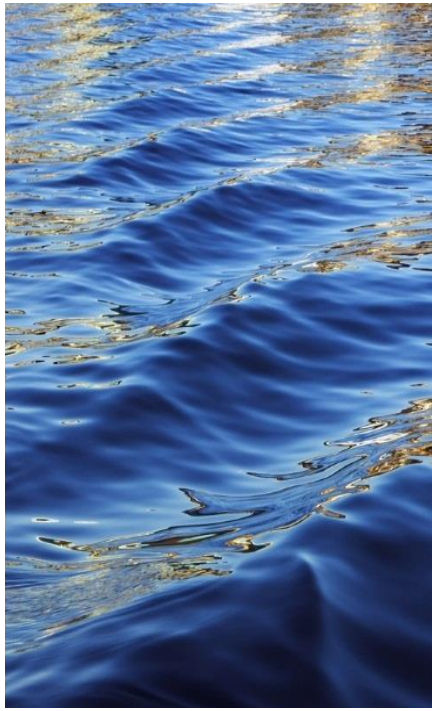
Environmental Thermal Engineering

Lecture Note #8

Professor Min Soo KIM



Refrigerant

Type of Refrigerant

- ❑ **Halocarbon** — CFC, HCFC, HFC, R-12, R-32, R-134a
- ❑ **Hydrocarbon** — R-50, R-170, R-290, R-600, R-1270
- ❑ **Inorganic compound** — Ammonia(R-717), water
- ❑ **Carbon dioxide** — R-744

Type of Refrigerant

❑ CFC (chlorofluorocarbon)

- Compound that consists of carbon, chlorine, fluorine
- R-12, R-113, R-114, R-115
- Most high ODP(Ozone Depletion Potential
- They have an effect on global warming

❑ HCFC (hydrochlorofluorocarbon)

- Compound of CFC which has at least one hydrogen atom.
- R-22, R-123, R-124, R-141b, R-142b
- With substitution of a portion of Cl with H, ODP has reduced
- They have a little effect on global warming

❑ HFC (hydrofluorocarbon)

- Compound that consists of only carbon, chlorine, hydrogen
- R-32, R-125, R-134a, R-143a, R-152a
- No influence on Ozone layer

Notation - Methane, Ethane, Propane (1)

❑ Notation (1)

- Expressed on treble figures each digit is related with elements
- Hundreds digit x = the number of carbon atom - 1
- Tens place y = the number of hydrogen atom+ 1
- Unit digit z = the number of fluorine

❑ Notation (2)

- Adding 90 on R-xyz, which makes new notation that each digit represent the number of elements
- Hundreds digit x = the number of carbon atom
- Tens place y = the number of hydrogen atom
- Unit digit z = the number of fluorine

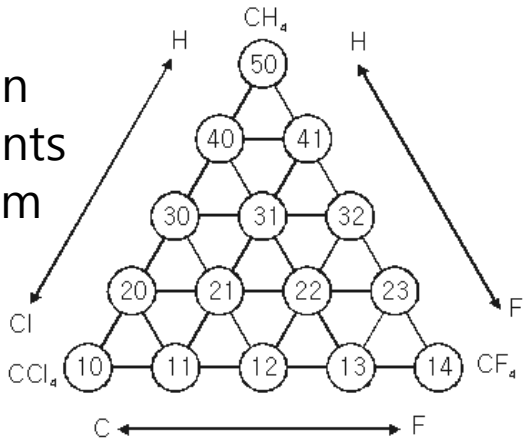


FIGURE Halocarbon (Methane series) Composition

Notation - Methane, Ethane, Propane (2)

❑ Notation (3)

- In the case that refrigerant is composed of 4 species -carbon, hydrogen, fluorine, and chlorine- the number of chlorine atom is 2x-y-z+5

- In the case that isomer exists, alphabet a or b is added for clarifying according to stability of halogen element

