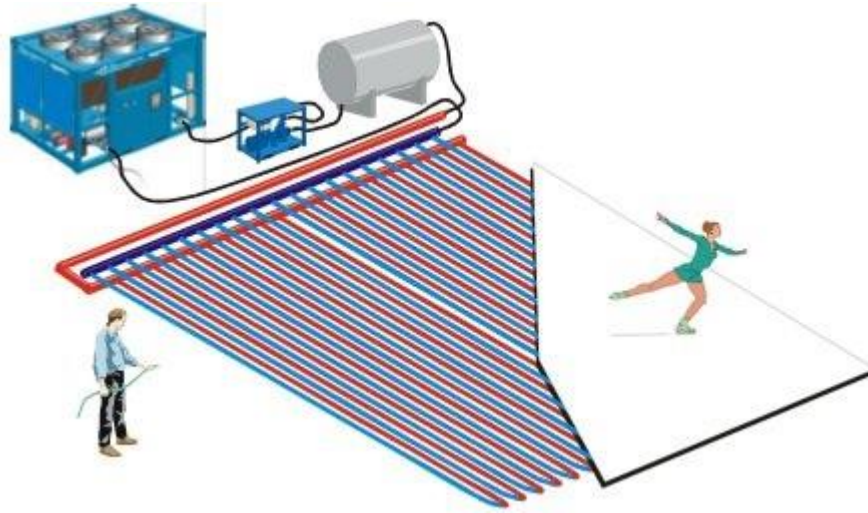
2. Dry Ice Pellets

# $CO_2$ as refrigerant - usage

## 3. Brine

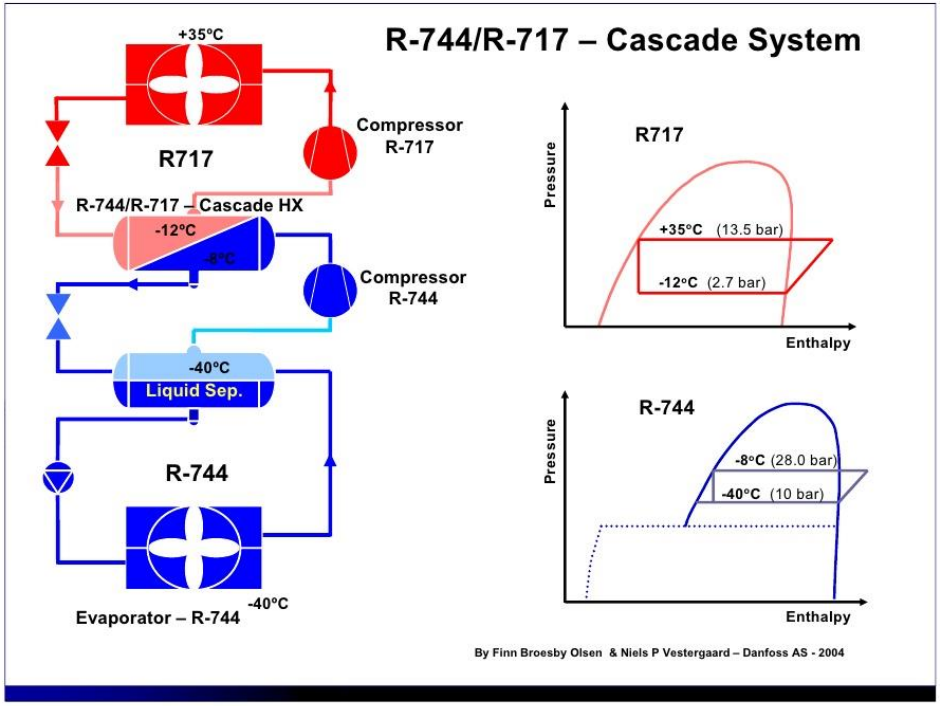


