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Montreal Protocol Unit

Workshop on Kigali Implementation Plans

Session 6: Panel Discussion on Mobile Air Conditioning Sector

15 June 2023 Vienna, Austria

KIGALI in ActiON

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Montreal Protocol Unit

15 June 2023
10.00-11.00 a.m. CET time

Session 6: Panel Discussion on

Mobile Air Conditioning Sector

Carloandrea Malvicino
Head of CO_2 Emissions Reduction Strategies, Stellantis

Kristen Taddonio
Director of Climate Control, Institute for Governance & Sustainable Development

Radhey S. Agarwa
(Online)
Technical Advisor to Ozone Cell India

Samuel Yana Motta
R&D Scientist/Engineer at Oak Ridge National Laboratory

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Carloandrea Malvicino
Head of CO_2 Emissions Reduction Strategies, Stellantis

Mr. Carloandrea Malvicino, is Head of CO_2 Emissions Reduction Strategies as part of Stellantis Enlarged Europe Organization. Mr. Malvicino is one of the Stellantis representatives for EU and UK technical issue related to CO_2 and GHG regulations.

Mr. Malvicino graduated in Physics in 1987, joined the "Centro Ricerche Fiat" in 1988 and working on sensor and microsystems then he took in charge the Thermal System department. Mr. Carloandrea moved to FCA Italy in 2013 to his current position.

He is member of Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC) of the United Nations Environmental Programme (UNEP) as leading author of the Chapter on Mobile Air Conditioning and author of several international patents, papers and publications in the automotive domain.

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Session 6: Panel Discussion Mobile Air Conditioning Sector

Mobile Air Conditioning New Challenges
F-gas in the MAC sector and its impacts on the industry

Carloandrea MALVICINO June 15 2023 Vienna, Austria

KIGALI in Action

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Mobile Air Conditioning (MAC) – Challenge 1

Light and heavy-duty vehicles use for 0.3 kg to **1.4 kg refrigerant**, buses up to 16 kg.

Today: **1.3 billion road vehicles** ca. worldwide: **1 million ton of refrigerant**, **125 kTon/year** (new car - approx. lifespan of 13 year - and recharge)

2040: up to **2 billion** (World Economic Forum): **210 ktonnes/year** of refrigerant, even more considering the effect of vehicles' electrification requiring slightly higher refrigerant charge.

Mostly and commonly used refrigerants: **HF-134a and HFO-1234yf**

Challenge: HFO-1234yf, HFC-134a generate PFAS (per and polyfluoroalkyl substances) as decomposition product and highly dangerous for most of living beings. EU started actions to limit or even ban the substances generating PFAS ➔ **refrigerant (r)evolution**

https://www.weforum.org/agenda/2016/04/the-number-of-cars-worldwide-is-set-to-double-by-2040

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PFAS issue and effect on MAC

Trifluoroacetic acid, TFA, one of the decomposition products **of some refrigerants** (HFC-134a, HFO-1234yf, …), is a chemical that is included within the OECD definition of per- and poly-fluoroalkyl substances **(PFAS).**

The PFAS are claimed to be dangerous for the environment and for the living beings.

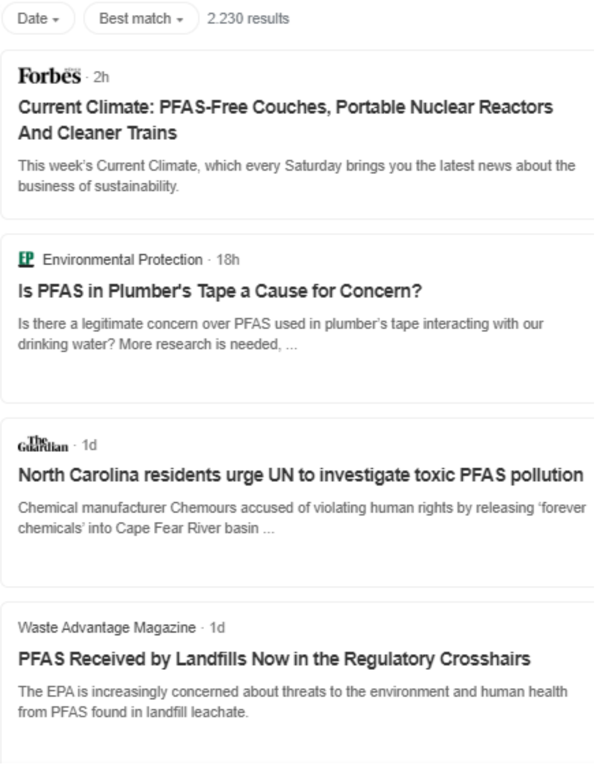
Five European countries (DE, DK, NL, NO, SE) published their intention to propose a REACH based restriction for PFAS.

As a next step, they submitted this PFAS proposal to the European Chemical Agency (ECHA) **on 7 February 2023** for further study and consultations.

Final decisions for possible regulations may be expected in the course of 2025.

This is creating some uncertainty at present for the long-term use of several HCFO/HFOs.

The automotive industry started to re-assess alternative technologies to overcome any potential new issue on MAC refrigerant.


Date · Best match · 2.230 results

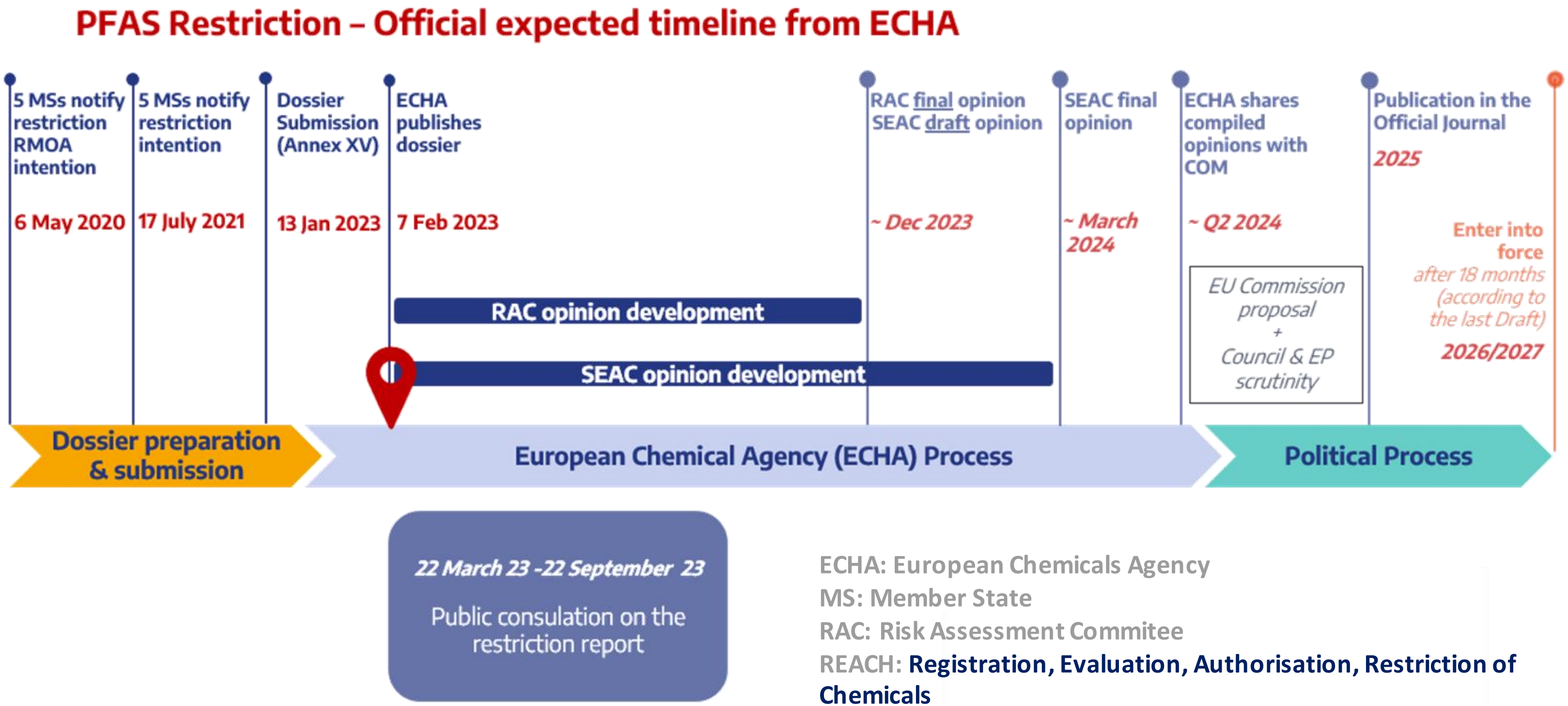
Forbes · 2h
Current Climate: PFAS-Free Couches, Portable Nuclear Reactors And Cleaner Trains
This week's Current Climate, which every Saturday brings you the latest news about the business of sustainability.

