OEWG48
Bangkok
13-17 July 2026

THE KIGALI AMENDMENT 2016–2026

Advancing Energy Efficient Low-GWP Technologies in Mobile Air-Conditioning and Heat Pump Systems in Article 5 Developing Parties

OEWG-48 Side Event, 14th July 2026

UNIDO

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CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

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THE KIGALI AMENDMENT 2016–2026

India's Transition Towards Sustainable Mobility Cooling

"Advancing Low-GWP Technologies and Workforce Readiness in the MAC Sector"

Sangeet Hari Kapoor
National Projects Coordinator (India), UNIDO

Formerly, General Manager (Climate Control)
TATA Motors Ltd

Contents

India’s Automotive Industry – Scale, Growth and Innovation Opportunity

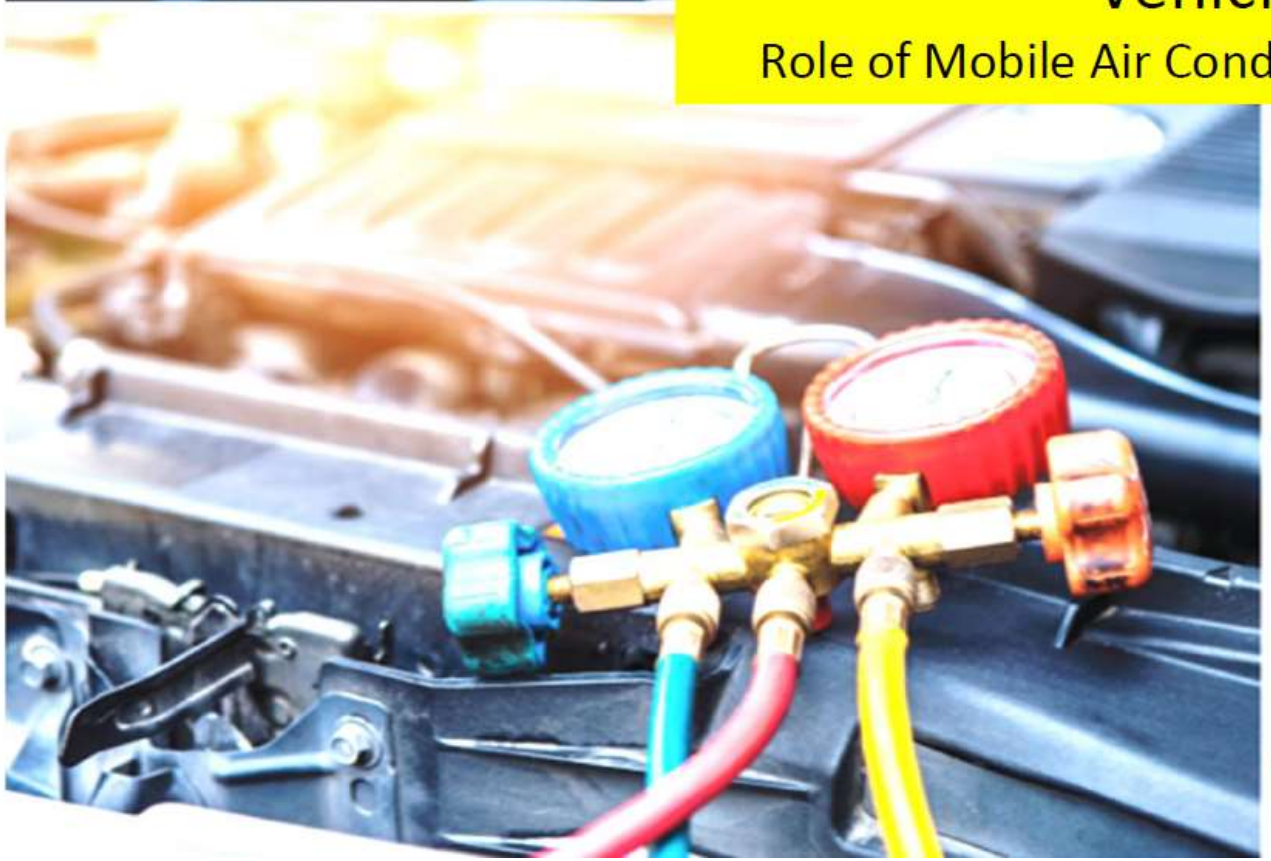
THE INDIAN ECOSYSTEM: WHERE WE ARE

Parameter	US	China	Germany	India	Japan
GDP (2025) ($Tn)	30.5	19.2	4.7	4.2	4.2
Manufacturing Units (Mn) (2024) (PV+CV)	10.56	31.28	4.07	6.01	4.4
Cars per 1000 people (2024)	779	251	590	38	670
R&D as a share of GDP	3.59%	2.56%	3.13%	0.65%	3.41%
Auto Industry as % of GDP	4.9%	10%	6%	7.1%	10%
~Auto Sector Size (2024)	$1200 Bn	$1400 Bn	$580 Bn	$240 Bn	$410 Bn
Global Innovation Index Rank (2025)	#3	#10	#11	#38	#12