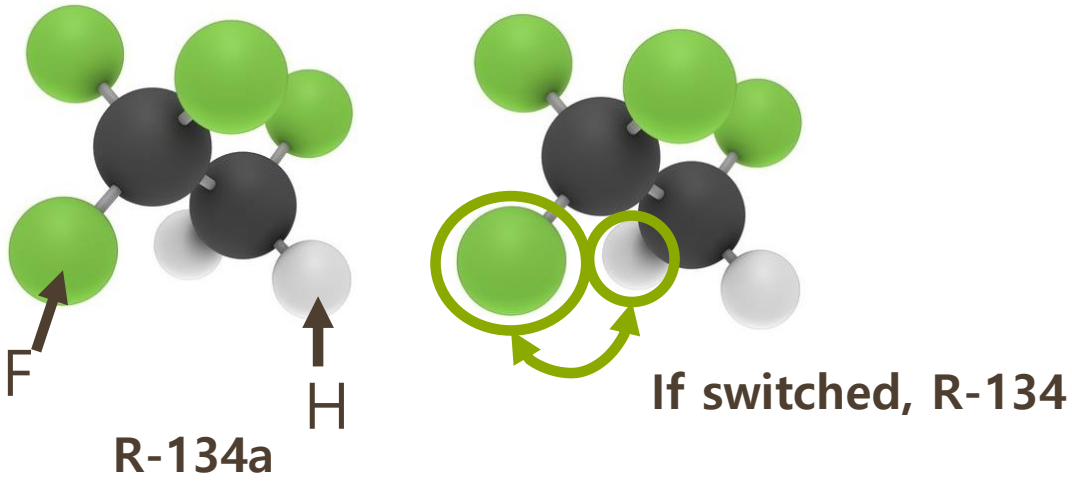


FIGURE Notation expressed by structure

Example

- **Question :** Figure out chemical compound of R-134a

- **Answer :** 134+90 = 224

  Carbon = 2
  Hydrogen = 2
  Fluorine = 4

  134

  Carbon = 1+1 = 2
  Hydrogen = 3 -1 = 2
  Fluorine = 4

Notation of Refrigerant

❑ Zeotropic mixture refrigerant

- Naming as R-400~
- The number and mass composition for a component of the compound should be specified in the ascending order of the boiling point

❑ Azeotropic mixture refrigerant

- Naming as R-500~

❑ Organic compound refrigerant

- Naming as R-600~
- Butane series : R-60O
- Oxygen compound : R-61O
- Organic compound : R-62O
- Nitrogenous compound : R-63O

Heat Pump Cycle

❑ Inorganic compound refrigerant

- Naming as R-700
- Last two digits mean molecular weight
  (For example, water is named as R-718)

❑ Unsaturated organic refrigerant

- Naming as R-1000~
  Following notation of halocarbon at the digits under hundreds

Notation of refrigerant : Halocarbons

No.	Chemical Name	Chemical formula
11	Trichloromonofluoromethane	CCl_3F
12	Dichlorodifluoromethane	CCl_2F_2
13	Chlorotrifluoroethane	$CClF_3$
22	Monochlorodifloromethane	$CHClF_2$
40	Methyl chloride	CH_3Cl
113	1,1,2-Trichlorotrifluoroethane	CCl_2FCClF_2
114	1,2-Dichlorotetrafluoroethane	$CClF_2CClF_2$

Requirements for Refrigerant

❑ Thermodynamic properties

- High latent heat
- Low coagulation pressure
- Higher critical temperature than ambient condition
- Higher boiling pressure than ambient condition in low temperature
- Low condensing pressure is recommended

❑ Physicochemical properties

- High electric resistance of refrigerant vapor
- Good heat transfer property
- Proper solubility to lubricant
- Low hygroscopic
- Chemical stability, no spoilage
- Inactivity, low corrosiveness