EP Environmental Protection · 18h
Is PFAS in Plumber's Tape a Cause for Concern?
Is there a legitimate concern over PFAS used in plumber's tape interacting with our drinking water? More research is needed, ...

The Guardian · 1d
North Carolina residents urge UN to investigate toxic PFAS pollution
Chemical manufacturer Chemours accused of violating human rights by releasing 'forever chemicals' into Cape Fear River basin ...

Waste Advantage Magazine · 1d
PFAS Received by Landfills Now in the Regulatory Crosshairs
The EPA is increasingly concerned about threats to the environment and human health from PFAS found in landfill leachate.

Timing of PFAS actions in Europe

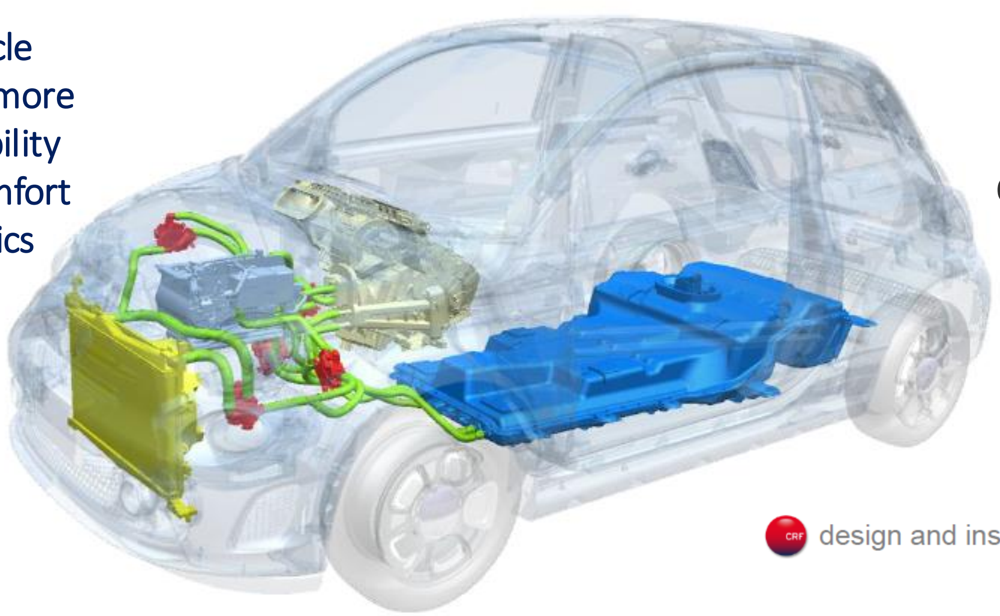


ECHA: European Chemicals Agency
MS: Member State
RAC: Risk Assessment Commitee
REACH: **Registration, Evaluation, Authorisation, Restriction of Chemicals**
RMOA: Regulatory Management Option Analysis
SEAC: Socio-Economic Assessment Committee

BEV Thermal System

In case of a Battery Electric Vehicle the MAC ensures also the heating (heat pump) being far more efficient than a simple electric heater

The Battery Electric Vehicle (BEV) Thermal system is more complex to ensuring visibility (defogging, de-icing), comfort and battery and electronics thermal management



OPTEMUS EU project
Demo car

design and installation

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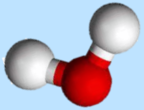
MAC alternative solutions under (re)evaluation

The development and deployment of a new generation of MAC system **requires at least 10 years** considering the component development and the industrialization for adapting the automotive platforms

R-744

(CO_2)



PROs

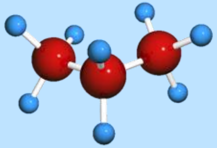
- Natural (no patent)
- Efficient in low/mild climate and sever winter conditions
- Direct and Indirect expansion
- Already in use (low volumes)

CONs

- Expensive
- Requires a new generation of components
- Not efficient in severe summer conditions

HC-290

(Propane)



PROs

- Natural (no patent)
- Compatible with the HFO/HFC technology (low cost)
- Efficient in mild/sever conditions

CONs

- Flammable (it requires dual loop)
- Not efficient as Heat Pump in severe winter conditions
- Not in use

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Mobile Air Conditioning (MAC) – Challenge 2

The average passenger car energy demand is of about **4˙700 kWh/year (125 gCO2/km)**

The MAC system operation increases this figure of about **6% i.e., 280 kWh/year** (Internal Combustion Engine) **up to 12%** (electric vehicles for ensuring heating in winter conditions).

Assuming 80% of circulating vehicles (1.3 B Units) has a MAC: **220 TeraWatt/year** are required, equivalent to approx. **200 MTonCO2eq/year i.e., the 6% of all CO2 emission due to road vehicles.**

Challenge: to improve the MAC efficiency to offset and mitigate the additional CO2 emissions due to the increase of circulating vehicle the progressive electrification.