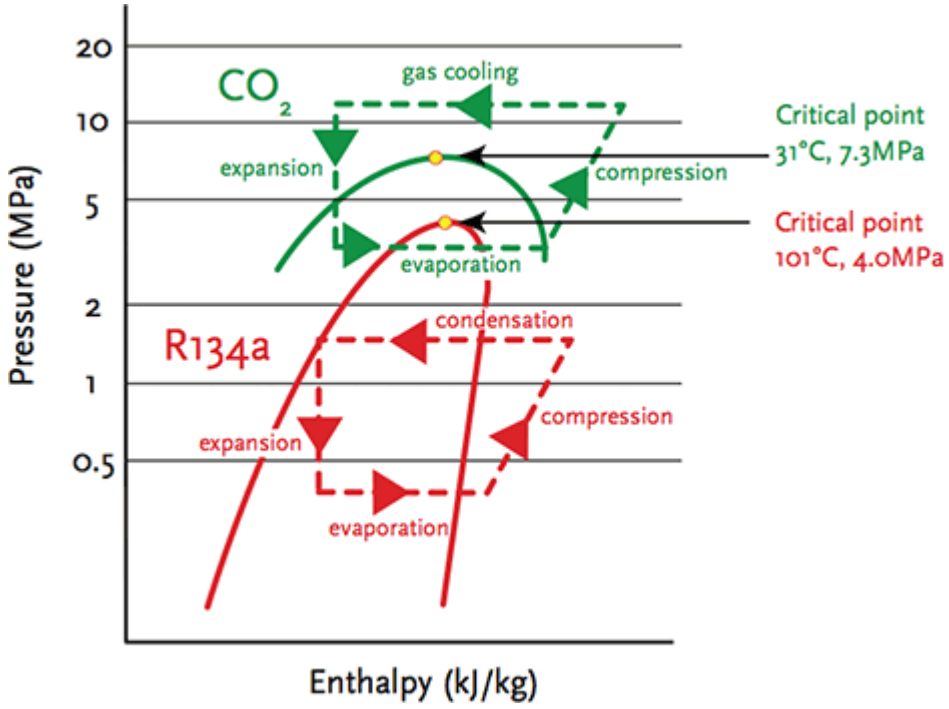
# $CO_2$ as refrigerant

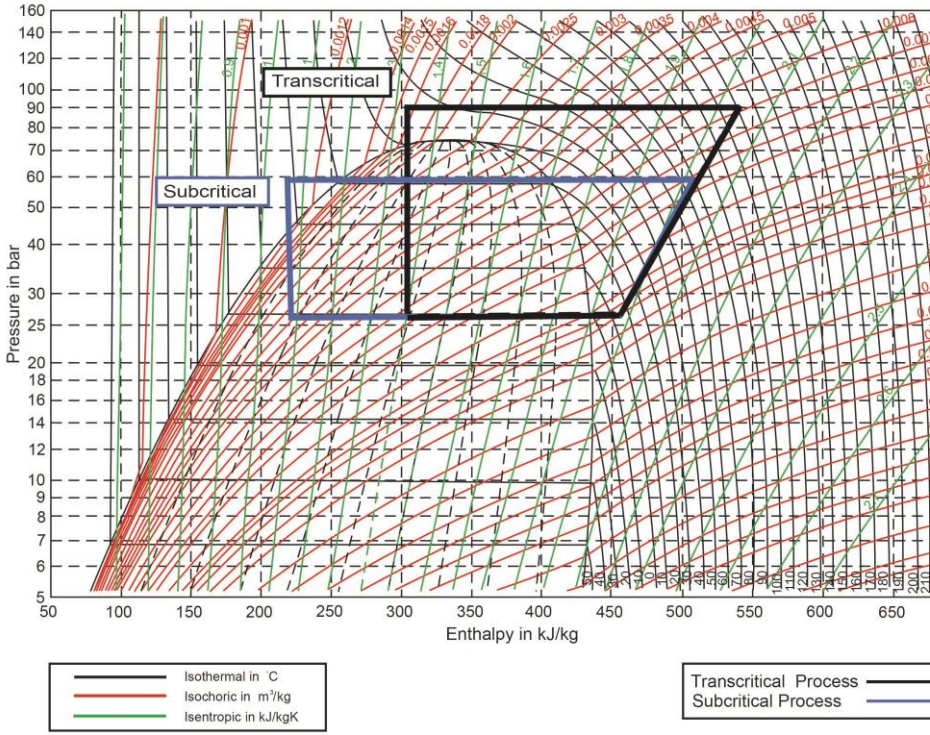
