Network Meeting of South Asia National Ozone Officers

(4th July, 2025 Bangkok)

Overview and Update on Mobile Air Conditioning (MAC) Sector

"Assessing the Use of R-290 in MAC Sector"

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Advisor and Technical Specialist MAC Systems

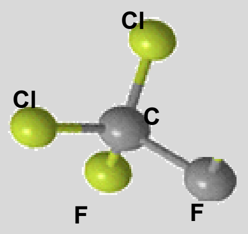
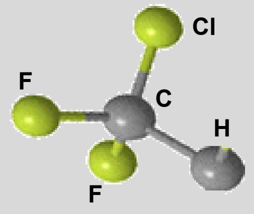
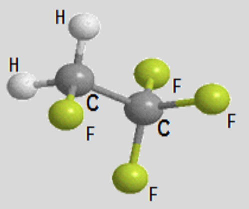
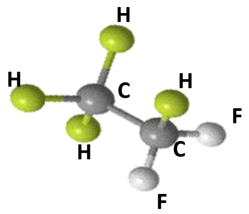
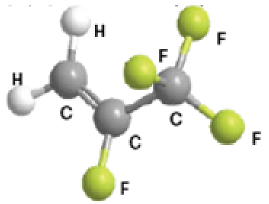
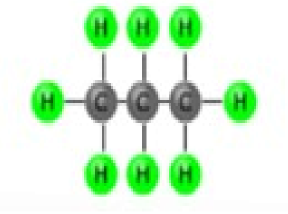
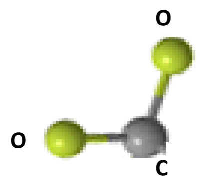
Formerly, GM (Climate Control)
TATA Motors Ltd

Contents

Forecast: Vehicle Sector Growth

- **By 2050, the MAC sector will be the 2^{nd} largest contributor to HFC emissions across all sectors (~ 15.5%) following the stationary air conditioning sector (~63%)**
- **Rapid urbanization** and rising income levels will increase sales of passenger vehicles by **~9% annually**
- Ownership of passenger vehicles has grown from ~20 vehicles per 1000 people (in 2019) to **~34 vehicles per 1000** people (in 2024)
- Buses for **public transport** are estimated to increase from ~2.2 million in 2017–18 to ~ **4 million** in 2037–38
- Almost all vehicles equipped with an **AC system use HFC-134a**, which has high GWP and will be phased out strategically as per the Kigali Amendment to the Montreal Protocol
- Automotive sector growth will have a **huge impact on fuel use** and **refrigerant demand**, which is estimated to grow from ~6000 metric tonnes (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 will be mandatory for all trucks from June, 2025**
  (The refrigerant demand for new trucks will surge by ~500 MT in 2025 and further increase to ~1500 MT in 2037)

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	>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

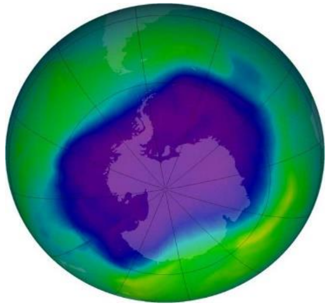
Indian Context: Three Generations of MAC Refrigerant

PAST	PRESENT	TRANSITIONAL & NEXT GEN
Chlorofluorocarbon, CFC	Hydrofluorocarbon, HFC	Flammability, Blends, Natural Refrigerants

- The Montreal Protocol (1989)
- Earth Summit Rio De Janeiro (1992)
- Kyoto Protocol Conceived (1997)
- World Summit on Sustainable Development (2002)
- 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)
- Kigali Amendment to Montreal Protocol (2016)
- Kigali Amendment to Montreal Protocol enter in force (2019)

PAST

High ODP (1)
High GWP (10900)

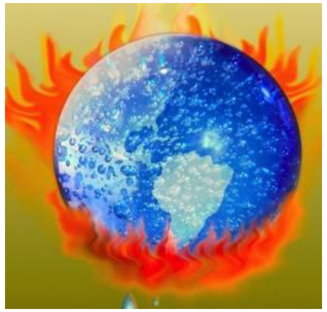


(Ozone Layer Depletion)

Refrigerants	ODP	GWP
CFC-12	1	10900

PRESENT

Zero ODP (0)
High GWP (1774)



(Global Warming)