MAC Energy demand

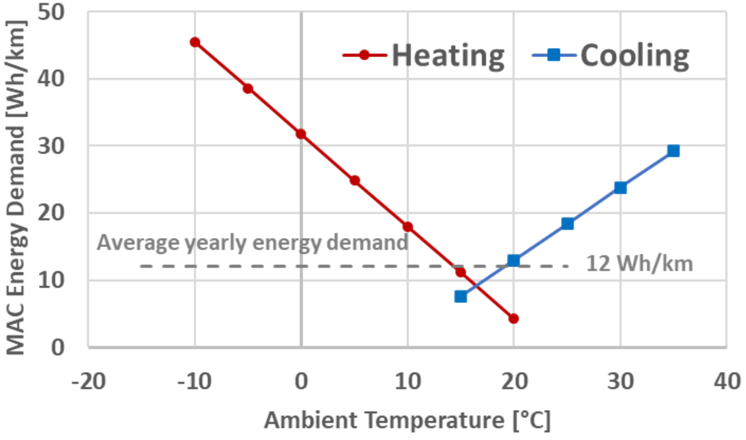
The MAC ensures the passenger **thermal comfort**, and its **energy demand** is a function of the **ambient conditions**

- The **cooling power** (summer comfort) is usually generated by means of a vapor compression cycle
- The **heating power** (winter comfort, de-icing, de-fogging) is coming from the **waste heat** of Internal Combustion Engine (ICE), while in case of BEV is generated with dissipative system (e.g., **electric heater**) or by means of vapor compression cycle (**Heat Pump**)

Simplified model of the required energy to ensure winter and summer comfort (WLTP cycle – 46.5 km/h)

The energy demand per travelled km increases reducing the speed and decreases increasing the speed

The MAC energy demand is a function of ambient conditioning and of the duration of the travel



ICEV and BEV

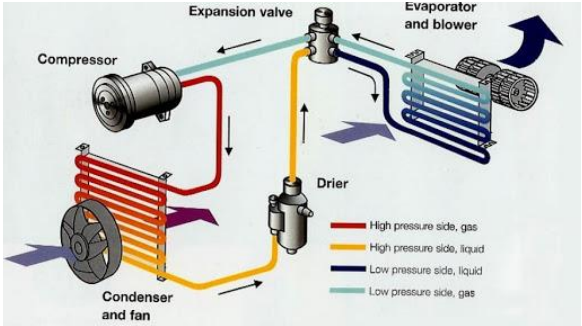
ICEV (base vehicle 125 gCO_2/km)

- The **cooling power:** vapor compression cycle
- The **heating power** from the ICE's **waste heat**

Assumptions:

- **+6% on annual base** (7.5 gCO_2/km)
- **20˙000 km/year**

CO_2 emissions: 150 kgCO_2 eq/year/vehicle



BEV (base vehicle 200 Wh/km)

- The **cooling power** vapor compression cycle
- The **heating power** with **electric heater**

Assumptions:

- **+12% on annual base** (cooling and heating)*
- **20˙000 km/year**
- **Electricity mix:** 475 gCO_2/kWh (World)/300 gCO_2/kWh (EU)
- **CO_2 emissions:**

228 kgCO_2eq/year/vehicle (World)

144 kgCO_2eq/year/vehicle (EU)

The electrification reduces the carbon footprint

The MAC contribution decreases much less to compensate the **lack of waste heat** to ensure winter comfort and functions (de-icing, de-fogging) → **improvement is required**

* The energy used by the MAC affects the BEV range proportionally

SCENARIO

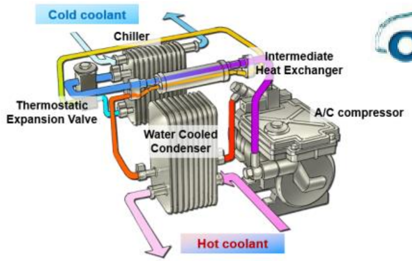
Despite the effort recently done, a further significant improvement of the MAC efficiency can be achieved[1]

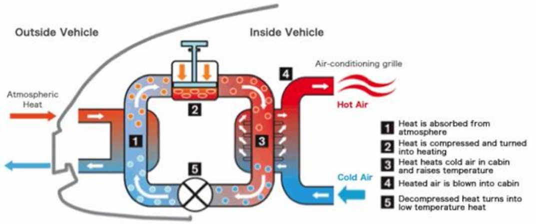
The focus should be on the BEV that are expected to become widely diffused worldwide in the next 10 years

- **Component enhancement**: electrical (fan, blower, …), mechanical (compressor, heat exchangers)
- **Vehicle thermal load reduction**: improved insulation, window coatings, …

System architecture: direct expansion vs indirect expansion, water cooled condenser, internal heat exchanger

Heat Pump: can **reduce** the energy demand by 17-**52% vs a typical electric heater**, depending on the geographical context[2].





1 Cooling on the Move The future of air conditioning in vehicles Available at https://www.iea.org/reports/cooling-on-the-move

2 Bellocchi S., Guizzi G. L., Manno M., Salvatori M. Zaccagnini A., 2018. Reversible heat pump HVAC system with regenerative heat exchanger for electric vehicles: analysis of its impact on driving range. Applied Thermal Engineering Volume 129, 25 January 2018, Pages 290-305. Available at https://www.sciencedirect.com/science/article/abs/pii/S1359431117338875

Conclusions

A **new (r)evolution** is required to further reduce the MAC environmental impact is incoming, despite the huge effort done recently

- **The current refrigerants HFO-1234yf and R-134a are at risk** of being restricted or even banned due their degradation product PFAS
- The **automotive industry** is reacting re-assessing alternative solutions such as **R-744 and HC-290**
- The ongoing **global decarbonization** effort requires to **further improve the MAC** energy **efficiency**
- The electrification will reduce the vehicle carbon footprint BUT need efficient solutions to ensure the winter comfort and winter function (de-icing and de-fogging)
- The **MAC must respond** to these needs with **very efficient solutions** that have to **minimize** the **carbon footprint** and the impact on **BEV actual range**

Carloandrea Malvicino
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THANK YOU!

15 June 2023
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Session 6: Panel Discussion on

Mobile Air Conditioning Sector

Kristen Taddonio
Director of Climate Control, Institute for Governance & Sustainable Development

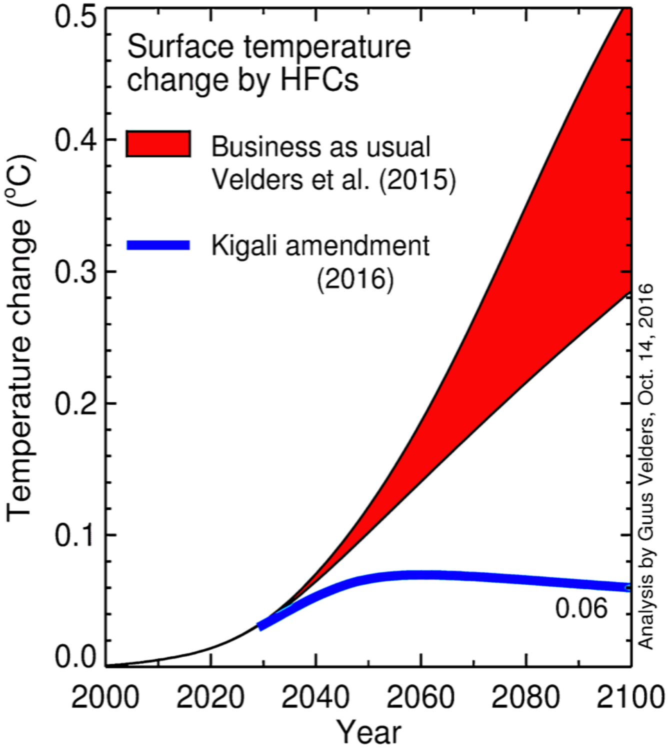
Ms. Kristen N. Taddonio is Director of Climate Control at the Institute for Governance & Sustainable Development (IGSD), specializing in energy efficiency and refrigerant emission mitigation pathways for compliance with the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, which requires Parties to phase down the production and consumption of hydrofluorocarbons (HFCs).