Patent Applications (Mn) (2024)	0.5	1.8	0.06	0.1	0.3
Startup Ecosystem Index (2025)	#1	#13	#7	#22	#18

- World's 3rd largest automobile market (by unit volume)
- Fastest growing passenger vehicle market (~7.3% CAGR from 2025 to 2030)
- Rapid EV adoption (~7.8% in FY 2025)
- Strong engineering capability
- Manufacturing hub

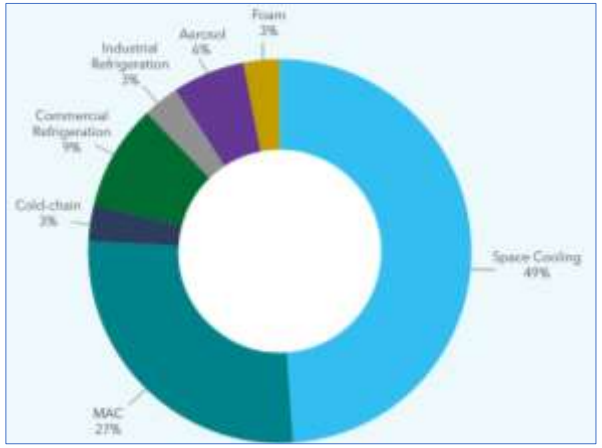
Vehicle Sector

Role of Mobile Air Conditioning in Global Warming

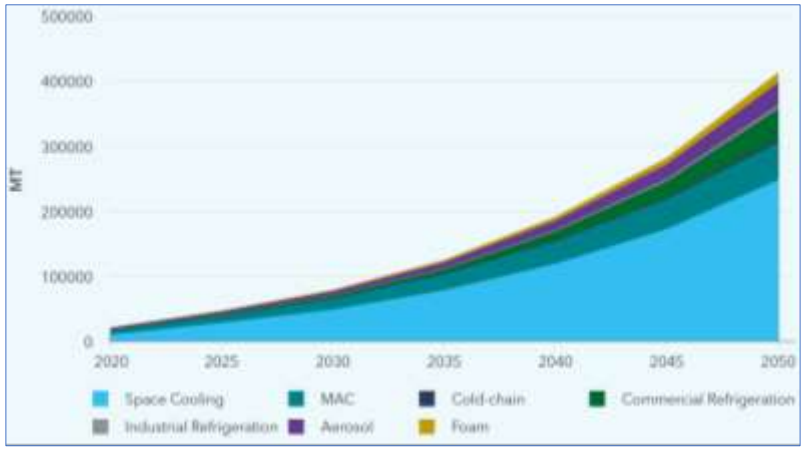


Why Sustainable Cooling Matters for India's MAC Sector

- **By 2050, the MAC sector will be the 2nd largest contributor to HFC emissions across all sectors (~ 15.5% to 20% estimated) following the stationary air conditioning sector (~63%)**
- **Rapid urbanization** and rising income levels will increase sales of passenger vehicles by **~9% annually**
- Rising ambient temperatures are driving increased cooling demand – AC penetration is approaching 100%, The overwhelming majority of vehicles currently **use HFC-134a as the refrigerant in their MAC systems, which has high GWP**
- Ownership of passenger vehicles has grown from ~25 vehicles per 1000 people (in 2019) to **~35 vehicles per 1000** people (in 2025); the transition to low GWP refrigerants is crucial for containing HFC emissions