Requirements for Refrigerant

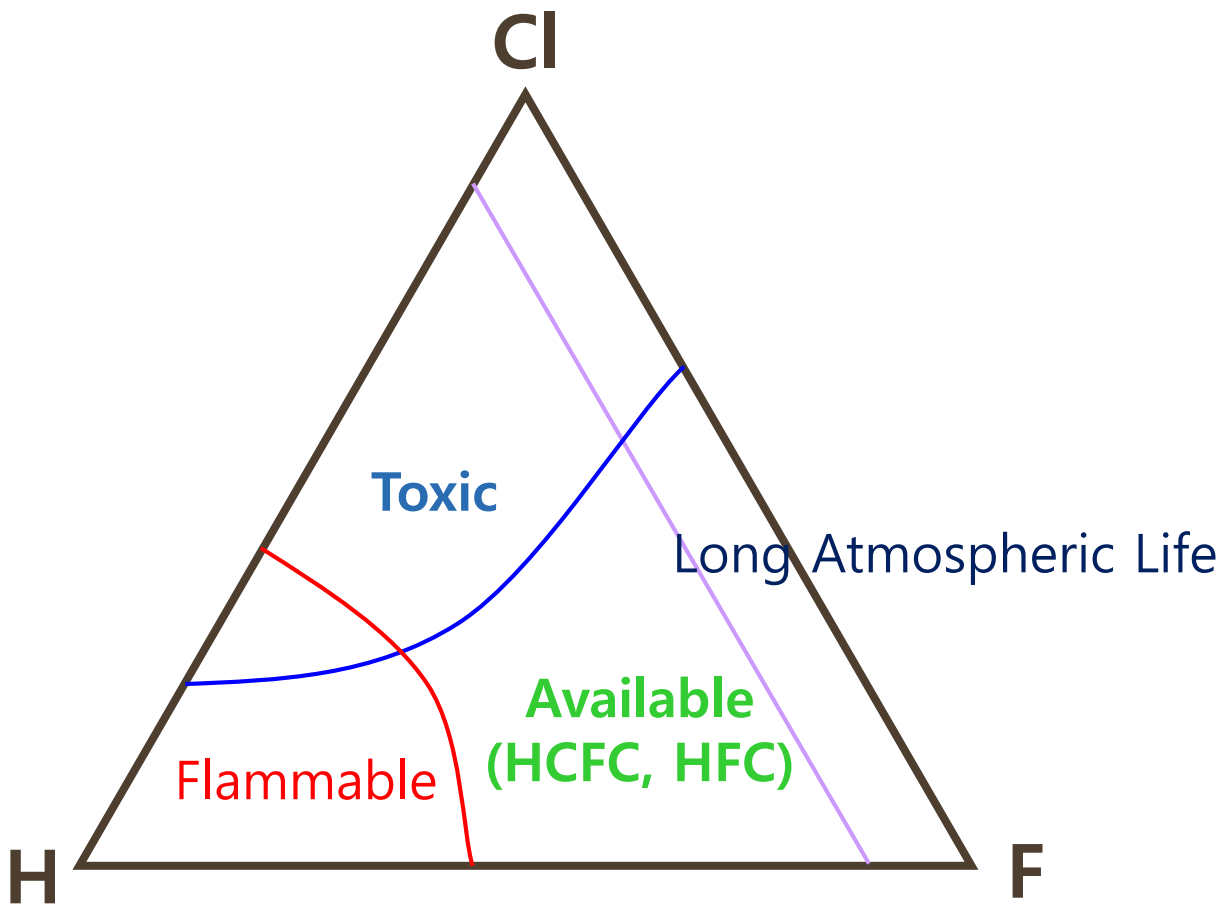
❑ Environmental properties

- No flammability and explosiveness
- No toxicity
- Contains are not to be damaged by refrigerant leaking
- Eco-friendly one is recommended

❑ Thermal Engineering Criteria

- Volumetric Capacity
- COP
- Discharge Temperature
- Compression Ratio

General Characteristics



Characteristics of Refrigerants

❑ Halocarbon

- Substituting saturated hydro-carbon for halogen series
- Clarified to CFC, HCFC, HFC by a presence of main components : hydrogen, fluorine, chlorine, carbon
- CFC and HCFC is prohibited because of their environmental problem
- R-143a and R-152a in HFC can substitute R-12
- R-32, R-125, and R-143a can be used as azeotropic mixture refrigerant

❑ Hydrocarbon

- Refrigerant composed of only hydrogen and carbon
- R-50(methane), R-170(ethane), R-290(propane), R-600(butane), R-600a(iso-butane), R-1270(propylene)
- Non-toxic, stable, eco-friendly
- A large specific volume which makes small quantities of refrigerant injection
- Flammability

Characteristics of Refrigerants

❑ Zeotropic mixture

- Mixture of more than two pure refrigerant
- Each refrigerant component has different properties so that the composition of the mixture changes while boiling and condensing
- The temperature rises when boiling reduces when condensing in constant pressure

Zeotropic Mixture Refrigerant

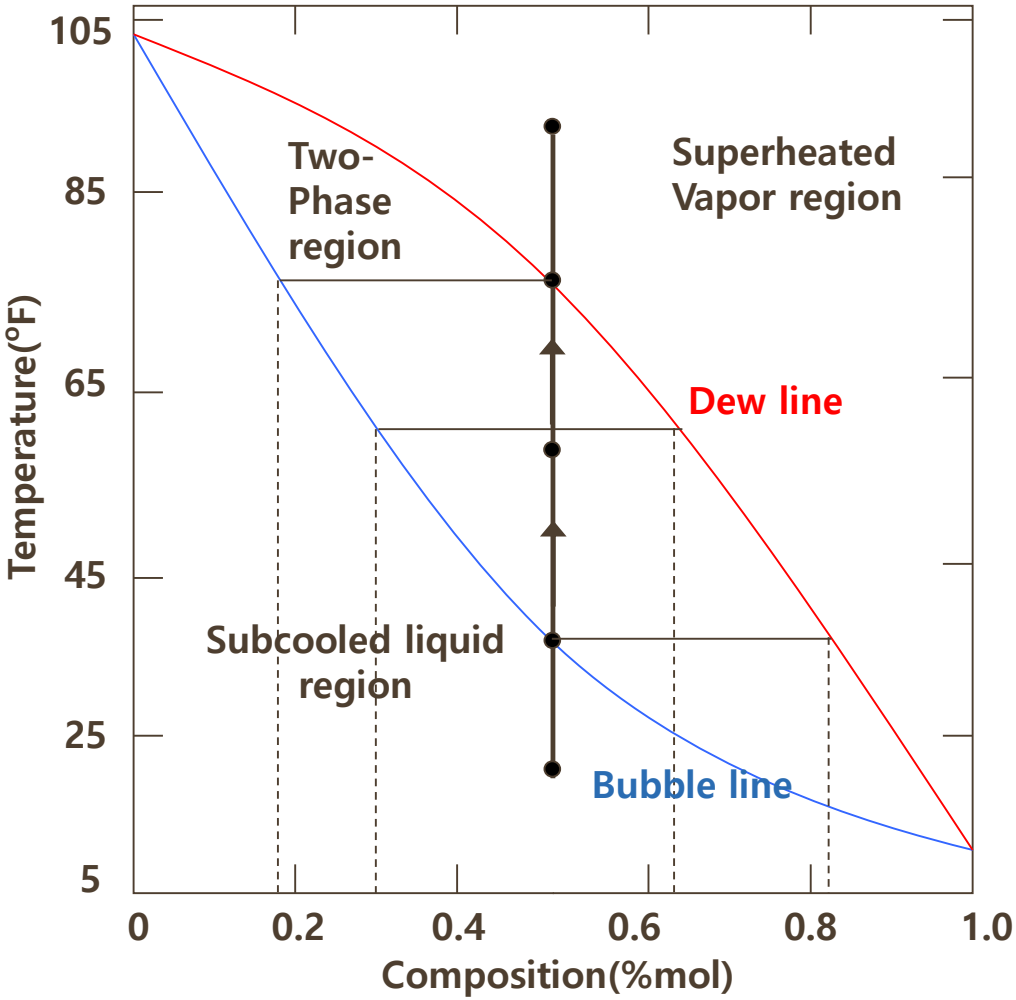
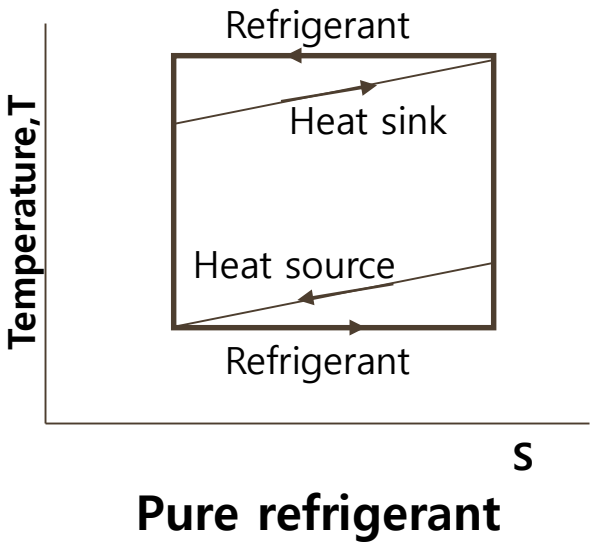