Prior to joining IGSD, Taddonio led commercial building technology research and deployment efforts at the U.S. Department of Energy's Building Technologies Office and managed the U.S. Environmental Protection Agency's Mobile Air Conditioning Climate Protection Partnership.

She is a member of SAE International (formerly the Society of Automotive Engineers), where she serves as a liaison to the Interior Climate Control committee, and is the current building energy efficiency representative on the State of Colorado's Energy Code Board.

Good news!

The 2016 Kigali Amendment to the Montreal Protocol will phase down HFCs and can prevent the red business-as-usual scenario from happening



The not-so-good news:

HFC-134a was still used in more than half of new vehicles manufactured worldwide as of 2022. Solutions urgently needed for growing & emerging markets.

It’s not just A5 manufactures using R134a: global non-A5 companies still use R134a in markets where they are not required to use refrigerant with GWP<150.

How the USA made the transition to low-GWP refrigerant and more efficient MAC:

✓ Incentives first to encourage *voluntary* switching,

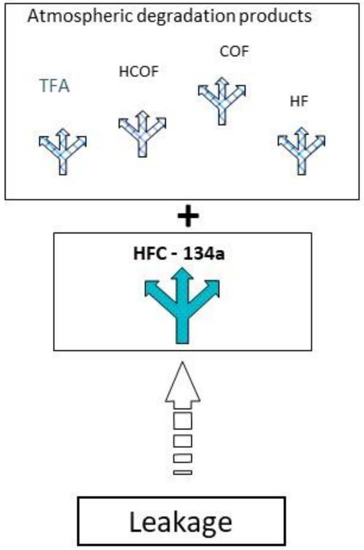
✓ then mandates making new technology a *requirement*

Over the last decade, manufacturers could earn credit (incentives) toward vehicle greenhouse gas standards for:

- Adopting a low-GWP refrigerant
- Reducing refrigerant leaks
- Improving MAC energy efficiency
- Reducing Thermal loads

Requirements:

- Starting in 2025, vehicles will be required to use low-GWP refrigerants. Refrigerant credits/incentives will be retired.
- Manufacturers can still earn credit toward vehicle fuel economy/GHG standards for improving MAC efficiency



Atmospheric Degradation Products
COF, HCOF, HF, TFA

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"Incentive First" approach: USA refrigerant credits

Manufacturers can use them to help achieve vehicle emissions standards

Vehicle Type	Max credit, leak reduction only	Maximum credit, leak reduction *and* low-GWP refrigerant
Cars	6.3 g CO_2/mile⁺ 9.5 g CO_2/mile*	13.8 g CO_2/mile
Trucks	7.8 g CO_2/mile⁺ 11.7 g CO_2/mile*	17.2 g CO_2/mile

⁺available to vehicles with **belt-driven compressors** and SAE standard J2727 score of 8.3 g of refrigerant per year or less
*available to vehicles with **electric compressors** and SAE standard J2727 score of 8.3 grams of refrigerant per year or less

These refrigerant leak reduction credits are quantified using SAE International standard J-2727. The comprehensive formulas used to determine credits appeared in the US Code of Federal Regulations 86.1867-12, *CO_2 credits for reducing leakage of air conditioning refrigerant.*

“Incentive First” approach: MAC efficiency credits

Efficiency Measure Eligible for Credit (USA)	MAC fuel savings potential	Car AC credit (g/mi)	Truck AC credit (g/mi)
Reduced reheat, with externally controlled, variable-displacement compressor	30%	1.5	2.2
Reduced reheat, with externally controlled, fixed-displacement or pneumatic variable displacement compressor	20%	1	1.4
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temp is 75 °F (23.9°C) or higher (variations allowed with engineering analysis)	30%	1.5	2.2
Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temp is 75 °F (23.9°C) or higher (variations allowed with engineering analysis)	20%	1	1.4
Blower motor control that limits wasted electrical energy (e.g. pulse width modulated power controller)	15%	0.8	1.1
Internal heat exchanger (or suction line heat exchanger)	20%	1	1.4
Improved evaporators and condensers (engineering analysis indicating COP improvement >10% compared to previous)	20%	1	1.4
Oil separator (internal or external to compressor)	10%	0.5	0.7
Maximum credit		**5**	**7.2**

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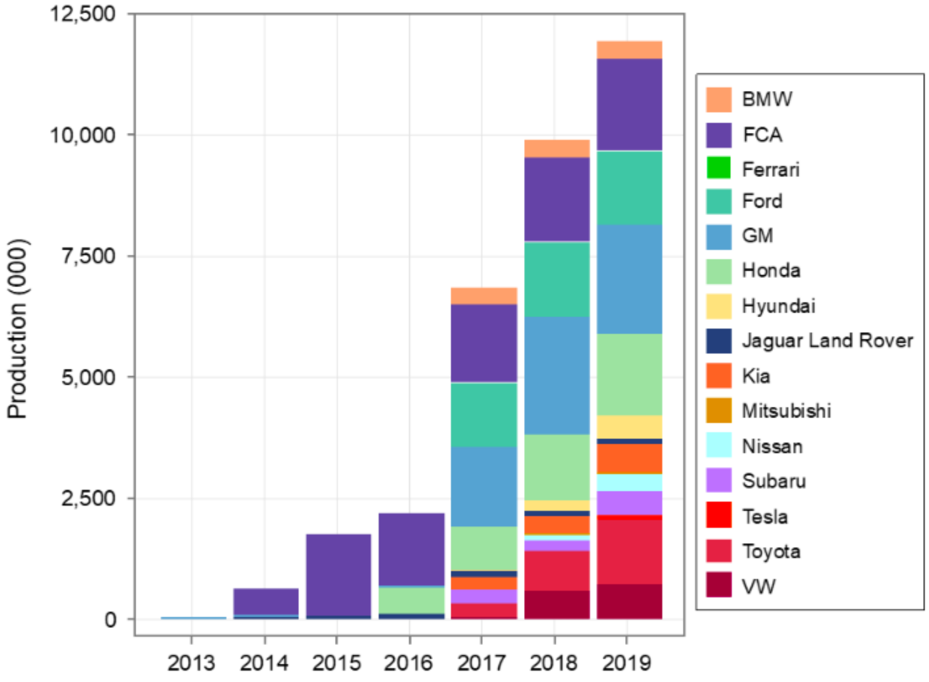
"Incentive First" approach: MAC efficiency credits for reducing thermal loads