HFC consumption (MTCO2eq) by sector for 2025, NRDC



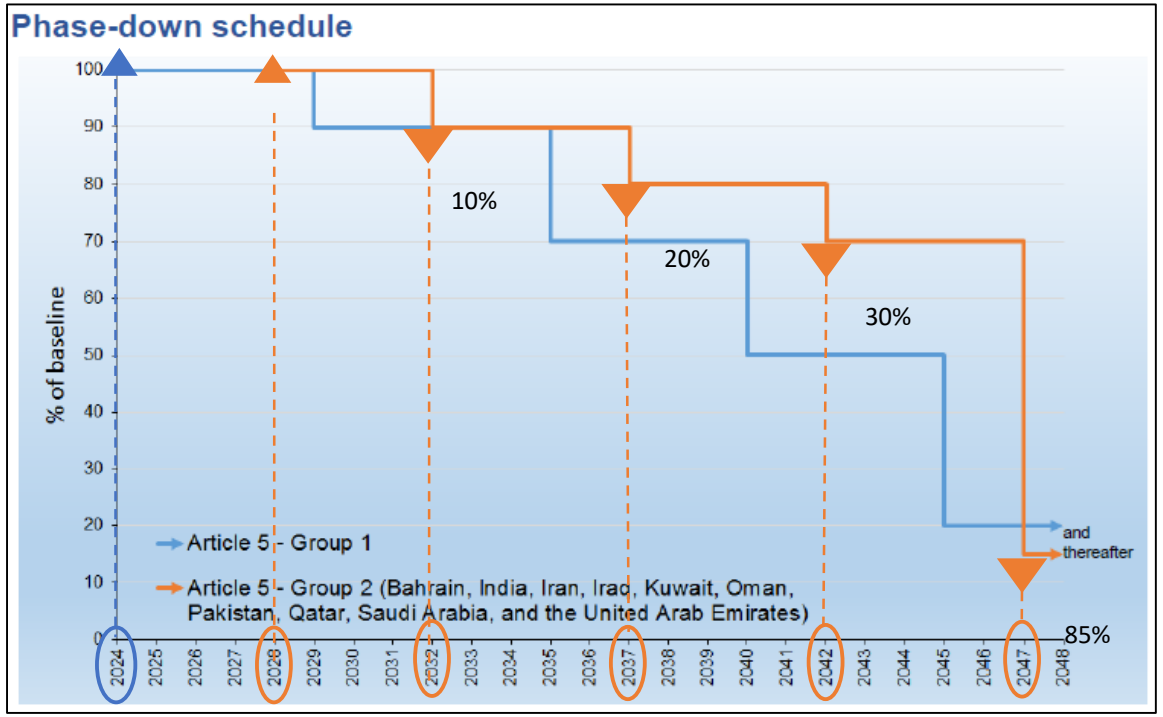
HFC consumption (MT) by sector in the BAU Scenario, NRDC

- Automotive sector growth will have a **huge impact on fuel use** and **refrigerant demand**, which is estimated to **grow 4 times** (~6000 MT in 2017 to ~25000 MT by 2038)
- The Union Minister for Road Transport and Highways has announced that for road safety, **air-conditioned cabins are mandatory for all trucks from June, 2025** (refrigerant demand for new trucks will surge by ~500 MT in 2025 and increase to ~1500 MT in 2037)

India's HFC Phase-Down Commitment under Kigali Amendment

Kigali amendment of Montreal Protocol: Reduction based on Average Refrigerant Consumption for Article 5 parties

	Article 5 Parties: Group 1	Article 5 Parties: Group 2
Baseline Years	2020, 2021 & 2022	2024, 2025 & 2026
Baseline Calculation	Average production/consumption of HFCs in 2020, 2021, and 2022 *plus* 65% of HCFC baseline production/consumption	Average production/consumption of HFCs in 2024, 2025, and 2026 *plus* 65% of HCFC baseline production/consumption
Reduction steps Freeze	2024	2028
Step 1	2029 10%	2032 10%
Step 2	2035 30%	2037 20%
Step 3	2040 50%	2042 30%
Step 4	2045 80%	2047 85%