FIGURE Phase change curve of R-22/R-114(Zeotropic mixture)

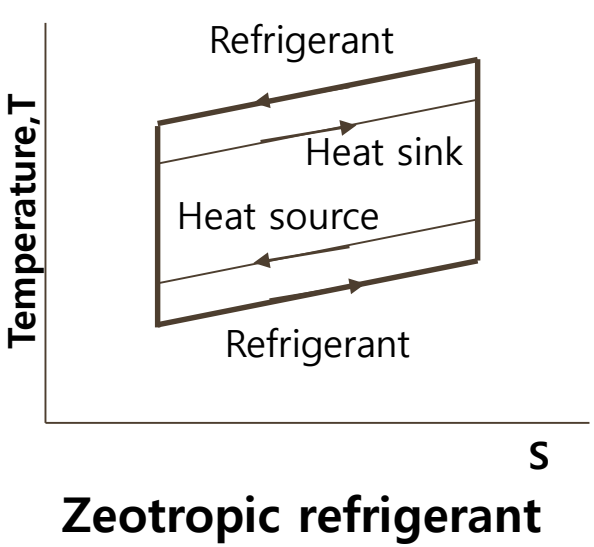
Zeotropic Mixture Refrigerant

❑ Advantages

- Temperature rises when the refrigerant boils in constant pressure
- Temperature reduces when the refrigerant condenses in constant pressure
  that is, a temperature gradient occurs in phase changing
- Heat exchanger efficiency can be improved by using this characteristic



Pure refrigerant



Zeotropic refrigerant

Zeotropic mixture refrigerant and make temperature of refrigerant and heat source parallel so that mean temperature difference and irreversibility has reduced with efficiency improvement

Zeotropic Mixture Refrigerant

❑ Disadvantages

- Large heat exchange requirement with low temperature difference

$$q = UA\Delta T \qquad \Delta T \downarrow \qquad A \uparrow$$

- High cost with counter-flow heat exchanger
- The most crucial problem is that when refrigerant leaks, composition changes because component with higher vapor pressure escape first. That is, In the case of re-charging, entire refrigerant should be took back and injected newly.

Zeotropic Mixture Refrigerant

- Mixture of more than two pure refrigerants
- Differently from the Zeotropic mixture, the temperature is uniform while phase changing in constant pressure
- The behavior of the material is similar to the pure material