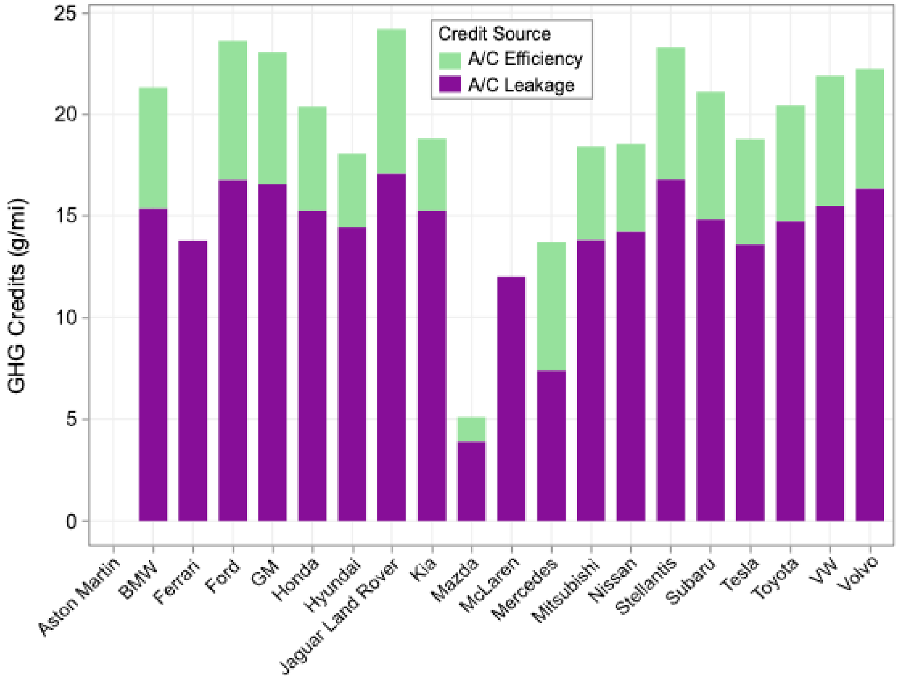
Thermal Load Reduction Measures (USA)	Car AC credit (g/mi)	Truck AC credit (g/mi)
Glass or glazing	≤2.9	≤3.9
Active seat ventilation	1	1.3
Solar reflective paint	0.4	0.5
Passive cabin ventilation	1.7	2.3
Active cabin ventilation	2.1	2.8
Maximum credit	**3.0**	**4.3**

Results:

Most manufactures voluntarily switched refrigerant by 2019.
By model year 2021, 95% of new vehicles sold used HFO-1234yf.



Most manufacturers took steps to reduce leaks and improve efficiency too (2021 model year data shown below).



Sources: US EPA. January 2021. *2020 Automotive Trends Report*. EPA-420-R-21-003. Page 87. https://www.epa.gov/sites/default/files/2021-01/documents/420r21003.pdf

See also: *2022 Automotive Trends Report*. EPA-420-R-22-02. Page 91.

Comparing & Contrasting Regional Approaches to MAC refrigerant and efficiency:

Country / Region	Refrigerant GWP <150 Limit or Incentive	Leak Reduction Rule or Incentive	MAC Efficiency Rule or Incentive
European Union	✓	✓	✓
United States	✓	✓	✓
Canada	✓	✓	✓
Japan	✓		✓
South Korea	✓		✓
Saudi Arabia			✓
Mexico	✓	✓	✓
China		✓	✓

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Important Reminder:

MAC Service Sector can consume twice as much refrigerant as the manufacturing sector.

- The "Improved Mobile Air Conditioning" (I-MAC) global cooperative research project involved over 100 industry experts supported by $3 million in industry and government contributions.
- Service goal: develop "technology and practices to reduce mobile air conditioning refrigerant emissions by 50% at vehicle service and end of life."
- A Service Team of 35 experts concluded that HFC-134a consumption and emissions for mobile air conditioning could be reduced through "the introduction and implementation of tools, equipment, techniques and policies as follows:
  1. More efficient refrigerant recovery and more accurate charging equipment and procedures
  2. Improved leak detection (tools and procedures).
  3. Mandatory repair of A/C system leaks before system recharge.
  4. Quality components with correct installation and connections.
  5. Reduction of emissions from refrigerant container heels.
  6. Elimination of do-it-yourself recharge of leaking systems.
  7. Better compliance with refrigerant recovery requirements and more efficient recovery at vehicle end of life.
  8. Restricting sale of refrigerant only to certified, trained technicians."

Refrigerants of the Future: Non-PFAS alternatives to HFO-1234yf for hot climates?

Tata-MAHLE Secondary Loop R152a-MAC Demo
(Climate & Clean Air Coalition funded)

- Improved MAC energy efficiency by adjusting the programming (control logic) that determines when the AC compressor engages
- Testing confirmed that vehicles with SL-MAC systems using HFC-152a achieve 1.9-2.6% greater overall vehicle fuel efficiency with AC on than vehicles equipped with the baseline HFC-134a DX system
- The Tata Aria was not equipped with stop-start technology. Overall fuel savings potential in urban environments could be even higher by integrating the SL-MAC's control algorithm and cooling reservoir with stop-start technology

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Why R-152a demo?

Low-GWP Option	GWP (AR5)	Efficiency relative to R134a at Indian temperatures	TFA/ PFAS	Flammability	Pressure vs. R134a	Price – Refrigerant vs. 134a	Price- Components vs. R134a
HFO-1234yf	< 1	Slightly lower	Yes	Mild (A2L)	Similar	5 – 10 times more	10-20% more
R744 (CO_2)	= 1	Lower	No	No (A1)	Higher	Similar or lower	100-200% more
HFC-152a	= 138	Better	No	Moderate (A2)	Similar	Similar or lower	10-20% more

- **More affordable refrigerant** than HFO-1234yf, **lower component cost** than R744, **Less flammable** than R290
- Lower pressure, higher efficiency in high ambient temperature
- >95% reduction in direct refrigerant emissions impact due to reduced charge & lower GWP
- Not PFAS, no TFA produced either
- Satisfies US EPA SNAP & EU F-Gas Directive (GWP<150)
- R152a is less effective at very low temperatures in heat pump application (vs. R744), but this is less critical in higher ambient temperature climates

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The Refrigerants of the Past vs. Refrigerants of the Future

- Electric vehicles in moderate and cold climates may use heat pumps more often to improve efficiency and range.
- R-1234yf does not work well in heat pumps, so SAE International organized a new cooperative research project to identify alternatives for EVs and heat pumps, called the "Thermal Management Refrigerant Cooperative Research Project."
  - All major North American manufacturers participating, including Tesla.
  - R744, R290, and several non-PFAS fluorinated refrigerant options are under testing and evaluation.
  - Information is restricted to participating parties, NDA may be required.
- Manufacturers and others interested in joining may contact Mark Klavon at Mark.Klavon@sae.org.

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Prof. Radhey S. Agarwa
(Online)
Technical Advisor to Ozone Cell India

- **Prof. Radhey S. Agarwa is Technical Adviser to Ozone Cell, Ministry of Environment, Forest and Climate Change on Montreal Protocol related technical and policy aspects (2008-2023);**
- Worked as Professor of Mechanical Engineering, IIT Delhi contributed to Teaching, Research & Development in the areas of alternative refrigerants, energy efficiency and HVAC&R technologies (1970 – 2008);
- Former Deputy Director and Dean (Industrial Research & Development), IIT Delhi;
- Co-Chair, UNEP Technical Option Committee on Refrigeration, Air-Conditioning and Heat Pumps and Member of Technology & Economic Assessment Panel of the Montreal Protocol (1996-2009), Member of RTOC (1989-2014) and co-chair and member of TEAP Taskforces;
- Recipient of several Professional Awards including:
  - Technical Leadership Award -2017, UN Environment at Montreal Canada;
  - Best of the Best Stratospheric Ozone Protection Award (2007) USEPA;
  - 2007 Nobel Peace Prize award as part of United Nations Inter-Government Panel on Climate Change (IPCC) team which was the joint winner of Nobel Peace Prize award 2007;
  - Hon’ble Prime Minister of India awarded a certificate of recognition, citing “The Government of India recognizes the contribution of Dr. R. S. Agarwal to the work of the United Nations IPCC, the joint winner of the Nobel Peace Prize for 2007”.
  - 2007 UNEP Montreal Protocol TEAP Champion Award in recognition of extra-ordinary services to the Parties to the Montreal Protocol and the global effort to protect the Ozone Layer.
  - 1998 US EPA Stratospheric Ozone Protection Award for Technical Leadership in CFC-Free Refrigeration, in Recognition of exceptional contributions to Global Environmental Protection.