## 4. Cascade refrigeration system



# $CO_2$ as refrigerant

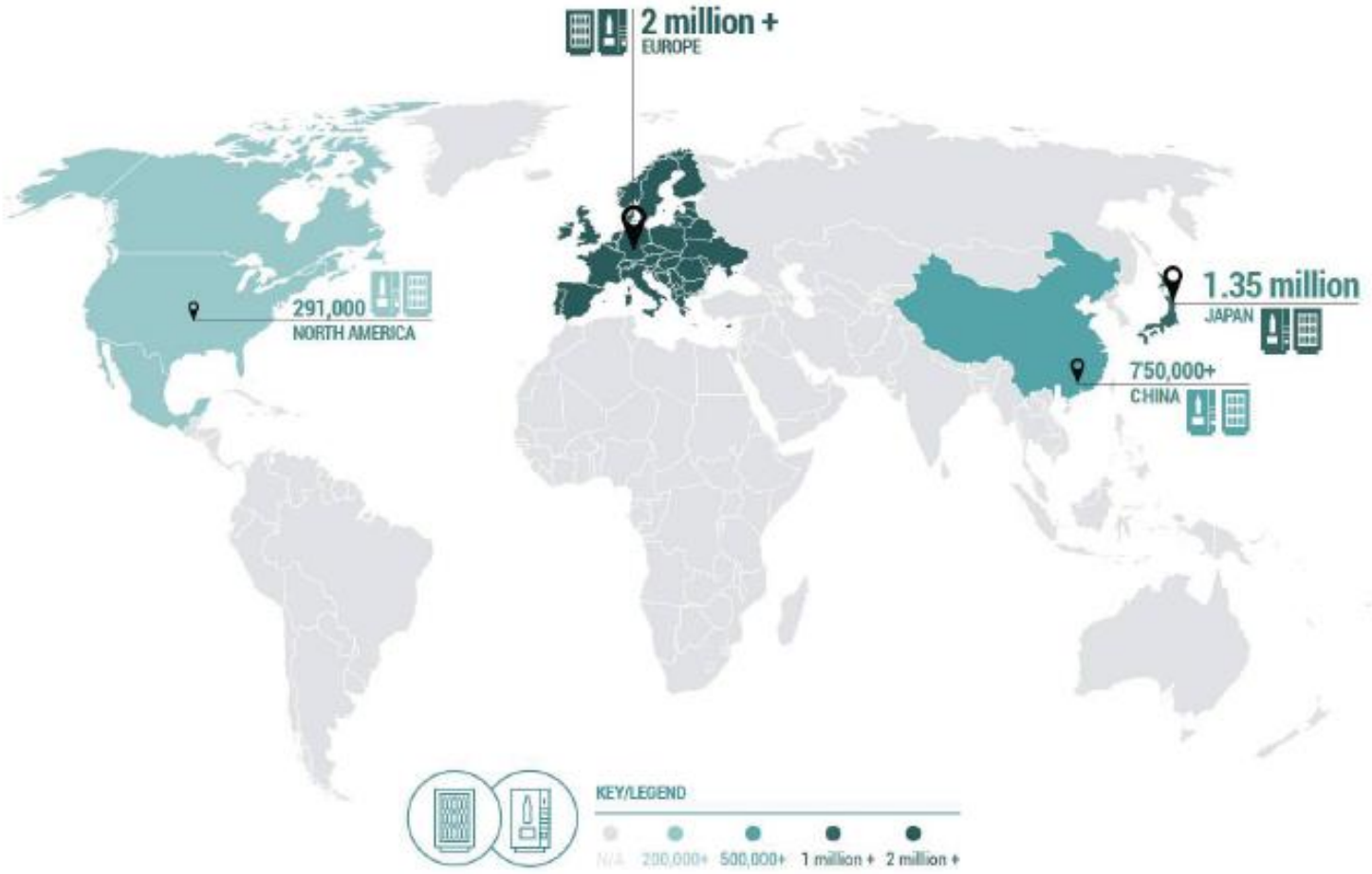
## 5. Transcritical refrigeration system