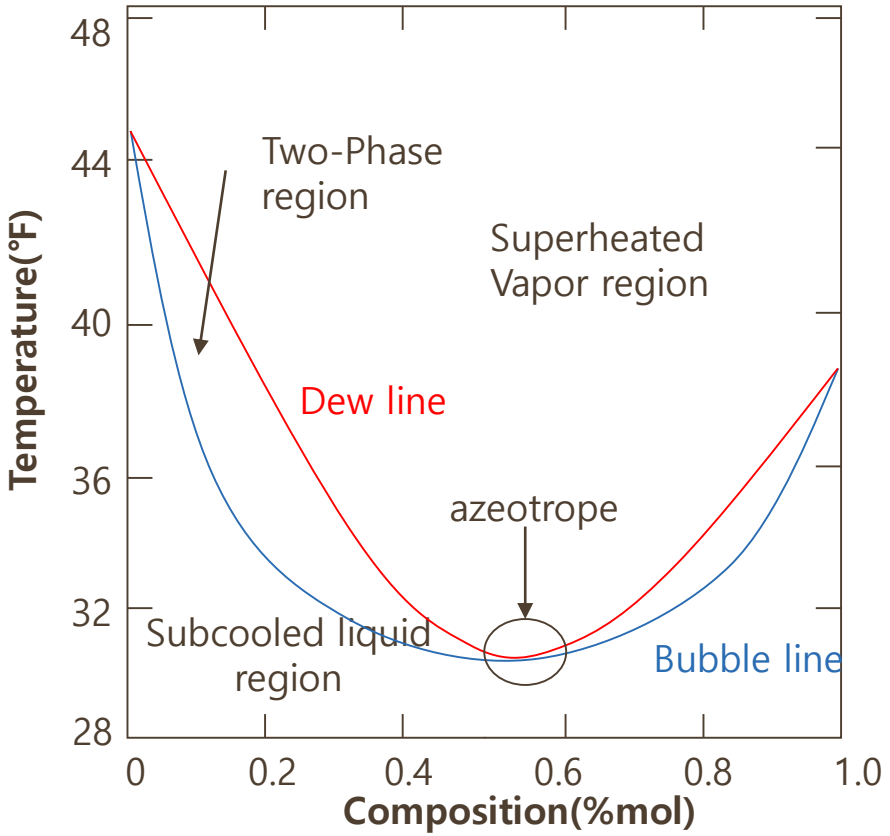


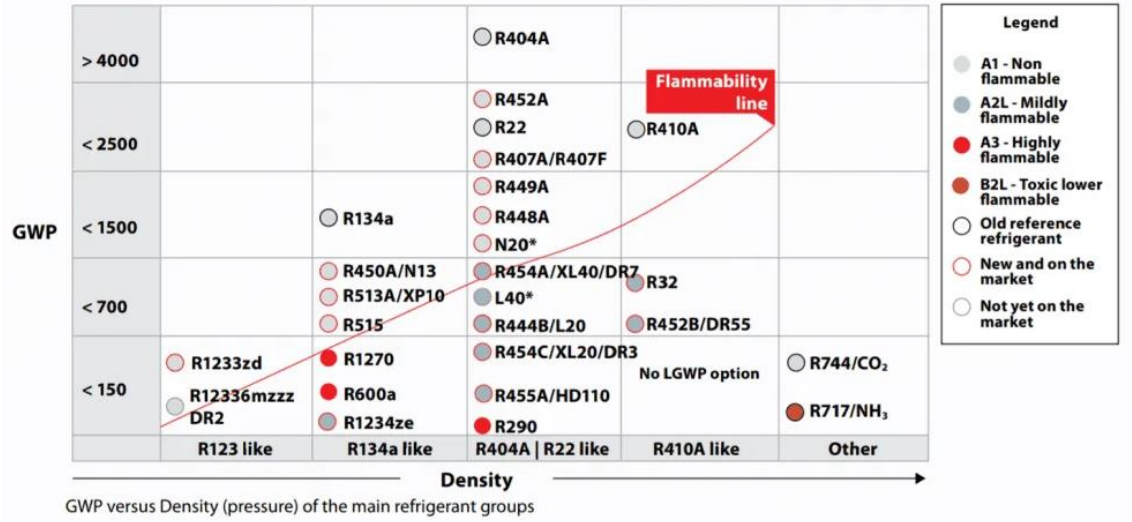
FIGURE Phase change curve of R-500(azeotropic mixture)

Safety Issue

❑ Flammability Classification (ASHRAE 34)

Flammability Class		Lower Flammability Limit (LFL, kg/m3)	Heat of Combustion (HoC, MJ/kg)	Burning Velocity (BV, cm/s)	Refrigerants
A3	Highly flammable	< 0.1	> 19		R290, R600a
A2	Flammable	> 0.1	< 19	> 10	R152a
A2L	Mildly Flammable	> 0.1	< 19	< 10	R32, R1234yf, R1234ze
A1	Non-Flammable				R410A, R404A, R134a

❑ GWP vs. Flammability



GWP versus Density (pressure) of the main refrigerant groups

Attention for Environment

- After finding out Freon gas and ozone layer destructing effect, attention for environmental pollution by emission has increased. And it is concretized by the climate change conventions.

Type	Source
CO_2	Fossil fuel, Forest fire
CH_4	Bacteria, Decomposition of organic matter
NO_2	Combustion, Nitrogenous fertilizer
CFC	Refrigerant, Spray

