TEAP Decision XXVII/4 Task Force Report for OEWG-37

by

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Decision XXVII/4

To prepare a report for consideration by the 37th OEWG meeting, and thereafter an updated report to be submitted to the 28th MOP, that would:

a) Update, where necessary, and provide new information on alternatives to ozone-depleting substances, including not-in-kind alternatives, based on the guidance and assessment criteria provided in subparagraph 1 (a) of decision XXVI/9, and taking into account the most recent findings on the suitability of alternatives under high-ambient temperatures, highlighting in particular:
   i. the availability and market penetration of these alternatives in different regions;
   ii. the availability of alternatives for replacement and retrofit of refrigeration systems in fishing vessels, including in small island countries;
   iii. new substances in development that could be used as alternatives to ODS and that could become available in the near-future;
   iv. the energy efficiency associated with the use of these alternatives;
   v. the total warming impact and total costs associated with these alternatives and the systems where they are used;

b) Update and extend to 2050 all the scenarios in the Decision XXVI/9 report.

Decision XXVII/4 Task Force

CO-CHAIRS

•Lambert Kuijpers (Netherlands, TEAP Senior Expert and RTOC member)
•Bella Maranion (USA, TEAP Co-chair)
•Roberto Peixoto (Brazil, RTOC Co-chair)

MEMBERS

- Denis Clodic (France, outside expert)
- Daniel Colbourne (UK, RTOC)
- Martin Dieryckx (Belgium, RTOC)
- Piotr Domanski (USA, outside expert)
- Dave Godwin (USA, RTOC)
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- Dan Verdonik (USA, HTOC Co-chair)
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- Asbjørn Vonsild (Denmark, RTOC)
- Jianjun Zhang (PRC, MCTOC Co-chair)
- Shiqiu Zhang (PRC, TEAP Senior Expert)

Considerations for the response to Decision XXVII/4

- Similarity between XXVII/4 and XXVI/9 Decisions
- Only six months between the XXVI/9 and XXVII/4 reports
- Focus on updating information
- Avoidance of repetition
- "Total warming impact" (Decision XXVII/4) has been taken as "total climate impact"
- Reliable data for BAU and mitigation scenarios are available for R/AC; not available for other sectors

Approach on the response to Decision XXVII/4

- OEWG-37, a first report on R/AC only
  - Updates on alternatives
  - Information on research studies on alternatives under HAT conditions
  - Extension of mitigation scenarios to 2050
- OEWG-38, a second report
  - Further updates to the R/AC sector information based on discussions at OEWG-37
  - Responds to other parts of the decision, including information on alternatives to refrigeration systems on fishing vessels
  - Updates and extends scenarios for other sectors than R/AC
- MOP-28, a Task Force update report, as appropriate, following discussions during OEWG-37 and -38

Outline of Report to OEWG-37

Executive Summary

Chapter 1 – Introduction

Chapter 2 – Update on the status of refrigerants

Chapter 3 – Suitability of alternatives under high ambient temperature conditions

Chapter 4 – BAU and MIT scenarios for A5/non-A5 countries for 1990-2050: R/AC

Annex – Updated tables for total, new manufacturing, and servicing demand

Key updates and issues for refrigerants

- 15 new fluids introduced since September 2015, mostly refrigerant blends
- The search for new alternative fluids (new molecules and blends) may yield more economical system designs
- Discovery of **radically different** refrigerant fluids seems unlikely
- Two approaches to determine energy efficiency of new refrigerants are discussed. Efficiency of refrigerants varies between equipment/use, and a consistent comparison of efficiency values is difficult. The economic feasibility of modifications of the system architecture is unclear

Key updates and issues for refrigerants (2)

- Total climate impact of various refrigerant applications is complex, making comparisons difficult
  - Direct contributions (related to refrigerant characteristics)
  - Indirect contributions (affected by the operating conditions, operating profile, system capacity, system hardware, power mix etc.)
- Total cost related to new refrigerants and their systems can only be estimated once the refrigerant and the system design are known

New fluids

15 new fluids have been included since the publication of the XXVI/9 report:

- All fluids are for use as refrigerants
- All new refrigerants are blends composed of already known molecules (except for two very low-pressure fluids (HCC-1130(E) and R-514A)
- Most new fluids are a result of optimisation and not totally different from fluids proposed previously

Refrigerant number	To replace	Safety class	Composition	GWP 100y IPCC5	GWP 100y RTOC
HCC-1130(E)	HCFC-123	B2	trans-dichloro-ethene (CHCl=CHCl)	<1	<1
R-514A	HCFC-123	B1	R-1336mzz(Z)/1130 (E) (74,7/25,3)	1,7	1,7
R-515A	HFC-134a	A1	R-1234ze(E)/227ea (88/12)	400	380
R-513B	HFC-134a	A1	R-1234yf/134a (58,5/41,5)	540	560
R-456A	HFC-134a	A1	R-32/134a/1234ze(E) (6/45/49)	630	650
R-407G*	HFC-134a	A1	R-32/125/134a (2,5/2,5/95,0)	1 300	1 400
R-449C	HCFC-22, R-407C	A1	R-32/125/1234yf/134a (20/20/31/29)	1 100	1 200
R-453A*	HCFC-22, R-407C	A1	R-32/125/134a/227ea/600/601a (20,0/20,0/53,8/5,0/0,6/0,6)	1 600	1 700
R-407H	HCFC-22, R-407C	A1	R-32/125/134a (32,5/15,0/52,5)	1 400	1 500
R-452C	R-404A	A1	R-32/125/1234yf (12,5/61,0/26,5)	2 000	2 200
R-454C	R-404A	A2L	R-1234yf/32 (78,5/21,5)	150	150
R-457A	R-404A	A2L	R-32/1234yf/152a (18/70/12)	140	150
R-455A*	R-404A	A2L	R-32/1234yf/744 (21,5/75,5/3)	150	150
R-452B	R-410A	A2L	R-32/1234yf/125 (67/26/7)	680	710
R-447B	R-410A	A2L	R-32/125/1234ze(E) (68,0/8,0/24,0)	710	750

All refrigerant numbers are preliminary except where marked with *

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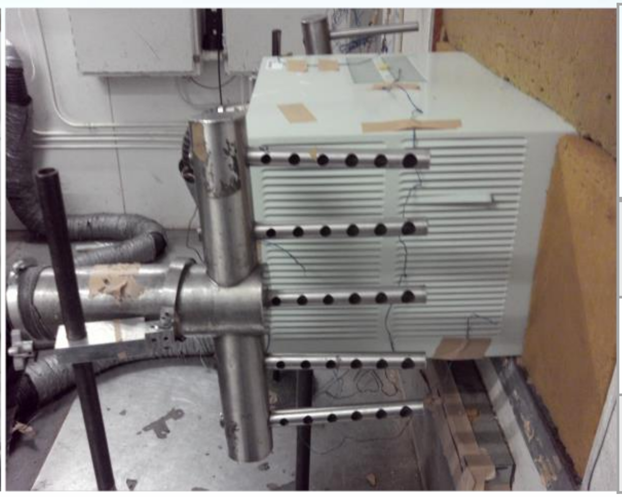
Energy efficiency depends on many parameters

- Important parameters include system configuration, component efficiencies, operating conditions, operating profile, system capacity, system hardware, system controls, etc.
- Two possible approaches:
  - Use a system architecture suitable for the specific refrigerant, while comparing it with a reference system for the refrigerant to be replaced
  - Screen for alternative refrigerants suitable for a given system architecture, with only minor modifications
- Two questions from both approaches:
  - How much modification of the system architecture is economically feasible?
  - Is consistent comparison possible?