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

TRANSITIONAL & NEXT GEN

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

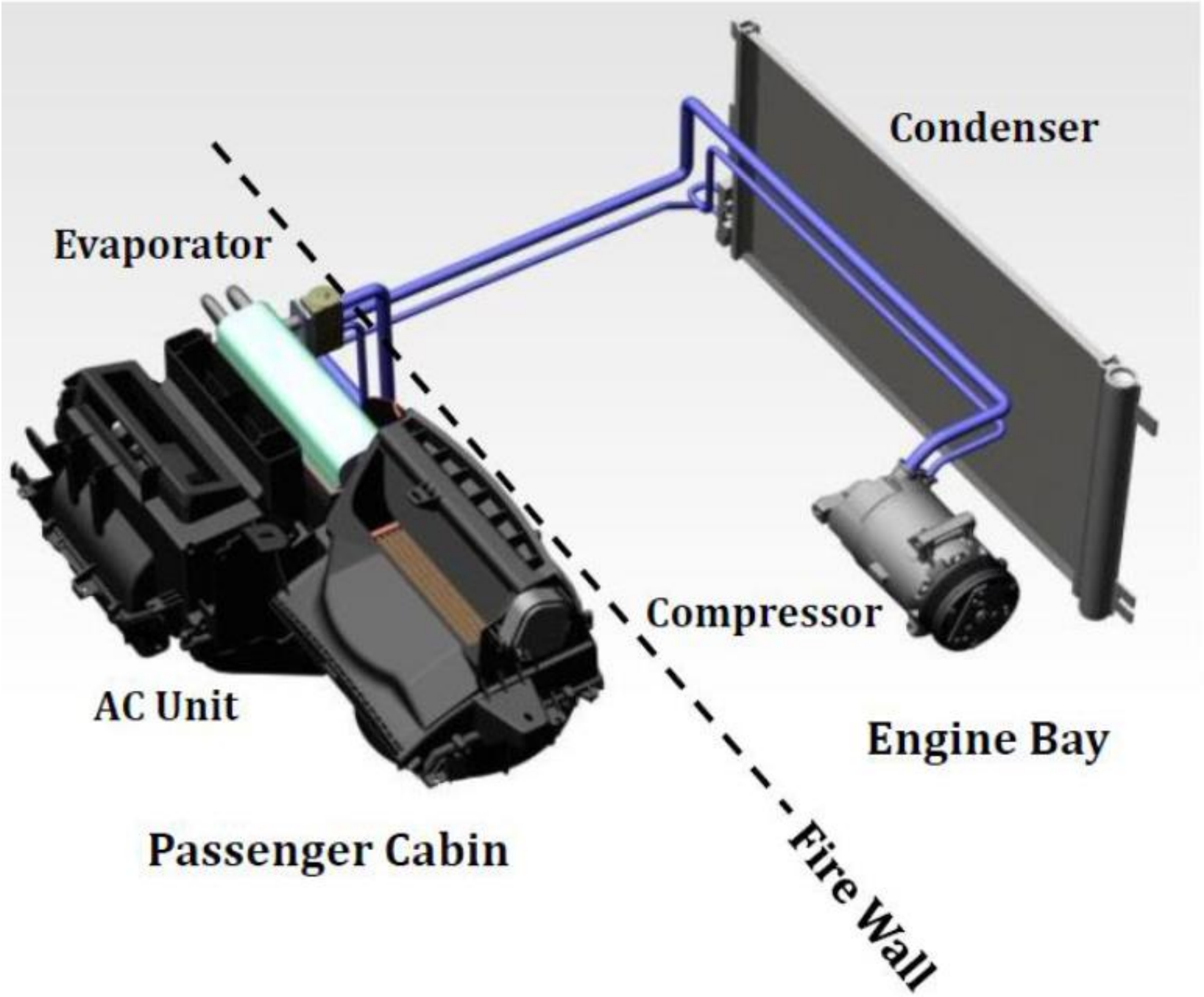
Options	ODP	GWP	
CO2	0	1	
HFO-1234yf	0	<1	PFAS
HFC-152a	0	124	HFC
HC-R290	0	3	R290