Attention for Environment

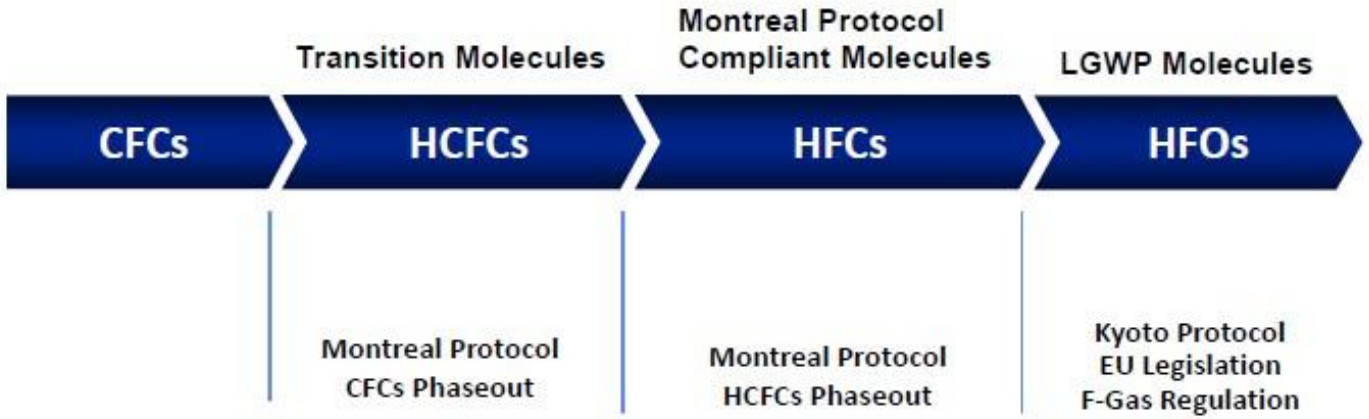
1. Carbon dioxide, methane, nitrogen dioxide - criteria for 1990
2. Alternative refrigerant (HFC, PFC) - criteria for 1995

The developed country plays a leading role for solution for environmental problem

Climatic Change Convention

- **Regulations related to refrigerant**
  1. **Montreal Protocol, 1989 : Ozone Layer Destruction Index (ODP) Regulation**
  2. **Kyoto Protocol, 1997 : Global Warming Index (GWP) Regulation**
  3. **Alternative refrigerant (HFC, PFC) - criteria for 1995**

➢ **The need for a new refrigerant to respond to regulations.**



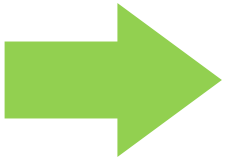
Climatic Change Convention

❑ Kyoto Protocol,1997

- **Goal and term are set up:** 2008 – 2012
- **Target for reduction**
  1. Carbon dioxide, methane, nitrogen dioxide - criteria for 1990
  2. Alternative refrigerant (HFC, PFC, SF6) - criteria for 1995
- Net CO2 emissions system and emission rights trade system introduced
- Eco-development fund settled – supporting developing countries
- Reduction goal has legal force
- Differential application through nations
  1. Developing countries are excluded
  2. Differentially applied for the advanced country, East-European countries

❑ Buenos Aires Plan of Action, 1998

- 170 countries consent with trade permit system, clean production developing system, joint carrying system until the sixth assembly in 2000