Alternatives testing at HAT conditions

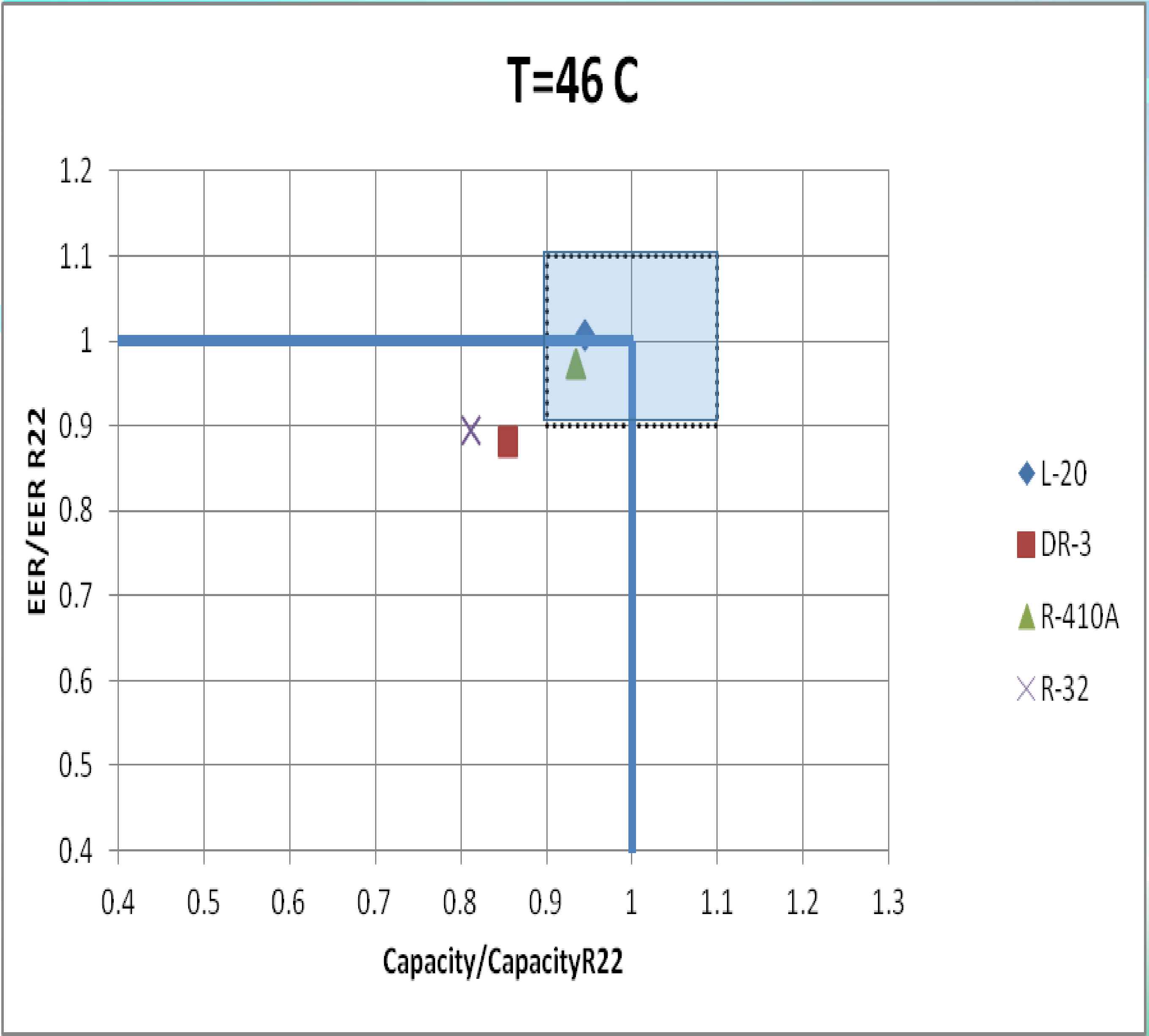
- “Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries” (**PRAHA**)
  - Concluded; report to be published soon; possible follow-up?
- “Egyptian Project for Refrigerant Alternatives” **(EGYPRA)**
  - Ongoing
- The Oak Ridge National Laboratory (**ORNL**) High-Ambient-Temperature Evaluation Program for low–global warming potential (Low-GWP) Refrigerants Phase I and II
  - Phase I concluded October 2015 with a report published
  - Phase II to be started in the course of 2016
- The Alternative Refrigerant Evaluation Program (**AREP**) Phase I and II
  - Phase I concluded in 2014; 40 test reports were published
  - Phase II to be concluded shortly (27 test reports are published, the last 7 available soon)

PRAHA Project



Comparable to HCFC-22	Comparable to R-410A
HC-290	HFC-32
R-444B (L-20)	R-447A (L-41-1)
DR-3	

13 custom-built prototypes in four categories ranging from 5 to 27 kW, testing five different alternatives against the baseline refrigerants HCFC-22 and R-410A