Group 1 Compliance Start: 2024
Group 2 Compliance Start: 2028

20% Tail : 2045
15% Tail : 2047

Freeze year for group 1 parties

Freeze year for group 2 parties

HCFC baseline for A5 parties is equal to average of 2009-2010

Microsoft Excel Worksheet

Building the Ecosystem for Sustainable Mobility Cooling in India

A Multi-Stakeholder Approach to MAC Sector Transformation

MoEF&CC
Ozone Cell
(Policy Leadership)

India's MAC transition is being driven through coordinated action among government, industry, international organizations, technical experts, and the servicing ecosystem

UNIDO
(Technology and Implementation)

SIAM
(Industry Coordination)

OEMs
(Vehicle Manufacturers)

Tier 1 Suppliers ACMA
(Systems and Components)

Service Technicians
(Organized and Informal Sector)

Consumers and Vehicle Owners

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS
(Funding Support)

NRDC NATURAL RESOURCES DEFENSE COUNCIL
(Analytics Support)

IGSD
(Technology Pathways and Partnerships)

CEEW Council on Energy, Environment & Water
(Workforce Assessment)

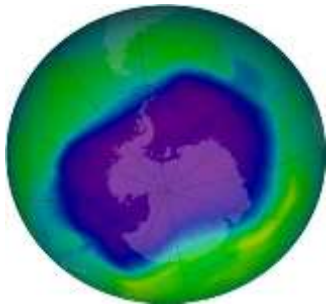
Technology Pathways for India's MAC Sector

PAST

Chlorofluorocarbon, CFC

The Montreal Protocol (1989) → Earth Summit Rio De Janeiro (1992) → Kyoto Protocol Conceived (1997) → World Summit on Sustainable Development (2002)

High ODP (1)
High GWP (10900)



(Ozone Layer Depletion)

Refrigerants	ODP	GWP
CFC-12	1	10900

PRESENT

Hydrofluorocarbon, HFC

Kyoto Forced (2005) UN Climate Change Conference Bali (2007) → Europe Regulation (2006/40/EC) (Leakage rate) (2008) → Europe Regulation (2006/40/EC) (F-Gas) (2013) → Paris Agreement COP 21 (2015)

Zero ODP (0)
High GWP (1774)

(Global Warming)

Refrigerants	ODP	GWP
HFC-134a	0	1430
HFC-407C	0	1774

TRANSITIONAL & NEXT GEN

Hydrofluoroolefin, Blends, Natural Refrigerants

Kigali Amendment to Montreal Protocol (2016) → Kigali Amendment to Montreal Protocol enter in force (2019)

Zero ODP (0)
Very Low GWP (<150)

GREEN EARTH PLAN
A future we can all contribute to

Each of the options has its unique challenge

Options	ODP	GWP
CO2	0	1
HFO-1234yf	0	<1
HFC-152a	0	124
HC-R290	0	3

ODP – Ozone Depletion Potential
GWP – Global Warming Potential

Why R – 290 (Propane)

- It **is safe for the ozone layer** or climate (ODP≈0), aligning with the goals of the Montreal Protocol and Kigali Amendment
- It has one of the **lowest GWPs (≈3)** of any refrigerant currently in use. It significantly reduces the environmental footprint compared to high GWP refrigerants like R-134a (≈1430) or even R-152a (≈124)
- It has **excellent thermodynamic performance**, energy efficient in both heating and cooling (SAE-TMR CRP results)
- Unlike HFO 1234yf, **it does not degrade into trifluoroacetic acid** (TFA), considered in some definitions as a per- and poly-fluoroalkyl substance (PFAS) commonly knows as “everywhere and forever” chemical, that is eco-toxic and polluting
- It is **inexpensive, naturally occurring** (a hydrocarbon), and **widely available at competitive price** making it ideal for mass production- lower refrigerant charge needed → **smaller system sizes** and reduced material costs
- Making it Safe - A small refrigerant charge is **safely used in a Monoblock secondary loop heat pump** and a nonflammable fluid to transfer hot and cold to occupied spaces, inverters, and batteries