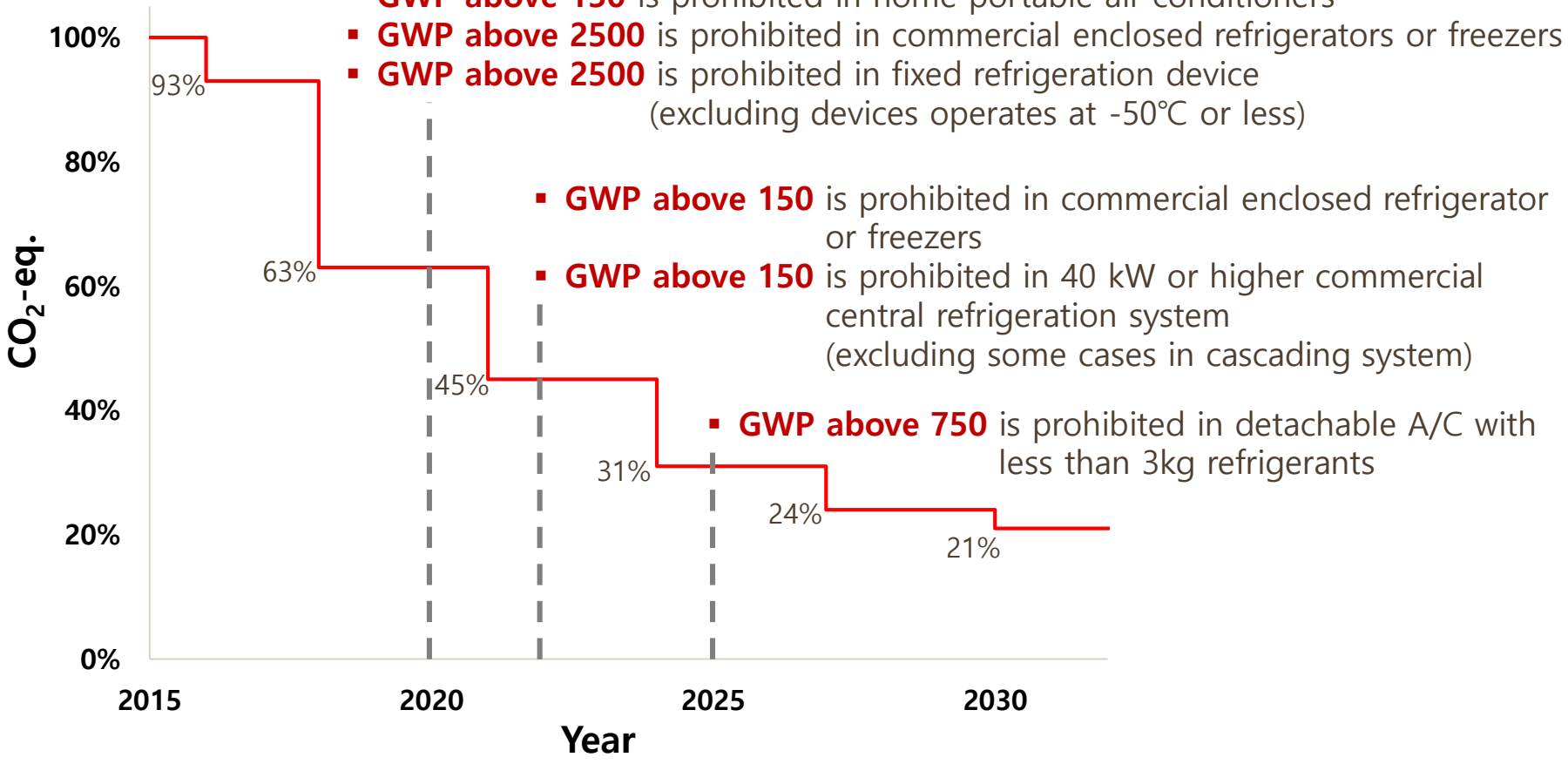


Visualization of birth of greenhouse gas market with scale of a billion ton annually

Climatic Change Convention

❑ EU F-gas regulation, 2005

- **Greenhouse gases above GWP 150 are prohibited from being used in all cars (2017)**



- **GWP above 150** is prohibited in home portable air conditioners
- **GWP above 2500** is prohibited in commercial enclosed refrigerators or freezers
- **GWP above 2500** is prohibited in fixed refrigeration device (excluding devices operates at -50℃ or less)
- **GWP above 150** is prohibited in commercial enclosed refrigerator or freezers
- **GWP above 150** is prohibited in 40 kW or higher commercial central refrigeration system (excluding some cases in cascading system)
- **GWP above 750** is prohibited in detachable A/C with less than 3kg refrigerants

Climatic Change Convention

❑ Refrigerant 1234yf

- Pressure characteristics and performance similar to R134a, which is widely used for vehicles.
- Low global warming index (GWP=4)
- Evaluation of refrigerant suitable for A/C for vehicles

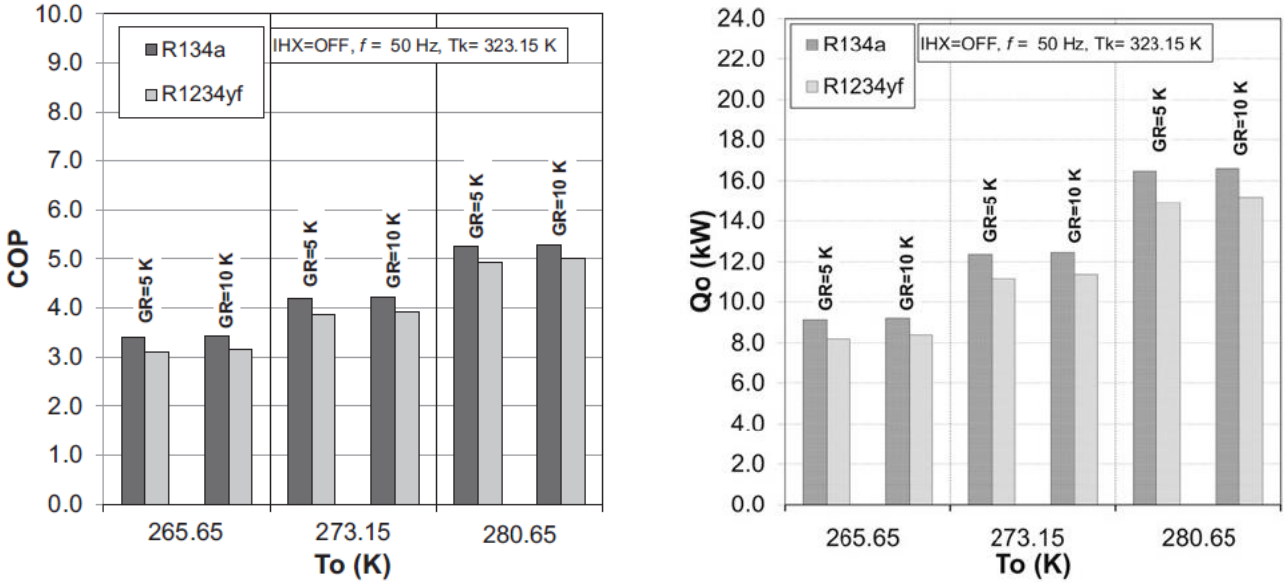


FIGURE Performance Comparison between R134a and 1234yf

Greenhouse Gas Regulation

❑ Solution for greenhouse gas prohibition

- Strengthening competition of the industry
- Improvement of efficiency, Alternation of fuel
- Forest conservation and reforestation industry
- Reduction of greenhouse gas emission
- Regulation of emission gas

❑ Current situation of Korea

- As Korea has transited to the energy conservation industry, the emission of pollutant material has reduced. However, it is still higher than the level of advanced country
- Most portion of greenhouse gas is due to energy area which is followed by industrial process area

❑ Greenhouse gas policy of authorities

- Continuous transition to the energy-saving industry is needed
- Consideration of regulation of greenhouse gas emission and alternative material is needed.