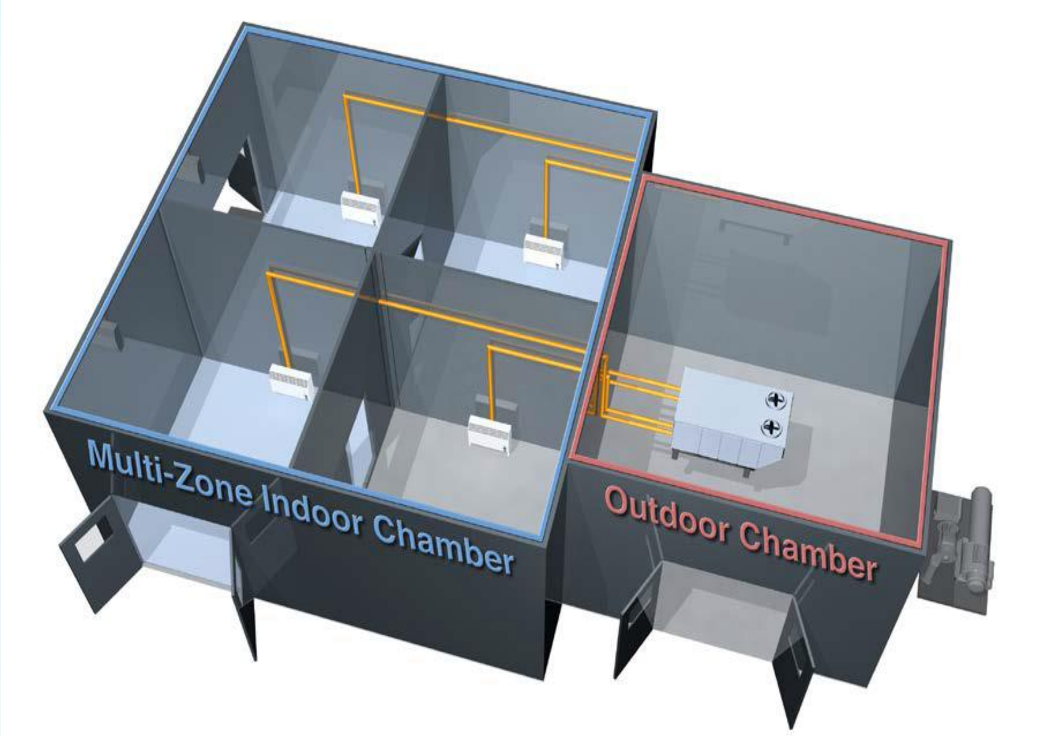


A PRAHA example

Energy Efficiency ratios versus Capacity ratios (compared to HCFC-22) for R-410A and a number of alternatives. The +/- 10% box indicates that alternatives falling within the box are potential candidates

Source: **PRAHA presentation at ASHRAE, Jan 16**

ORNL project testing 2 mini-split systems



Comparable to HCFC-22	Comparable to R-410A
N-20B	HFC-32
DR-3	R-447A (L-41-1)
ARM-20B	DR-55
R-444B (L-20A)	ARM-71a
HC-290	HPR-2A

Testing 10 alternatives in two units of 5 kW cooling capacity against HCFC-22 and R-410A, changing the amount of refrigerant charge and expansion device (soft optimization)

ORNL result for the HCFC-22 based mini-split

	Hot ambient Outdoor: 52°C (125.6°F)		Extreme ambient Outdoor: 55°C (131°F)	
	COP	Capacity	COP	Capacity
R-22 (baseline)	1.98	5.00	1.82	4.76
N-20B	1.77 (−11%)	4.26 (−15%)	1.64 (−10%)	4.1 (−14%)
DR-3	1.7 (−14%)	4.41 (−12%)	1.55 (−15%)	4.21 (−12%)
ARM-20B	1.76 (−11%)	4.84 (−3%)	1.61 (−11%)	4.62 (−3%)
L-20A (R-444B)	1.85 (−7%)	4.79 (−4%)	1.69 (−7%)	4.59 (−4%)
R-290	2.12 (+7%)	4.5 (−10%)	1.96 (+8%)	4.33 (−9%)

- HC-290 had better efficiency but lower cooling capacity than the baseline HCFC-22
- Other alternatives showed lower cooling capacity (around 5%) and lower efficiency (around 10%) than the baseline (unit)

ORNL results for the R-410A based mini-split

	Hot ambient Outdoor: 52°C (125.6°F)		Extreme ambient Outdoor: 55°C (131°F)	
	COP	Capacity	COP	Capacity
R-410A (baseline)	2.07	3.98	1.87	3.75
R-32	2.17 (+5%)	4.43 (+11)	1.98 (+6%)	4.23 (+13%)
DR-55	2.14 (+3%)	3.99 (0%)	1.93 (+3%)	3.76 (0%)
L41 (R-447A)	2.13 (+3%)	3.77 (−6%)	1.96 (+5%)	3.63 (−3%)
ARM-71A	2.11 (+2%)	3.83 (−4%)	1.90 (+2%)	3.62 (−3%)
HPR-2A	2.16 (+5%)	3.93 (−1%)	1.98 (+6%)	3.77 (+1%)

- R-32: better capacity & efficiency, higher compressor discharge temperatures and pressures;
- DR-55 and HPR-2A: same cooling capacity as baseline but better efficiency;
- R-447A and ARM-71a: lower cooling capacity than the baseline, R-447A better efficiency, ARM-71a same efficiency

AREP-II results

- General trends in “HAT performance” are similar for all alternative refrigerants
- Systems with alternatives generally provided similar to higher capacities than R-410A systems at HAT i.e., smaller decrease in capacity as ambient temperatures increase
- AREP-II was conducted by several entities with different test protocols which contributed to differences in results

Rpt	Organization Equipment	R32	DR-5A	DR-55	L-41-1	L-41-2	ARM-71a	HPR2A
#42	Goodman 3 RT Split-Sys	◉*					* R32 w/standard POE R32+ w/prototype POE	
#46	CES Armines 2.4 RT a/c Chiller	◉	◉		◉	◉		
#47/ #53	Lennox 5 RT Rooftop	◉	◉	◉		◉	◉	◉
#52	UTC/Carrier 3 RT Split-Sys		◉		◉	◉	◉	◉
#54	Danfoss 2½ RT Split-Sys	◉†	◉			◉‡	† R32 w/same charge R32+ w/opt charge ‡ Wet suction, no HAT	
#55	Zamil 6 RT Rooftop	◉						
#56	IR/Trane 4 RT Rooftop	◉	◉	◉				

Key messages for HAT applications

- Current HAT project results are difficult to compare
- New refrigerants tested show promise in meeting specific, current R/AC equipment requirements for operation under HAT conditions
- Comparable testing parameters in future testing and field trials will be helpful in assessing results
- There is need for a comprehensive risk assessment for flammable alternatives at installation, servicing and decommissioning at HAT conditions
- Commercial availability of both new refrigerants and components for optimization of R/AC equipment will affect the transition