# Beverage Vending Machines

source Shecco 2016



# $CO_2$ for supermarkets

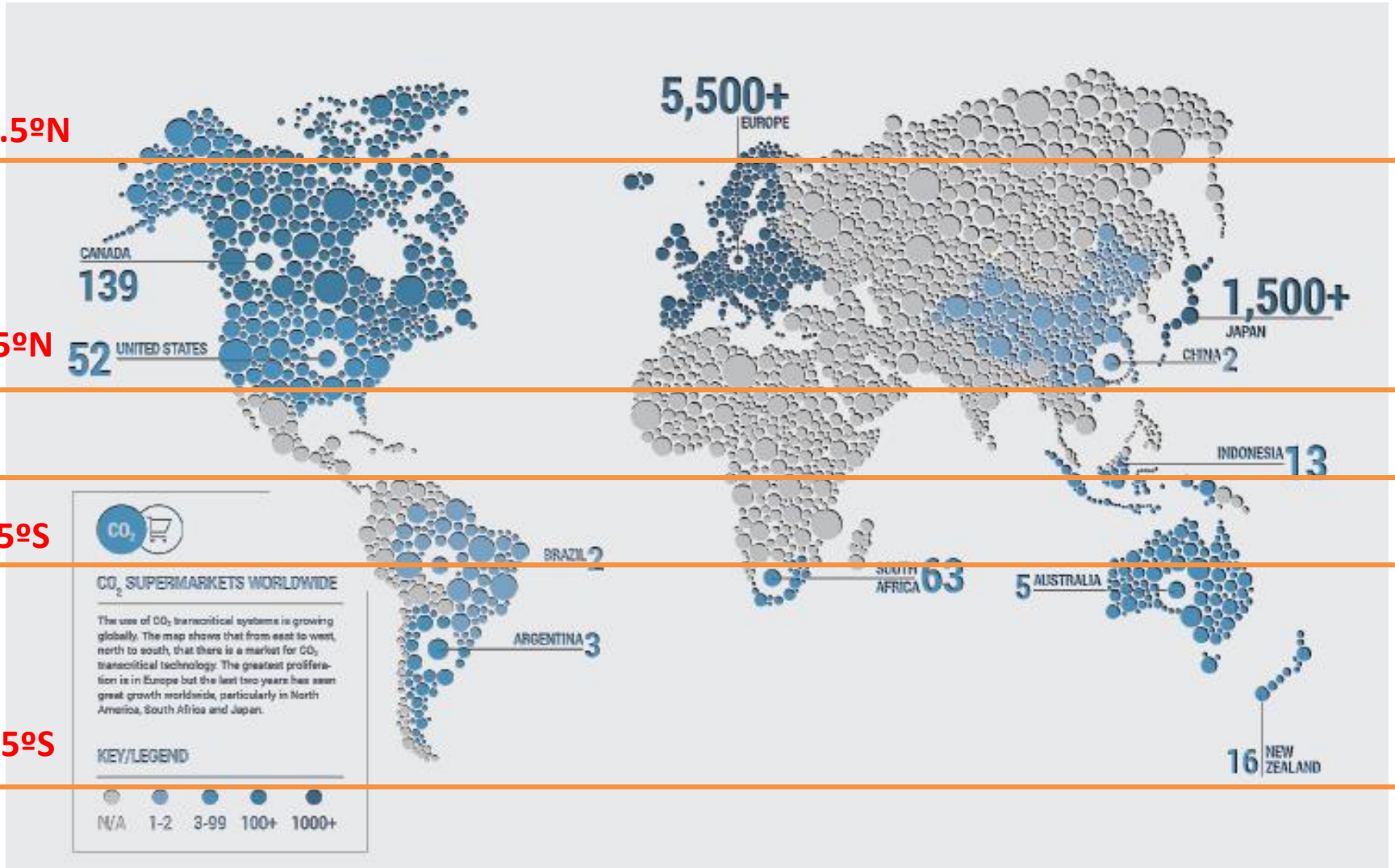
**CO2 presently very popular in supermarkets to replace high GWP refrigerant for refrigerated display cabinets : for fresh as well as frozen products conservation.**

**A central unit chiller is generally used to distribute the chilled transfer media at 2 different temperatures through the cabinets.**