Greenhouse Gas Regulation

❑ Domestic reduction plan related to refrigerant regulation.

- According to the Montreal Protocol, HCFC use reduction began in 2013
- Based on the Montreal Protocol, the annual reduction rate is 5.1% → ('13~15) 6.3% → ('16~20) 13.1% → ('21~25) 42.6% based on the Montreal Protocol.

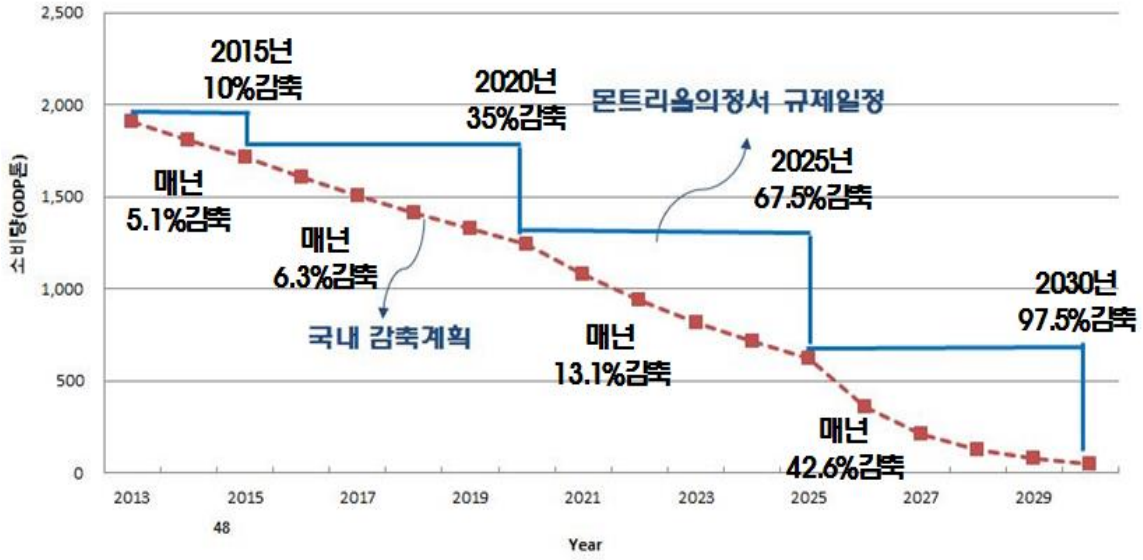


FIGURE Domestic HCFCs Refrigerant Consumption Reduction Plan (Draft)

Greenhouse Gas Regulation

❑ 2030 GHG reduction Target for Korea : 40% (Compared to 2018)

〈 부문별 감축 목표 〉

(단위: 백만톤CO_2eq)

구분	부문	기준연도('18)	現 NDC ('18년 比 감축률)	NDC 상향안 ('18년 比 감축률)
배출량*		727.6	536.1 (△191.5, △26.3%)	436.6 (△291.0, △40.0%)
배출	전환	269.6	192.7 (△28.5%)	149.9 (△44.4%)
	산업	260.5	243.8 (△6.4%)	222.6 (△14.5%)
	건물	52.1	41.9 (△19.5%)	35.0 (△32.8%)
	수송	98.1	70.6 (△28.1%)	61.0 (△37.8%)
	농축수산	24.7	19.4 (△21.6%)	18.0 (△27.1%)
	폐기물	17.1	11.0 (△35.6%)	9.1 (△46.8%)
	수소	-	-	7.6
	기타(탈루 등)	5.6	5.2	3.9
흡수 및 제거	흡수원	-41.3	-22.1	-26.7
	CCUS	-	-10.3	-10.3
	국외 감축**	-	-16.2	-33.5

* 기준연도('18) 배출량은 총배출량, '30년 배출량은 순배출량(총배출량 – 흡수·제거량)

** 국내 추가감축 수단을 발굴하기 위해 최대한 노력하되, 목표 달성을 위해 보충적인 수단으로 국외 감축 활용

※ 상기 배출량은 직접배출량을 기준으로 작성

Type of Natural Refrigerant

Refrigerant	Advantages	Disadvantages
H_2O	Non-toxic Direct usage of refrigerant	System enlargement
Air	Non-toxic Applied for high speed Train in Germany	Gas cycle
He	Used in stirring engine	Gas cycle Low efficiency
HC	Good property Working in low pressure	Combustible
CO_2	Good property Used for ship	High pressure Low critical temperature
NH_3	Used in industry (in large scale plant)	Toxic combustible

Question and Answer Session