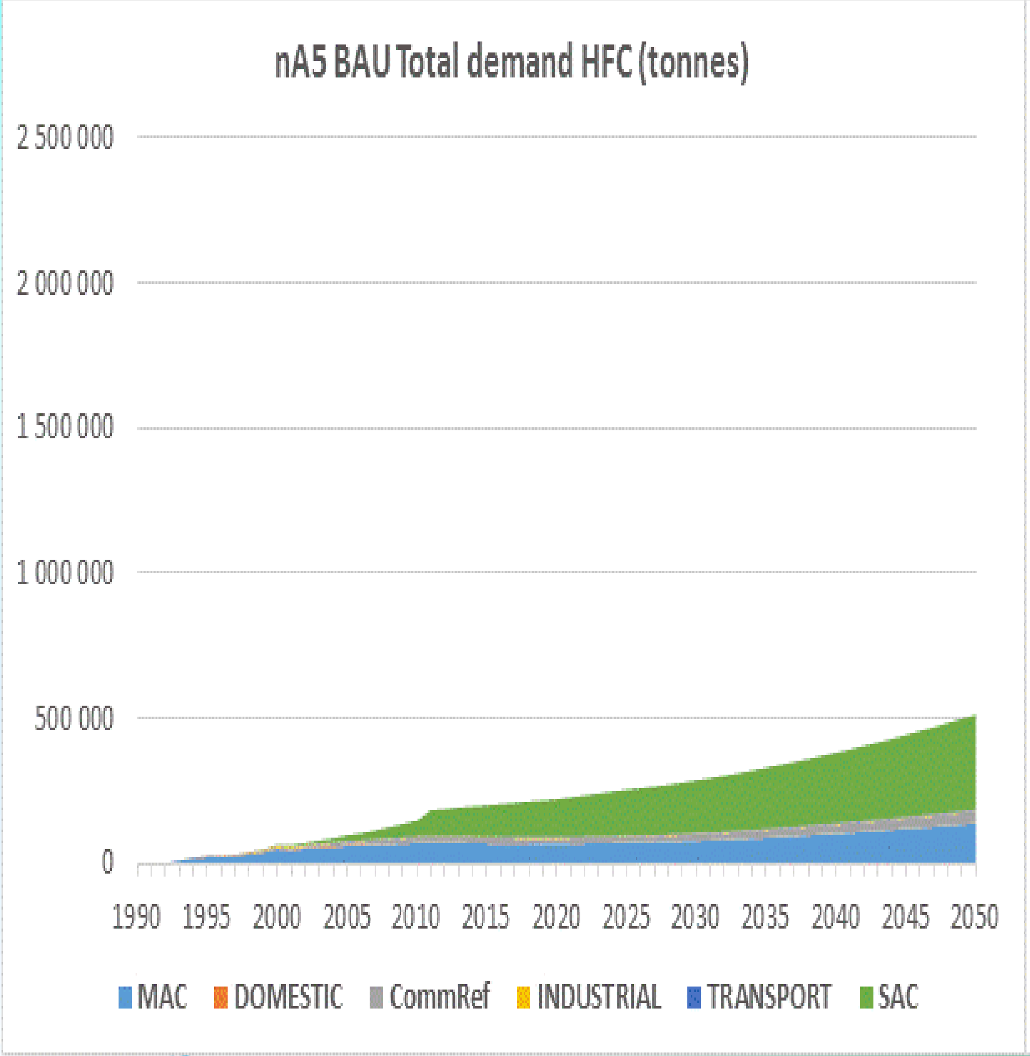
BAU and mitigation demand scenarios to 2050: R/AC

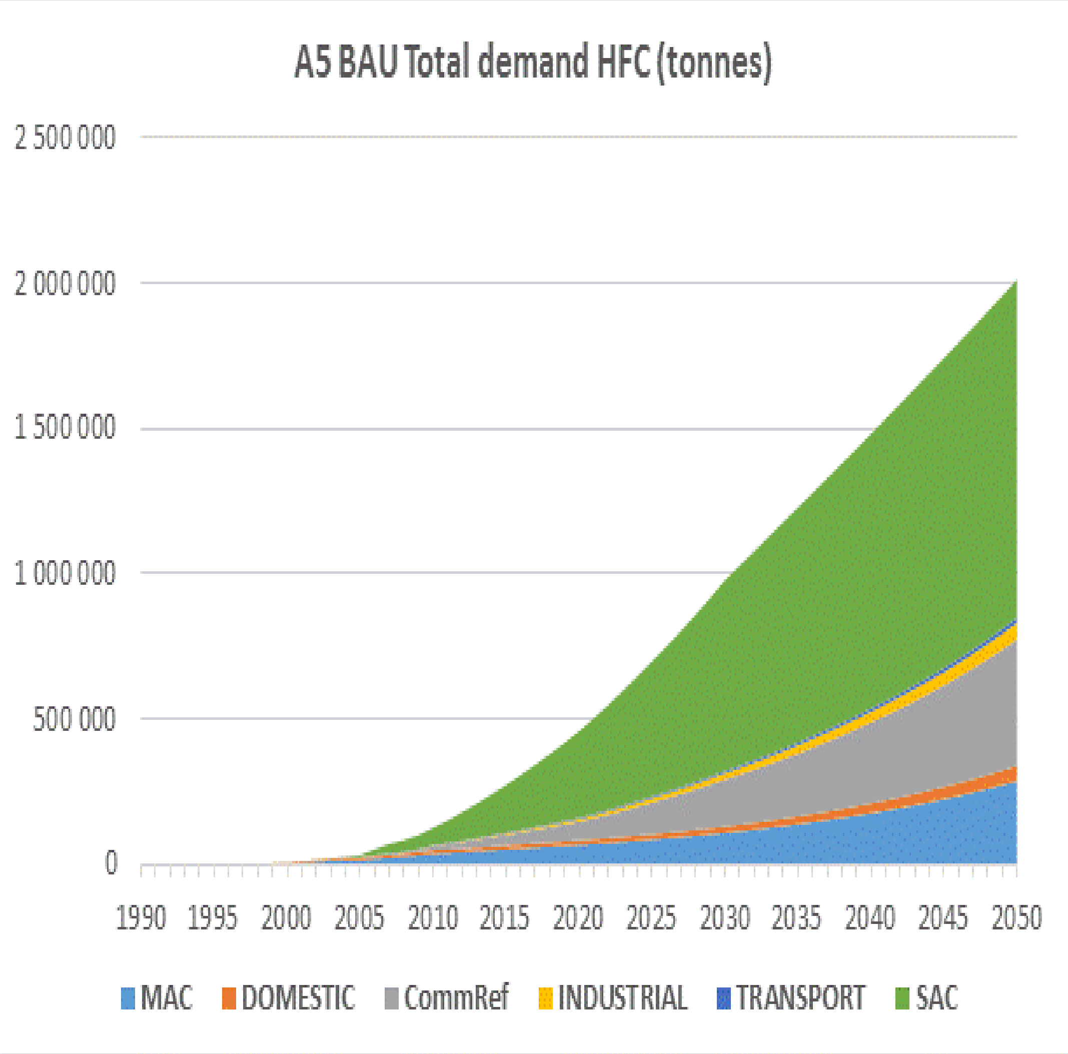
- The period over which demand is considered has been extended to 2050
- The following remain the same as in the XXVI/9 report:
  - GWP values for refrigerants
  - The different manufacturing conversion periods:
    - 3 years in non-Article 5 Parties
    - 6, 8, 10 or 12 years in Article 5 Parties
  - The mitigation scenarios with manufacturing conversions to commence:
    - MIT-3: All R/AC subsectors in 2020
    - MIT-4: All R/AC subsectors in 2020 *except stationary AC* which is assumed to be delayed to 2025
    - MIT-5: All R/AC subsectors in 2025