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Options for HFC Phase-down in MAC Sector

Challenges and Opportunities to Phase-down of HFCs in MAC Sector

Prof. Radhey S. Agarwal

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Post Kigali Low-GWP Options for Air Conditioning Sector

Fluorocarbon Refrigerants HCFCs & HFCs Prior to Kigali Amendment

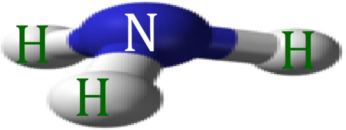
High Pressure Applications
Widely used HFC refrigerants:
R-410A, R-407C , HFC-32

Medium Pressure
Commonly used HFCs:
HFC-134a

Low Pressure
Commonly used refrigerant:
HCFC-123

Post Kigali Refrigerants-Low GWP Options

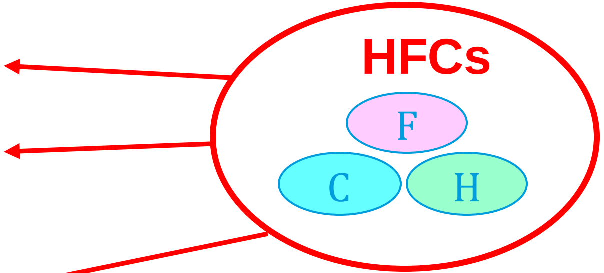
Ammonia



HFOs

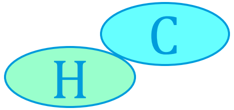
e.g. 1234yf
&
(blends of HFO-HFC)

HFCs



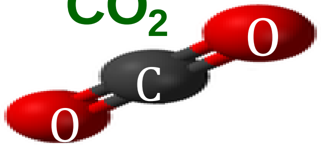
e.g. HFC-134a &
HFC blends

Hydrocarbons



e.g. R-290; R-600a

CO_2



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Mobile Air-Conditioning (MAC) Sector

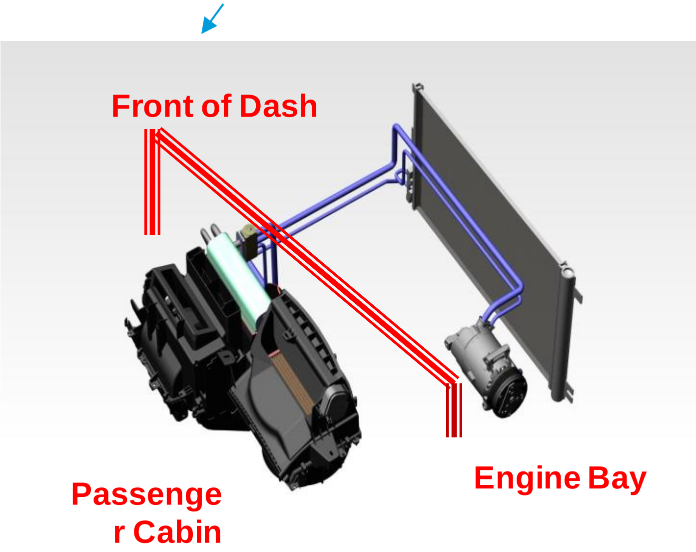
Mobile Airconditioning Sector

- Historically automobile industry globally used one refrigerant, CFC-12 earlier switched over to HFC-134a;
- Car air conditioning sector is one of the largest HFC consuming sectors; HFC-134a is widely used globally in this sector.

Low-GWP Refrigerant Options for Car Air-conditioning

	GWP	Efficiency	TFA *	Flammable	IP
HFO-1234yf	< 1	Good	Yes	Mildly flammable (A2L)	Yes
Carbon Dioxide - CO_2	1	Poor at High Ambient	No	No	No
HFC-152a	124	Good	No	Flammable (A2)	No

* TFA: Trifluoroacetic Acid /trifluooroacetate



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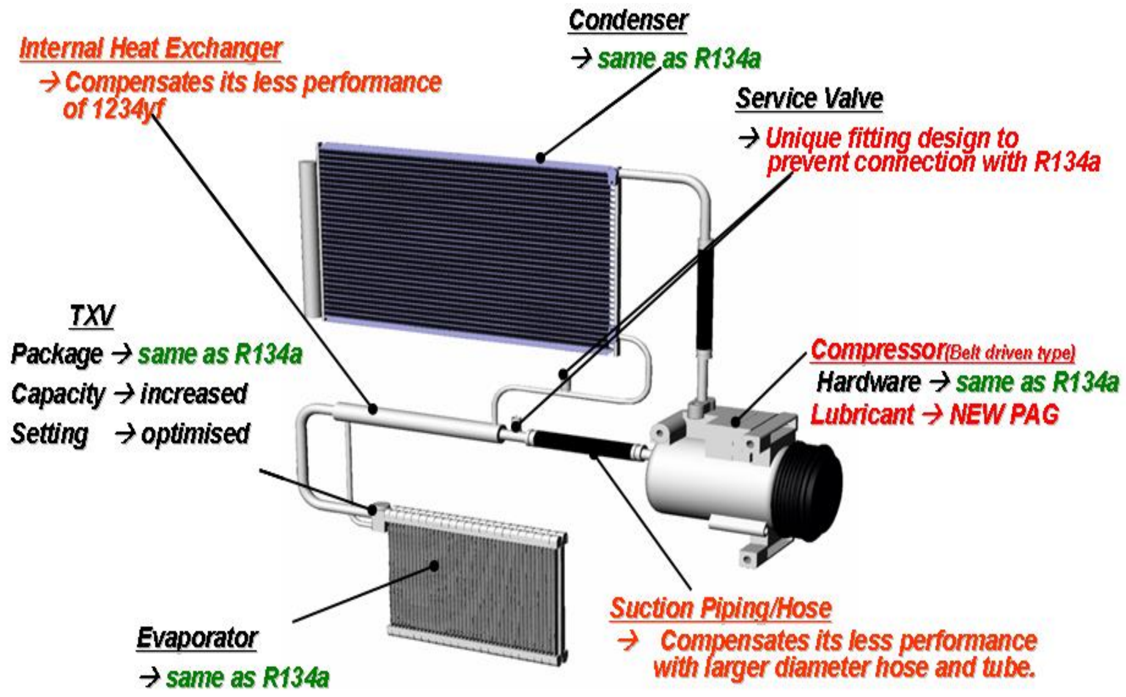
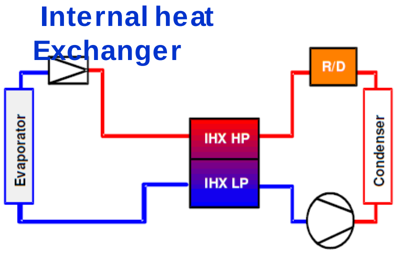
Low-GWP Options - HFO-1234yf for MAC