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

Ministry of Environment, Forest and Climate Change

SUSTAINABLE DEVELOPMENT GOALS

Pilot Project of R-290 Refrigerant Substitution Technology for Electric Vehicles

Project Overview

Technology Demonstrations

TATA MOTORS

- Pilot project of HC-290 **refrigerant substitution technology for Electric Vehicles** operating under typical Indian climatic conditions
- Development of guidelines for **standard operating procedures on safe use of HC-290 in Mobile AC systems**
- The learnings from this pilot project can **benefit other sectors such as room and building air conditioning**

Capacity Building and Knowledge Dissemination

SIAM

- Conduct a **Train-the-Trainers workshop** and build a robust and future-ready capacity within India's organized automotive servicing ecosystem → transition to **low-GWP refrigerants**
- Support safe and efficient adoption of **next-gen, low-GWP refrigerants e.g. HC-290 (propane)**
- Disseminate the achievements and outcomes of the pilot project domestically and internationally

Outlook for 2026

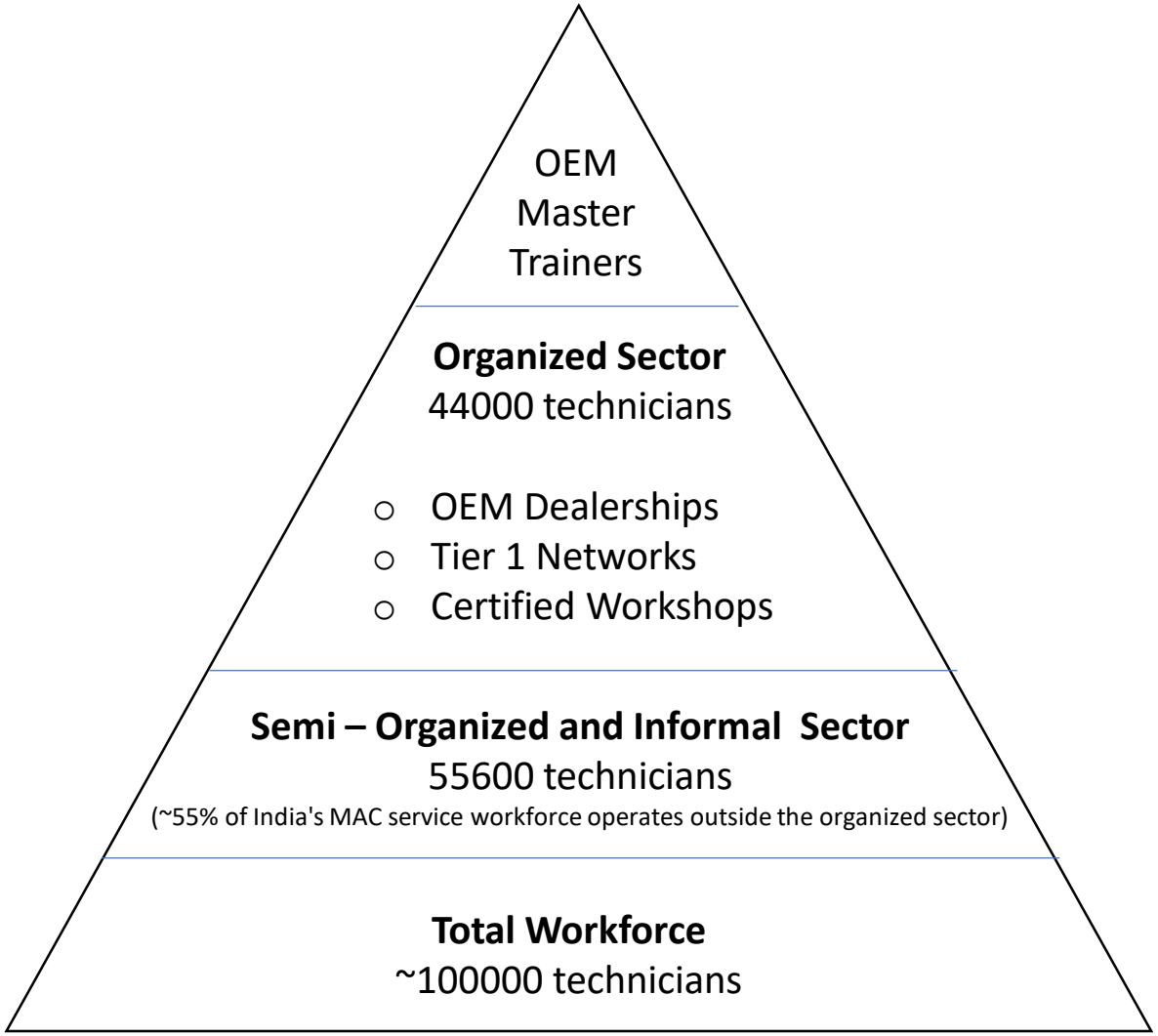
- Organize an 'Inception Workshop' on 'Demonstration of R-290 Refrigerant Substitution Technology for Electric Vehicles in India', with participation from, Ozone Cell, MoEF&CC, auto OEM's, Tier 1 vendors, SIAM and discuss case studies by international experts from China, USA and Europe
- Build a certified pool of master trainers within OEMs and Tier 1 ecosystem to organize the Train the Trainer Workshop with National and International trainers
- Identify a suitable Nodal Agency and develop a plan for pursuing further activities linked to Service Training in the Informal MAC Sector; with inputs and direction from Ozone Cell, MoEF&CC