Regulations considered for Non-A5 BAU scenarios

- EU F-gas regulation 517/2014 and MAC 2006 directive
- US EPA 80FR 42870, 20 July 2015
- Other HFC regulations not yet considered

R/AC - BAU Non-A5 and A5





R/AC – BAU Non-A5 and A5

Comments to the previous slide (not presented)

- Non-A5 BAU scenario shows a 300% growth between 2015 and 2050
- A5 BAU scenario shows a 800% growth between 2015 and 2050
- Bottom-up estimated demand has been checked with best guess for production data for the year 2015
- For demand, the stationary AC sub-sector is the most important one over the entire period 2015-2050
- Uncertainties due to production data, economic growth assumptions, equipment parameters etc.; they are significant if extrapolated to 2050
- 2015-2050 may be too long of a period to consider, with significant uncertainty for later years

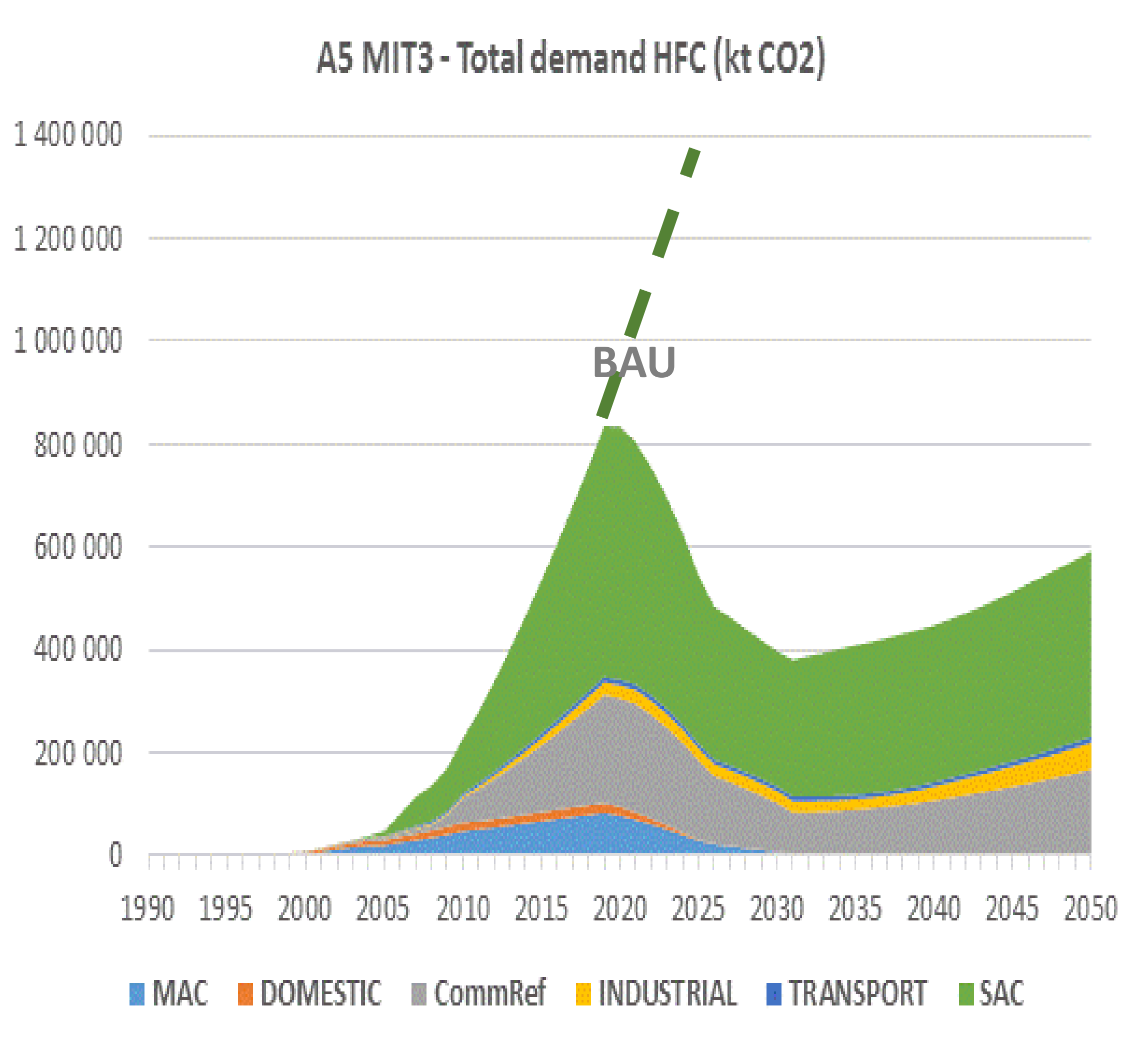
MIT-3 and MIT-5 scenarios

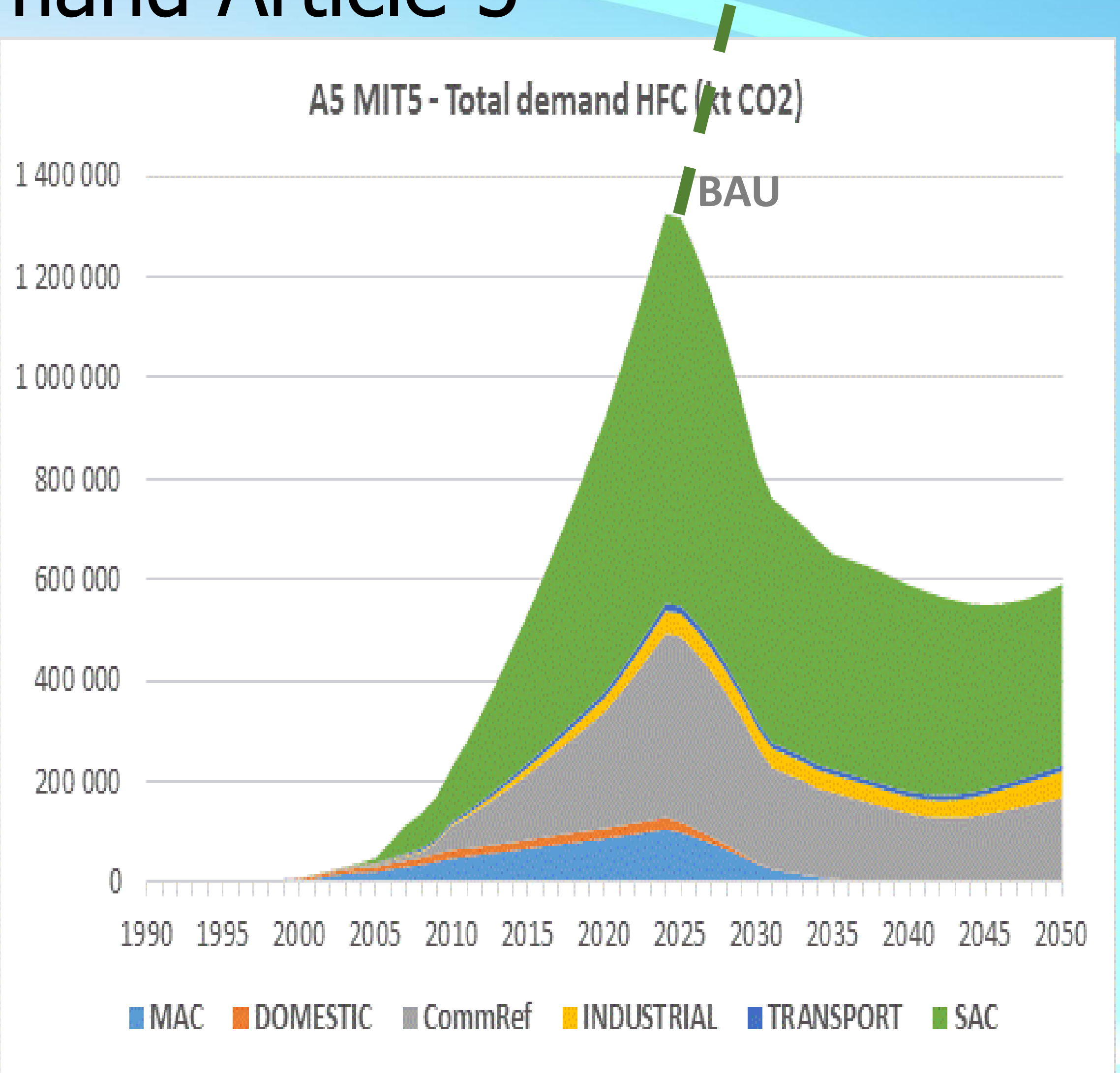
The following slides present revised (1990-2050) scenario results for Article 5 Parties:

- MIT-3 and MIT-5 total demand
- MIT-3 and MIT-5 manufacturing and servicing demand
- Impact of the conversion period for MIT-3 and -5

(with particular emphasis on a 6 year conversion period in Article 5 Parties for MIT-3 (w/2020 conversion start) and MIT-5 (w/2025 conversion start))

MIT-3 and -5 total demand Article 5



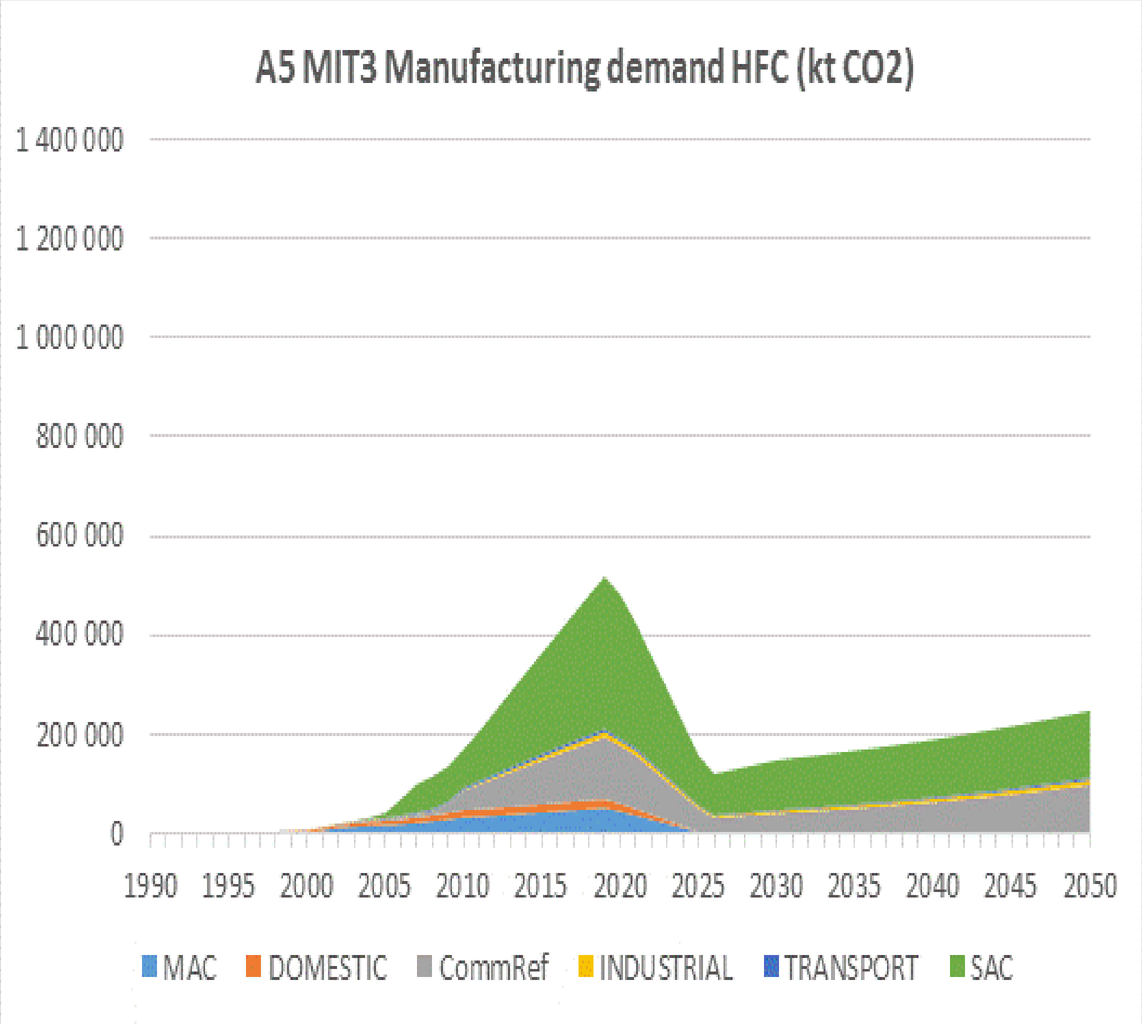


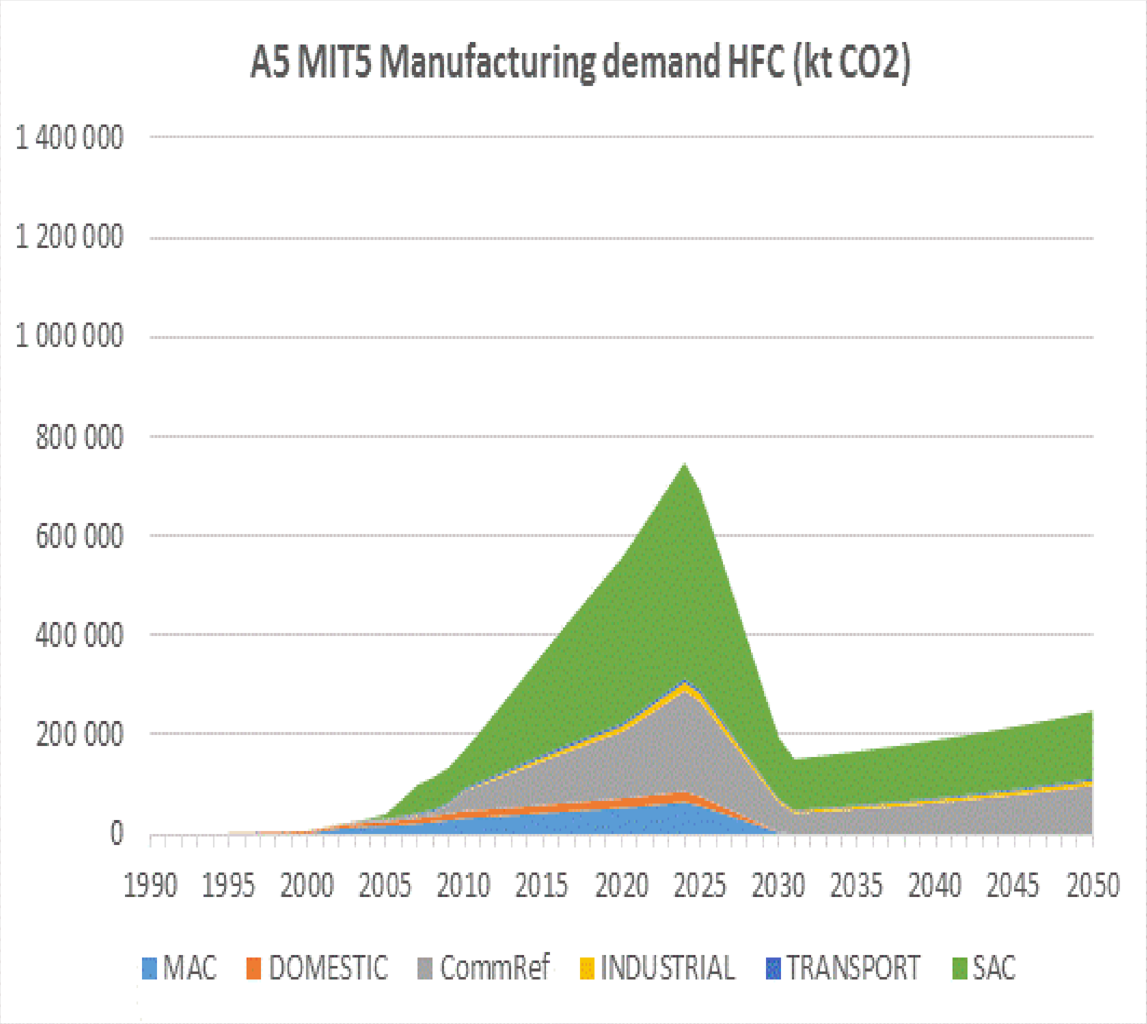
MIT-3 and -5 total demand Article 5

Comments to the previous slide (not presented)

- The 5 year later start of manufacturing conversion in the MIT-5 scenario results in a peak demand that is 60% higher than in case of MIT-3
- The demand estimated for the MIT-5 scenario in 2030 is twice the one for MIT-3
- MIT-5 demand remains higher during 2035-2040 due to more servicing; by 2040-45 the MIT-3 and MIT-5 demand are the same again
- Stationary AC is the determining subsector, followed by commercial refrigeration