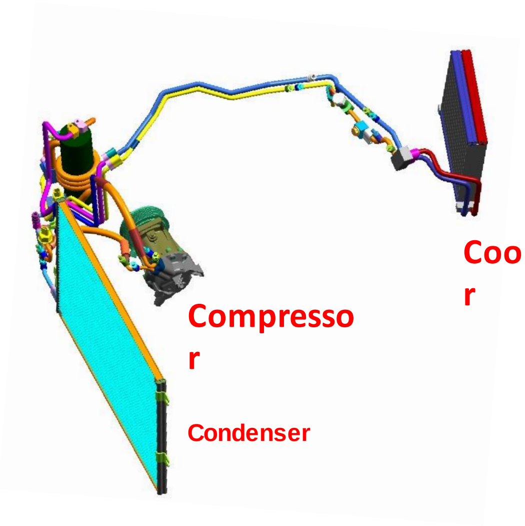
HFO-1234yf has comparatively lower latent heat than R134a that results in reduction in cooling capacity by 8%





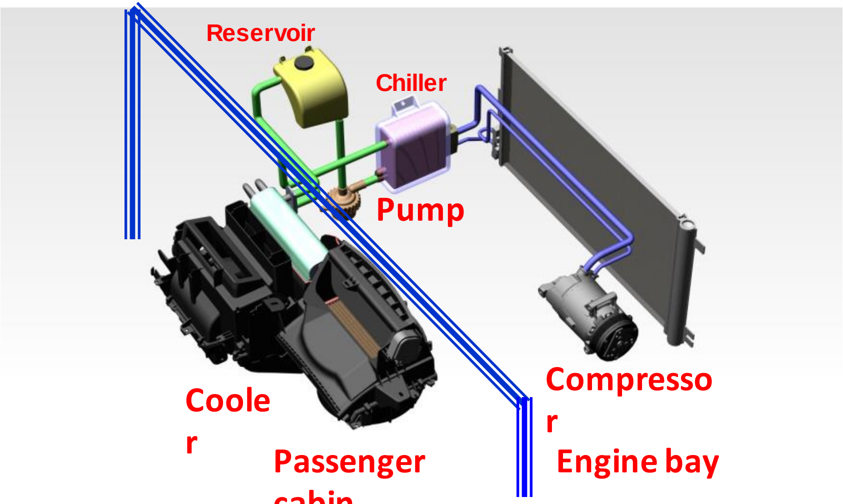
Low-GWP Options for MAC

CO_2 MAC System: System components are similar to HFC-134a



Note: 1. CO_2 systems are being tested more than a decade
2. To be re-designed to handle the high pressures of CO_2

Secondary Loop System using R-152a



Evaporator replaced by cooler

Note: Refrigerant contained within engine bay: Cabin is cooled by secondary coolant

Challenges in Phase-down of HFCs in MAC Sector

- Technical options are still emerging. No consensus within the industry on low-GWP options;
- Currently HFO-1234yf is the choice of refrigerant of automobile industry in some markets but it may not be the final. Debate is still on about break-down products of HFO-1234yf and its impact on environment;
- Availability still continue to be an issue, especially in Article 5 countries due to limited producers with low production capacity, may be due to uncertainty of its future demand.
- Relatively higher cost of refrigerant that would put extra financial burden to users and the country, especially for servicing;
- The retro-fitment or drop-in replacement of R134a by R1234yf will cause a performance impact of about 8% less cooling capacity in the present cars.
- In order to match the performance of MAC with R1234yf to the present value of R134a, mandatorily an additional internal-heat exchanger (IHX) must be installed in the vehicle;
- **The additional cost and packaging of IHX** (additional component) in the present cars need to be addressed along with the technology transfer of IHX from developed countries.

Opportunities in Phase-down of HFCs in MAC Sector

- MAC being one of the largest HFC consuming sectors provides an opportunity for greater environmental benefit;
- Thermodynamic characteristics of HFO-1234yf are similar to HFC-134a thus it requires minimal system changes;
- HFO-1234yf technology is well developed and simple technology to convert;
- Automobile industry is already using HFO-1234yf MAC systems manufactured in India in export vehicle models;
- HFO-1234yf MAC system could be serviced similar to HFC-134a MAC taking due safety measures;

Experience in CFC Phase-out in MAC Sector

- Montreal Protocol was signed in September,1987 and became effective in 1989. In early years the chemical producing industry was not having adequate understanding about the non-ODS alternatives;
- The Scientific and technical community took few years to identify HFCs could be the alternatives as these are similar to CFC molecules and are not having chlorine and bromine in their molecules;
- HFC-134a was identified as the alternatives to replace CFC-12. It has similar thermodynamic characteristics that of CFC-12 but it is very reactive to some of the materials especially the nonmetallic materials used in RAC equipment. In addition, oil compatibility was another major concern for the equipment manufactures;
- The MAC industry in India was on board since inception of the Montreal Protocol and having good collaboration with leading MAC manufacturers in the world and there was consensus globally among the vehicle manufacturers on the alternative, the HFC-134a;
- The MAC manufacturers excepted the challenge and converted to opportunity in close cooperation with vehicle manufacturers. The MAC manufactures came forward to convert their manufacturing facilities in early stage of the Protocol;
- India successfully converted all MAC manufacturing without any exception as early as 1st January, 2003. The import of any equipment containing CFCs were also banned under the Ozone Depleting Substances (Control and Regulation) Rules, 2000.

Way Forward

- MAC servicing sector accounts for about 40% of refrigerant consumption in the sector;

- Refrigerant management of the existing MAC systems of the vehicles can play a vital role in meeting compliance targets of phase-down of HFCs in this sector.

- There is huge stock of refrigerant gas with high-GWP contained in the MAC systems that are either already operational or that will be added to the existing stock till country completely addresses phases-down of HFCs in new manufacturing of MAC;

- A large quantity of refrigerant gets emitted into the environment due to leakages during life time of the vehicles as well as at the end of life of vehicles;

- It may be in the interest of users and the environment to address these emissions through lifecycle refrigerant management (LRM) practices:

  - Preventive measures to minimise leakages during operation of the vehicle and
  - Recovery of the gases during servicing as well as end-of-life of the vehicle and recycling/reclaiming it for reuse and/or destroying the non-reusable refrigerant gas.

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THANK YOU

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15 June 2023
10.00-11.00 a.m. CET time

Session 6: Panel Discussion on

Mobile Air Conditioning Sector

Dr. Samuel Yana Motta
R&D Scientist/Engineer at Oak Ridge National Laboratory

Dr. Samuel F. Yana Motta is an expert in thermal systems with more than 25 years of experience in the development of heat transfer fluids and HVAC equipment. He is currently a distinguished R&D scientist in the Energy and Transportation Science Division at the US Department of Energy's Oak Ridge National Laboratory.