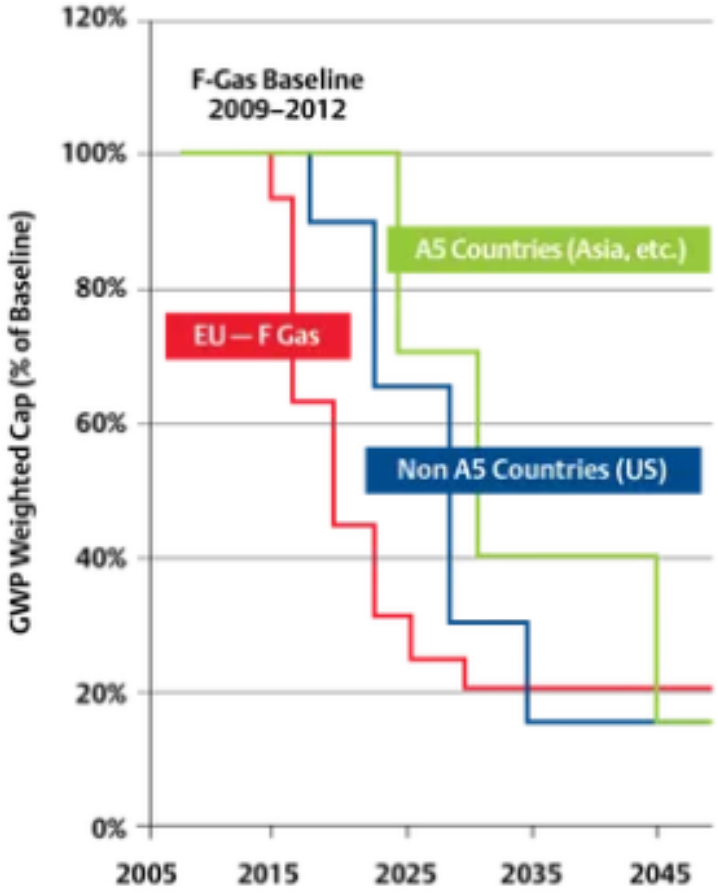
compSUPER XS2x2VP

# $CO_2$ TC store in the World

source Shecco 2016



# Europe's New F-Gas Phase-Down and Bans Go Into Effect January 1, 2015




| Service and maintenance bans | GWP | Timing |
|---|---|---|
| HFC's | 2,500 | Jan. 2020 |
| **'Placing on the market' (new equipment) bans** | | |
| Domestic refrigerators and freezers | 150 | Jan. 2015 |
| Refrigerators and freezers for commercial use (hermetically sealed systems) | 2,500 | Jan. 2020 |
| Refrigerators and freezers for commercial use (hermetically sealed systems) | 150 | Jan. 2022 |
| Stationary refrigeration equipment (except equipment for temperatures below -50 °C) | 2,500 | Jan. 2020 |
| Multipack centralized refrigeration systems for commercial use with a capacity of ≥ 40 kW (140 kBTU/hr) (except in the primary refrigerant circuit of cascade systems, where fluorinated greenhouse gases with a GWP of less than 1,500 may be used) | 150 | Jan. 2022 |
| Movable room air-conditioning appliances (hermetically sealed equipment which is movable between rooms by the end user) | 150 | Jan. 2020 |
| Single split air-conditioning systems containing < 3 kg | 770 | Jan. 2025 |

# JAPAN F-GAS LAW
# DESIGNATED PRODUCTS

| Designated products | | Present refrigerant (GWP) | Target value (GWP) | Target year |
|---|---|---|---|---|
| Room air conditioning |  | R410A (2090), R32 (675) | 750 | 2018 |
| Commercial air conditioning (offices & stores) |  | R410A (2090) | 750 | 2020 |
| Condensing units and refrigeration units (> 1.5kW) |  | R404A (3920), R410A (2090), R407c (1774), $CO_2$ (1) | 1500 | 2025 |
| Cold storage warehouse (> 50.000m³) |  | R404A (3920), $NH_3$ (0) | 100 | 2019 |
| Mobile air conditioning |  | R134a (1430) | 150 | 2023 |

# USA F-GAS : DESIGNATED PRODUCTS

## MOTOR VEHICLE AIR CONDITIONING - NEW LIGHT-DUTY SYSTEMS

| Substitutes | Decision |
|---|---|
| HFC-134a | • Unacceptable as of Model Year (MY) 2021, except where allowed under a narrowed use limit through MY 2025.<br>• Acceptable, subject to narrowed use limits, for vehicles exported to countries with insufficient servicing infrastructure to support other alternatives, for MY 2021 through MY 2025.<br>• Unacceptable for all newly manufactured vehicles as of MY 2026. |

## RETAIL FOOD REFRIGERATION

| End-use | Substitutes | Decision |
|---|---|---|
| Supermarket Systems (Retrofit) | R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A | Unacceptable as of July 20, 2016 |
| Supermarket Systems (New) | HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A | Unacceptable as of January 1, 2017 |
| Remote Condensing Units (Retrofit) | R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A | Unacceptable as of July 20, 2016 |
| Remote Condensing Units (New) | HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A | Unacceptable as of January 1, 2018 |
| Stand-Alone Units (Retrofit) | R-404A, R-507A | Unacceptable as of July 20, 2016 |

## VENDING MACHINES

| End-use | Substitutes | Decision |
|---|---|---|
| Retrofit | R-404A, R-507A | Unacceptable as of July 20, 2016 |
| New | FOR12A, FOR12B, HFC-134a, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-426A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), SP34E | Unacceptable as of January 1, 2019 |

# The refrigerants challenges for tropical climates

- Routes do exist for **post Kigali cooling solutions** for tropical climates including mainly:
  - **$CO_2$ systems**
  - **Hydrocarbons systems**
- But, the best solutions for temperate climates are not always good for tropical climate.
- **Specific studies on the best natural refrigerant solution for tropical climate are to be determined**
  - **for air conditioning**
  - **as well as for commercial & industrial refrigeration**

# Challenges for Malaysia

- New policy
- Know how for natural refrigerant
- Professional certificate for handling these refrigerants
- Awareness program, Safety regulation, Code of practise …etc

# Thank you!

ngwenbin@unikl.edu.my