Technology Demonstration Alone is Not Enough

Successful transition requires

- ✓ Technology
- ✓ Standards
- ✓ Safety
- ✓ Skilled technicians
- ✓ Industry readiness

Skills Development: India's MAC Sector, Scale of the Opportunity



Source: CEEW
MAC Sector Estimates and Projections, 2025

Challenge	Opportunity
Refrigerant leakage	Technician training
Safety risks	Certification
Informal servicing	Capacity building
End-of-life emissions	Recovery & recycling

Successful refrigerant transition requires capacity building across the entire servicing ecosystem

TRAIN-THE-TRAINER
↓
NATIONAL CERTIFICATION
↓
SAFE LOW-GWP REFRIGERANT USE
↓
KIGALI COMPLIANCE & EMISSIONS REDUCTIONS

"Technology transition alone is insufficient. A successful HFC phase-down requires a trained, certified and future-ready servicing workforce across both organized and informal sectors"

Barriers To Large Scale Adoption of Hydrocarbon Refrigerants

Main Characteristics of Refrigerants

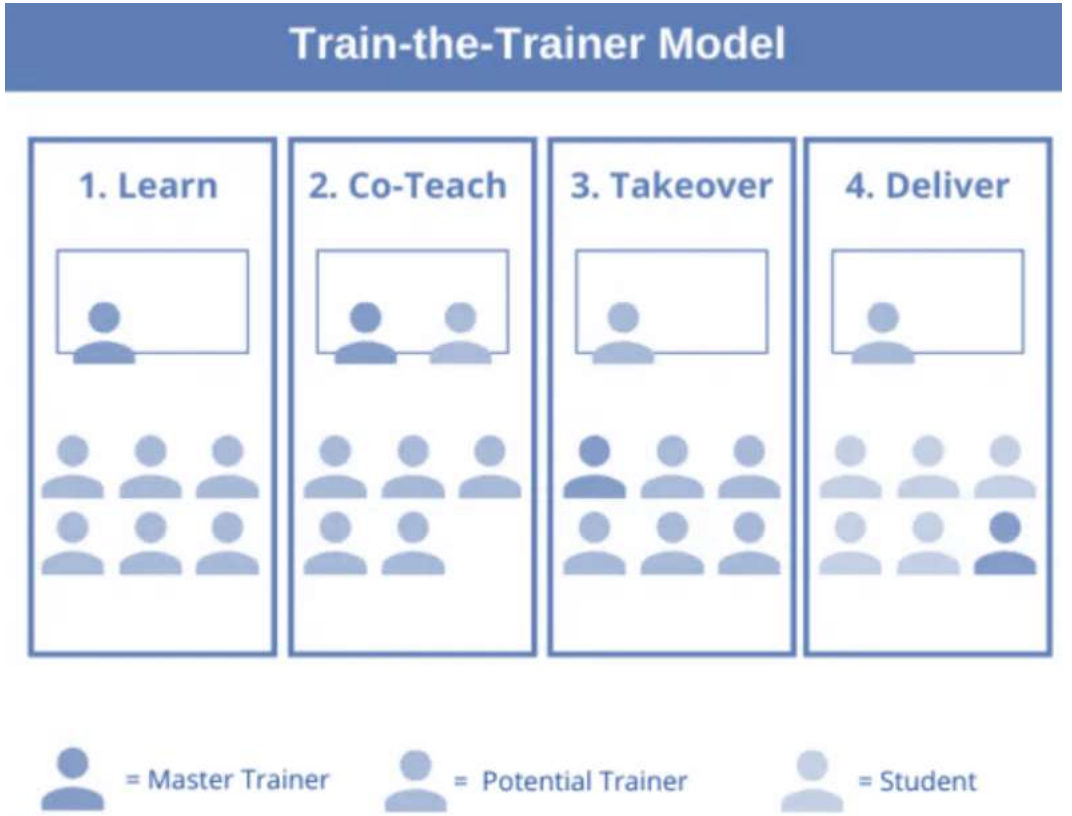
Refrigerant	GWP	TFA	Flammable	Toxic	Comparative costs	
					Refrigerant	Installation
HFCs	High	Some are and a few form TFA	No GWP < 750 Moderate	Low, but toxic fumes when burning	Moderate	Low
HFOs	Low	Some are and several form TFA	Moderate	Not acute, but toxic fumes when burning	High	Low Drop In
Hydrocarbons	Low	No	Yes	Low	Low	Moderate System Engineering
Carbon Dioxide	Low	No	No	Above 10%	Low	Moderate System Engineering