He worked for Honeywell for 21 years as global director of technology and research fellow with a demonstrated history of innovation (author of more than 30 patents) and successful development of commercial products (R-1234yf, R-1234ze, and R-448A). He has authored numerous publications in scientific journals, is a member of high-level expert committees such as the UNEP Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee, and is a member of technical committees of ASHRAE and ISO.

He holds a PhD and an MS in mechanical engineering from the Catholic University of Brazil, and a BS in mechanical engineering from the National Engineering University in Peru.

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Session 6: Panel Discussion Mobile Air Conditioning Sector

Findings and recommendations to phase out/down HFCs in Mobile A/C Applications

Samuel F. Yana Motta

Distinguished Scientist at the Oak Ridge National Laboratory (ORNL USA)

June 15 2023 Vienna, Austria

KIGALI in ActiON

Agenda

- Main measures needed for the Implementation of HFCs phase-down
- Low GWP Refrigerant alternatives for MAC
- Global, regional, and national coordination/cooperation needed to phase down HFCs
- Concluding Remarks

Main measures needed for the Implementation of HFCs phase-down

- Increase awareness of new technologies available through seminars specifically designed for stakeholders.
- Joint Brainstorming to find out technologies/solutions tailored for the specific needs of each region/country.
- Establish projects to provide training to the work force. Some of the new technologies will require additional skills.
- Implement a calendar based on realistic goals for A-5 countries (SMART: Specific, Measurable, Achievable, Relevant, Time-Bound)

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Low GWP Refrigerant alternatives for MAC

Flammable (A2L) R-1234yf and Transcritical CO2 are the main alternatives for new vehicles.

Both of them are more complex than currently R-134a systems

	Type of Vehicle	HFC-134a Current	HFO-1234yf Current	HFO-1234yf Future Options	R-744 (CO2) Current	R-744 (CO2) Future Options	HFC-152a [2] HC-290 [2] Possible Alternatives
Light duty	ICE/Hybrid passenger Cars	WW [1]	EU,NA,CN, JP	WW			IN, EU, NA
Light duty	Hybrid passenger cars	WW [1]	EU,NA,CN, JP	WW		WW	
Light duty	EV Passengers Cars	WW [1]	EU,NA,CN, JP	WW	EU, NA, CN	WW	IN, EU, NA
Light duty	Small trucks	WW	EU	WW			
Heavy Duty	Large trucks	WW	EU	WW			
Heavy Duty	Buses	WW		WW	EU	WW	
Heavy Duty	Utility Vehicles (construction, agriculture)	WW	EU, NA	WW			

Current: Now thru approx. 2035
Future Options: After approx. 2035
Possible Alternatives: under investigation
[1] Not allowed on PC in EU/UK
[2] Secondary Loop, under re-assessment

EU: European Union and UK
NA: North America (US, Canada)
CN: China
IN: India
JP: Japan
WW: WorldWide

Highly flammable R-152a (A2) and R-290 (A3) can only be used with a secondary loop system.

They are also quite complex

- New MAC technologies will require significant training for the workforce. Significant manufacturing is located in A-5 countries (Brazil, Mexico, China). These technologies will eventually arrive to A-5 countries.
- Some reduction of emissions is possible if retrofitting of R-134a to class A1 mixtures occurs. Example: R-513A (GWP<600, class A1). It may help during transition.

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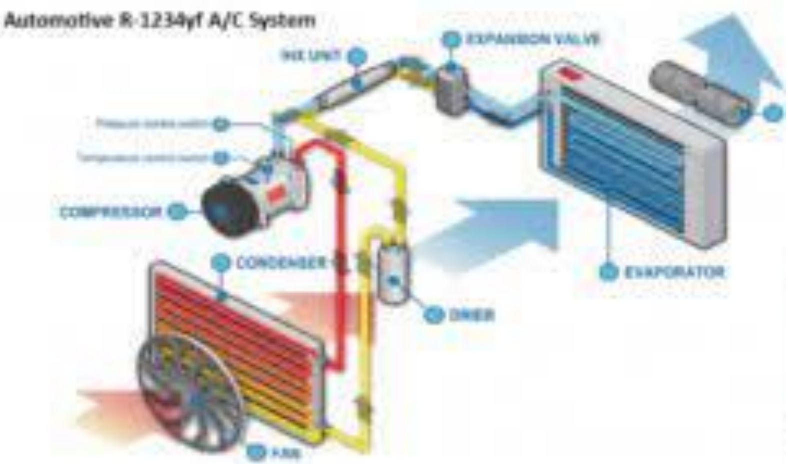
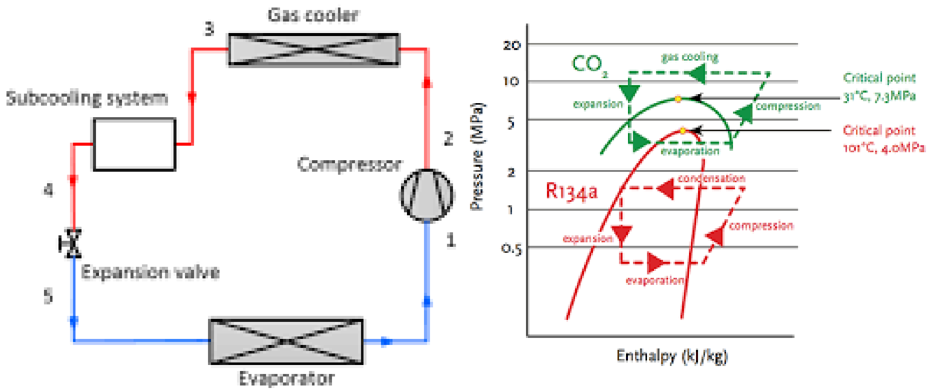
Flammable A2L R-1234y



Transcritical CO2 System



- ➢ Regular refrigeration cycle with the basic components but the system has been designed to handle a flammable gas (class A2L by ISO 817)
- ➢ Operating pressure are similar to R-134a (<250 psig)

- ➢ Due to low critical temperature, it uses a cooler instead of a condenser, and the high-side pressure is optimized.
- ➢ High operating pressures (above 1500 psig)

Global, regional, and national coordination/cooperation needed to phase down HFCs

- Developed countries (US, Europe) have already developed standards and guidelines for the handling of new refrigerant technologies. They should share with A-5 countries.
  - Example for the US: SAE research and standards for R-1234yf technologies
  - Example for Europe: Industry guidelines for Transcritical CO2 systems
- Awareness and transfer of publicly available technology following these steps:
  - Workshops for each region including detailed description of new technologies and brainstorming to develop options tailored for A-5 countries). Options for developed countries may not fit well for A-5 countries.
  - Training program using knowledge tailored for A-5 counties
  - Provide tools for handling new technologies.
- New technologies tend to be more expensive so incentive programs may be required for the HFC phase-down to happen in under-developed A-5 countries.

Concluding Remarks

- Dissemination of knowledge in several languages and training of local experts will be fundamental to implement new MAC technologies in A-5 Countries
- The globalization of the auto market is making cars with A/C affordable in a-5 countries. Two main drivers:
  - Improvements of life quality and lowering of the auto cost.
  - A/C becoming a more standard feature due to security/safety
- A-5 countries with large populations can produce significant GHG emissions unless they adopt low GWP refrigerant technologies.

Thank you