MIT-3 and -5 manufacturing demand Article 5





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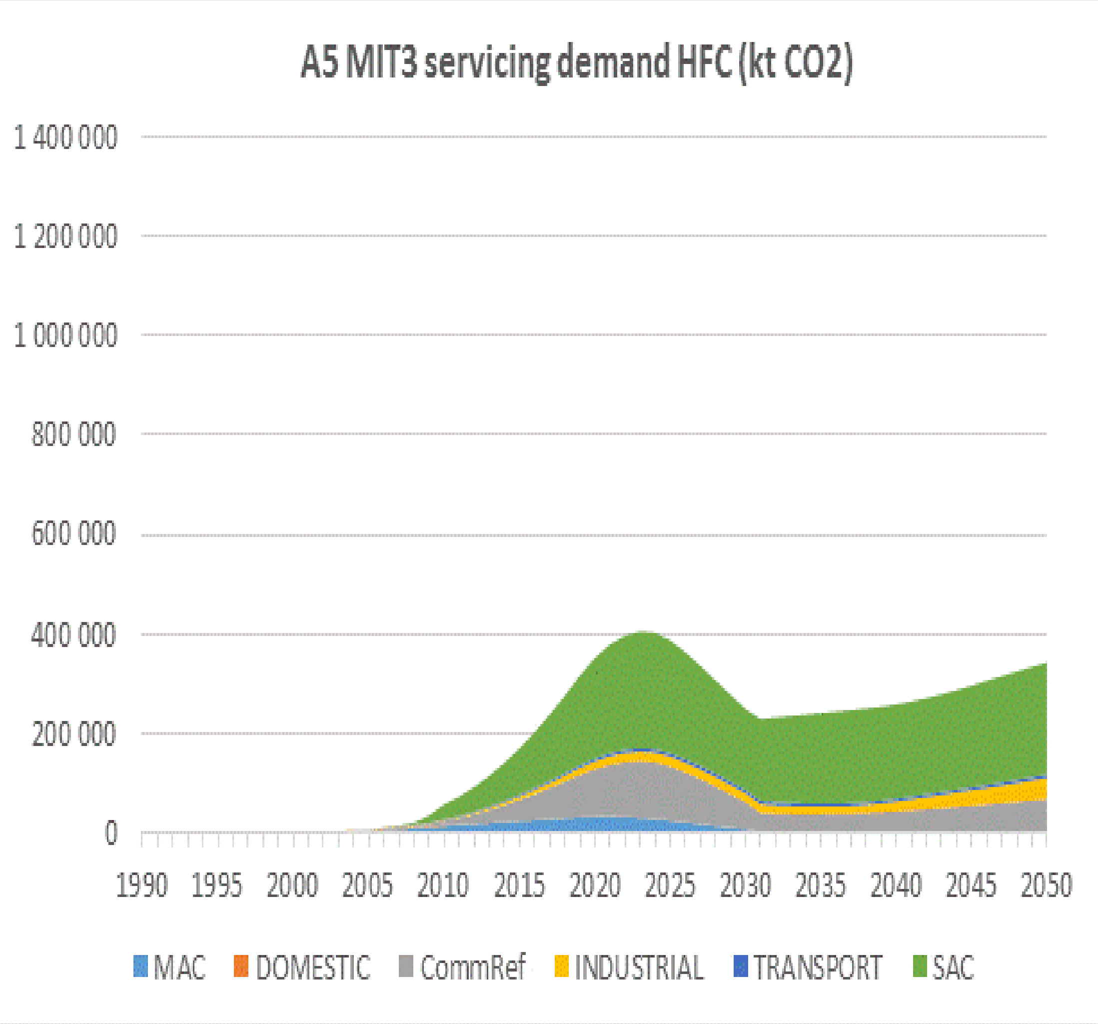
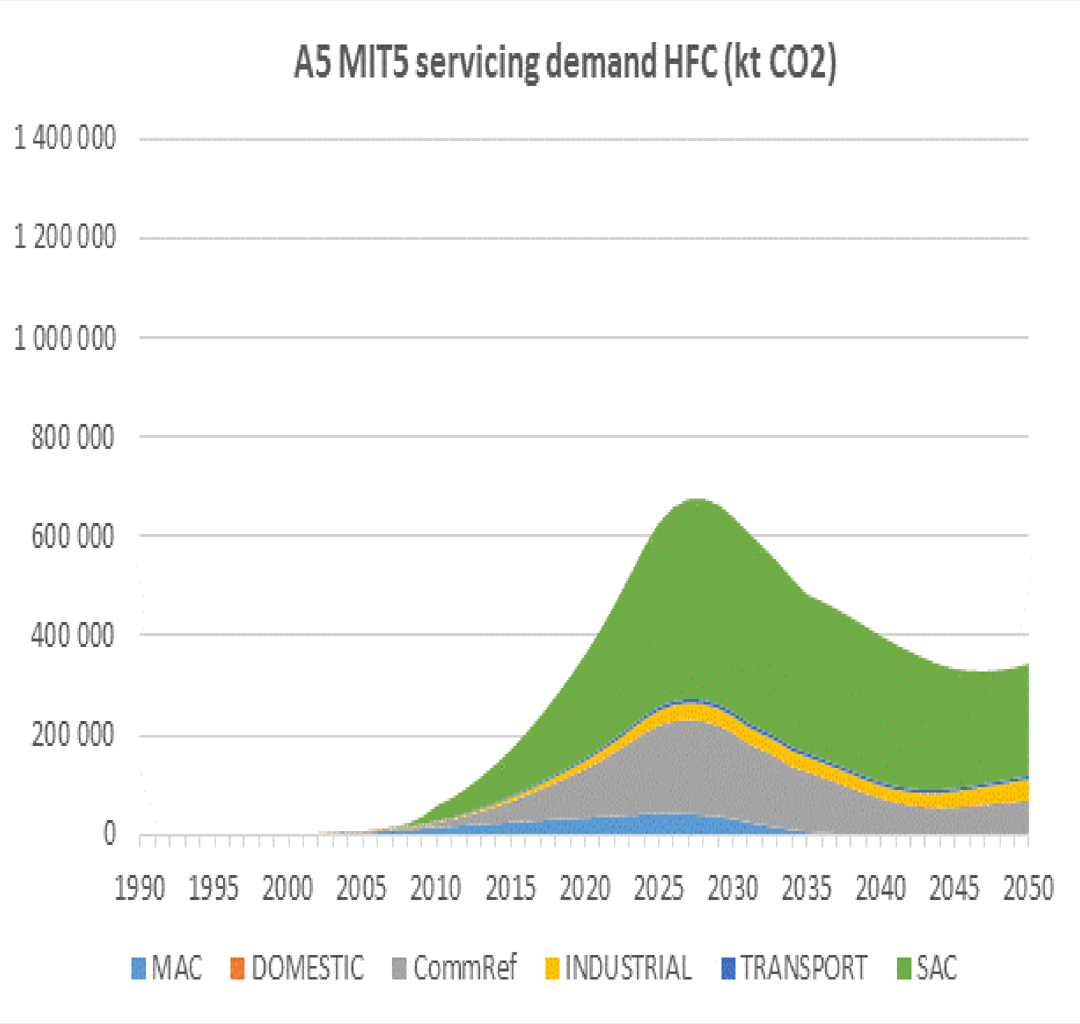
MIT-3 and -5 servicing demand Article 5





MIT-3 and -5 manufacturing and servicing demand

(slide not presented)

- In the MIT-3 scenario, new manufacturing demand is estimated to peak at 500 Mt CO_2-eq (2020), in the MIT-5 scenario at about 750 Mt CO_2-eq., the latter about 5 years later (2025)
- The values for servicing have peaks at more or less the same level, however, 3-4 years later; the decrease in the demand is slower than the decrease in demand for new manufacturing.
- After 2040-45, the total demand values for MIT-3 and -5, the new manufacturing and servicing values, are the same again (impacts from manufacturing conversion and the servicing of "old" equipment are not noticeable anymore)

Demand for various conversion periods

- A six year manufacturing conversion period results in a fast decrease of the total demand in both MIT-3 and MIT-5, after that conversion starts
- A 12 year conversion period results in a very slow decrease of the total demand in the 5-10 years after that conversion starts
- For all conversion periods the total demand in the MIT-5 scenario is almost twice as much as in the MIT-3 scenario
- **This clearly shows the impact of an early start and a rapid conversion**
- **Delaying and/or extending** the conversion for the dominant stationary AC sector significantly increases the overall climate impact