Technology: Need for system redesign
Safety: Flammability concerns
Standards: On going Development
Servicing: Technician readiness
Economics: Cost of alternatives
Policy: Regulatory clarity

The Central Question

How do we enable safe commercialization?

UNIDO–SIAM Train-the-Trainer Programme for Service Personnel in the Organized MAC Sector



Dr Rashid Hasan

Senior Advisor

Society of Indian Automobile Manufacturers

Mr Santosh Venu, Principal Engineer R-290 Demonstrator Project

Deputy General Manager (Climate Control)
Engineering Research Centre, TATA Motors Passenger Vehicles Ltd

Way Forward

- India's MAC sector is entering a **critical transition phase** as the country prepares for its **HFC freeze in 2028** and phased **reductions beginning in 2032**
- Technology innovation and demonstration projects such as the **UNIDO-CCAC-Tata Motors R-290 initiative** are helping **de-risk future low-GWP refrigerant pathways** and generate knowledge for industry-wide adoption
- In the interim, **HFO 1234yf based MAC Systems at a competitive price will gain traction on ICE vehicles** in A5 markets as compared to other low GWP refrigerants, as HFO 1234yf is already accepted in Asian, European, and North American non-Article 5 markets
- The **availability and patent related high price of HFO 1234yf is the primary barrier to early adoption among Indian OEMs** and it is being reconsidered in Europe due to PFAS concerns
- Workforce readiness is equally important. A successful transition will require **structured training, certification, and capacity building across both, the organized sector** (like the UNIDO – SIAM Train the Trainer Project) **and informal servicing sectors**
- The transition cannot be delivered by any single stakeholder. Success will depend on **continued collaboration** among governments, industry, international organizations, technical institutions, and the servicing community

Acknowledgements

The presenter gratefully acknowledges the contributions of UNIDO, CCAC, IGSD, SAE International, MoEF&CC (Ozone Cell), SIAM, Tata Motors Passenger Vehicles Ltd., CEEW, and all project partners whose work has informed this presentation

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14. Additional technical inputs and project data courtesy of Tata Motors Passenger Vehicles Ltd., UNIDO Project Team, SIAM, IGSD, and participating project partners.

India's Transition Towards Sustainable Mobility Cooling

Successful refrigerant transition is not simply about **selecting a refrigerant**
It requires **technology innovation, safety engineering, standards development, workforce capacity, and strong partnerships** ….

…. together, countries can accelerate the transition toward climate-friendly mobility cooling **through cooperation, knowledge sharing and innovation**

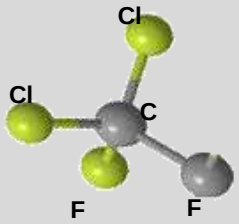
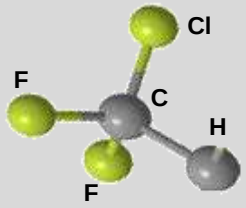
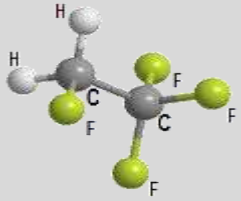
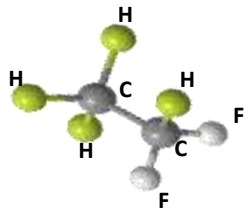
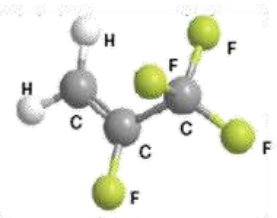
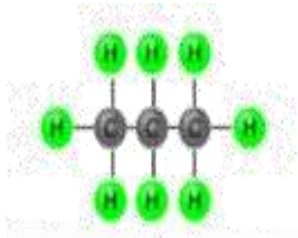
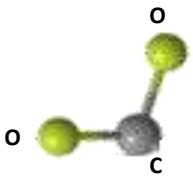
Thank You for your Time and Attention!
Happy to take Questions …

Back Up

Data Collection: Production and Consumption of HFCs

Parameter	Gas			2005	2006	2007	2008	2009	2010	
Mobile air conditioning										
Cars Buses, Trucks	Installed base at year starting	*000 units*								
	Newly installed units	*000 units*								
	Number of decommissioned units	*000 units*								
	Weighted average unit refrigeration capacity	*kW*								
	Weighted average refrigerant charge size per equipment	*kg/unit*								
	CFC - 12	%	*The sum of all components should be 100%.*							
	HFC - 134a	%								
	HFO - 1234yf	%								
	Other refrigerants (*specify*)	%								
	Total	%		0%	0%	0%	0%	0%	0%	0%
	Leakage rate during initial charge	%								
	Annual operational leakage rate from banked gas	%								
	Equipment lifespan	*years*								
	Initial charge remaining in the equipment at End-of-life	%								
	End-of-life recovery rate	%								

Three Generations of MAC Refrigerant: Potential Alternatives

Status →	Phased Out		Current	Future: Potential Alternatives			
Category →	CFC	HCFC	HFC	HFC- Blends	HFO	HC	CO_2
Parameter ↓	R12	R22 Building Air Conditioning	R134a	R152a	R1234yf	R290	R744
Bonding							
Molecular Formula	CF_2Cl_2	CHF_3Cl	CH_2FCF_3	CH_3CHF_2	CH_2CFCF_3	$CH_3CH_2CH_3$	CO_2
IUPAC Name	Dichloro Difluoro Methane	Chloro Difluoro Methane	1,1,1,2- Tetra Fluoro Ethane	1,1- Di-Fluoro Ethane	2,3,3,3- Tetra Fluoro Propane	Propane	Carbon Di-Oxide
ODP	1 (2 Chlorine Atoms)	0.05 (1 Chlorine Atom)	0	0	0	0	0
GWP (100 Years)	10900	1810	1430	124	<1	3 (20)	1
Atmospheric lifetime	100 years	12 years	14 Years	1.4 Years	4 Years (TFA generation)	0.041 Year (VOC)	>100 Years
Flammability (ASHRAE)	A1	A1	A1	A2 (Slightly)	A2L (Mildly)	A3 (Extremely Flammable)	A1
Critical Temperature (°C)	111.9	96.14	101.06	113.26	92.42	96.7	31.04
Critical Pressure (Bar)	41.36	49.9	40.6	45.16	33.82	42.5	73.85
Normal Boiling Point (°C)	-29.8	-40.7	-26.3	-25	-29.4	-42.1	-78

R-744 has some production in small, cold environments by some EU OEMs, but, given its low efficiency at high ambient temperatures and high pressures and complex controls, is not a good option for India

A1 : No flame propagation
A2 : Slightly flammable- Lower flammability limit @ 60°C: > 100 g/m3 or Heat of Combustion < 19 Mega J/kg
A2L : Mildly flammable-Lower flammability limit @ 60°C: > 100 g/m3 and Heat of Combustion < 19 Mega J/kg With Maximum Burning Velocity < 10 cm/s
A3 : Extremely flammable