Total integrated high GWP HFC demand in A5

The following demand values and reductions compared to BAU were calculated 2020-2050:

BAU:	**80,200 Mt CO_2 eq.**	
MIT-3:	**15,800 Mt CO_2 eq.**	**80% reduction to BAU**
MIT-4:	**21,000 Mt CO_2 eq.**	**75% reduction to BAU**
MIT-5:	**24,500 Mt CO_2 eq.**	**70% reduction to BAU**

2020-2040:

BAU:	**42,300 Mt CO_2 eq.**	
MIT-3:	**10,600 Mt CO_2 eq.**	**75% reduction to BAU**
MIT-4:	**15,600 Mt CO_2 eq.**	**63% reduction to BAU**
MIT-5:	**18,800 Mt CO_2 eq.**	**56% reduction to BAU**

Observations

- **Shifting the start** of all R/AC subsector conversions to later than 2020 (as in 2025 the MIT-5 scenario), results in a substantially higher demand (climate impact) beyond 2030 for Article 5 Parties in particular
- For a six year conversion period, if the year conversion start is chosen as the "starting point", **an average annual reduction rate of 5%** in the total demand is obtained for all the scenarios studied
- For **longer** conversion periods, the average annual reduction rate would be lower

Next steps on the response to Decision XXVII/4

Next steps:

- For OEWG-38, a second report that:
  - Further updates the R/AC sector information based on discussions at OEWG-37
  - Responds to other parts of the decision, including information on alternatives to refrigeration systems on fishing vessels; and
  - Updates and extends scenarios for sectors other than R/AC to the extent new information is available
- For MOP-28, a Task Force update report, as appropriate, following discussions during OEWG-38

THANK YOU !