Secondary Loop

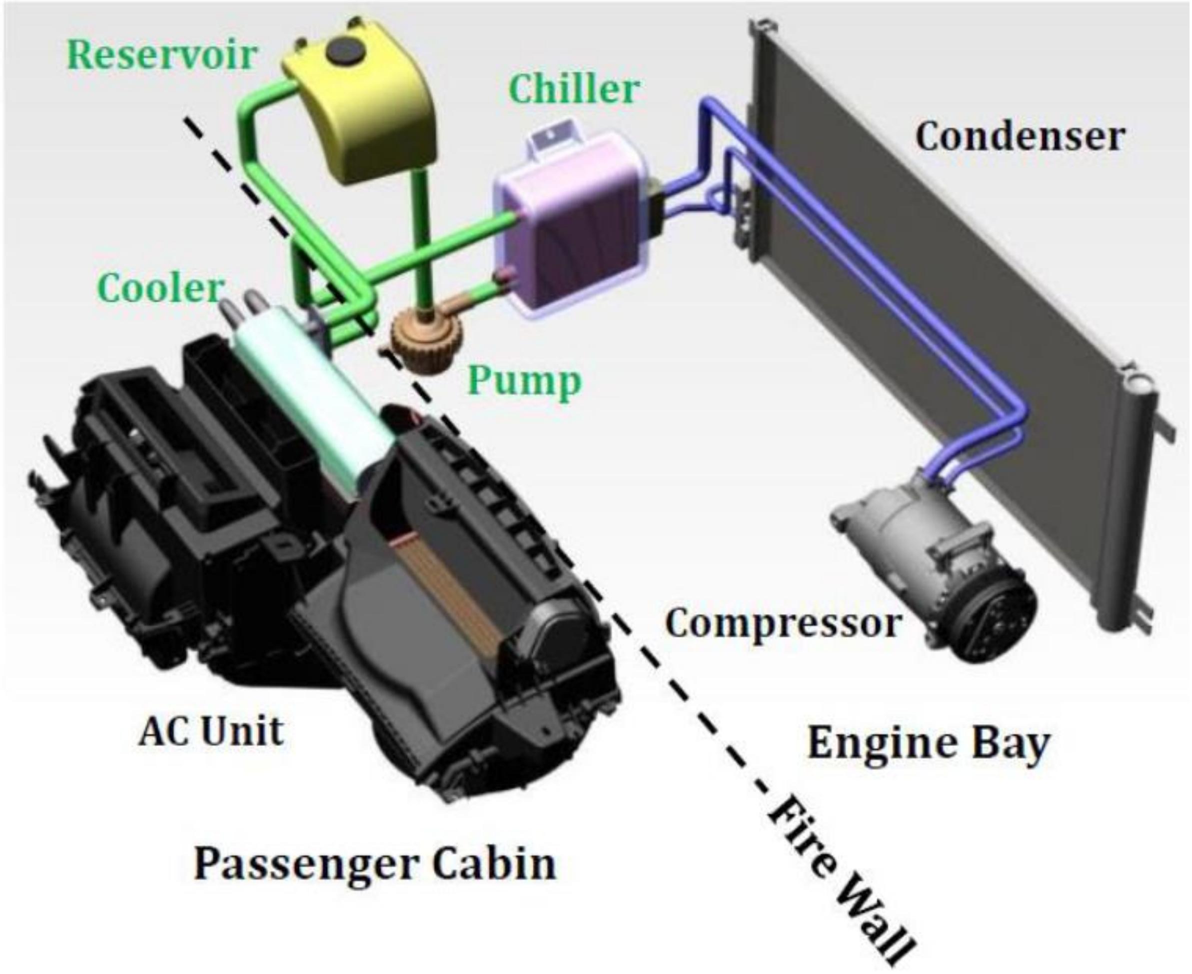
ODP – Ozone Depletion Potential
GWP – Global Warming Potential

TATA Motors, Mahle, IGSD 2017 Secondary Loop Demonstration Project

Conventional Mobile AC System (R134a)



Secondary Loop Mobile AC System (SL MAC) (R152a)



Addressing the flammability issue: Refrigerant is contained in the engine compartment and does not enter cabin

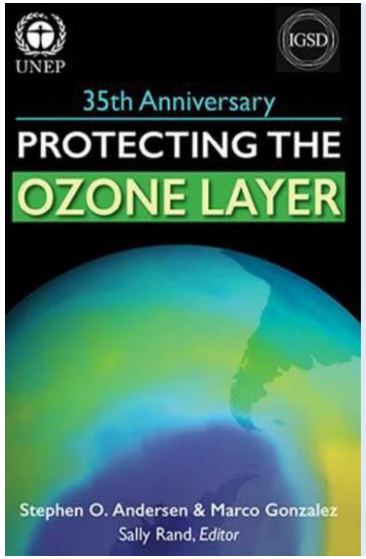
Development, Validation and Results …

Simulated testing under "extreme" weather condition

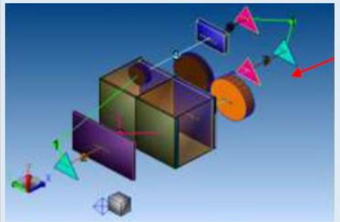
Full soak and cool down at 45°C, 40%RH, 1200W/m2 Solar Load

In-territory Road Trials (~2100kms)

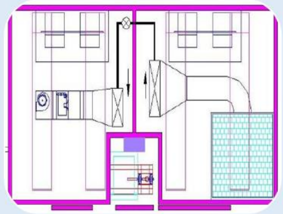
2019, SAE International, Environment Excellence in Transportation (E2T) Award



CAE Simulations → System Bench Analysis → Electronic Control Unit Development → Aria Demonstrator



Component sizing



Refrigerant charge optimization

Programming to convert cold energy for saving fuel

First demonstrator in the world to use R152a in a Dual AC

Two Patents Filed on AC Control Logics and Operations

1. IPR Filed: 3730/MUM/2014
2. IPR Filed: 201921002842

Safe use of low GWP, slightly flammable refrigerant (R152a)

Refrigerant (GWP)
Baseline: 1430
Achieved: 138

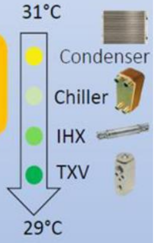
Lifetime CO_2 Emissions reduced by **7.5%** per vehicle

Compressor Power Consumption
Baseline: 5.5kW
Achieved: 5.0kW
(9.1% reduction)

Fluctuation in Vent Temperature
Baseline: ≤ 4°C
Achieved: <2° C

Fuel Economy with AC ON
Baseline: 12.55kmpl
Achieved: 1.9-2.6% improvement

Cooling at 45°C
Baseline: 29°C
Achieved: 31°C



Charge Quantity Reduction (grams)
Baseline: 800gms
Achieved: 430gms
(46% reduction)

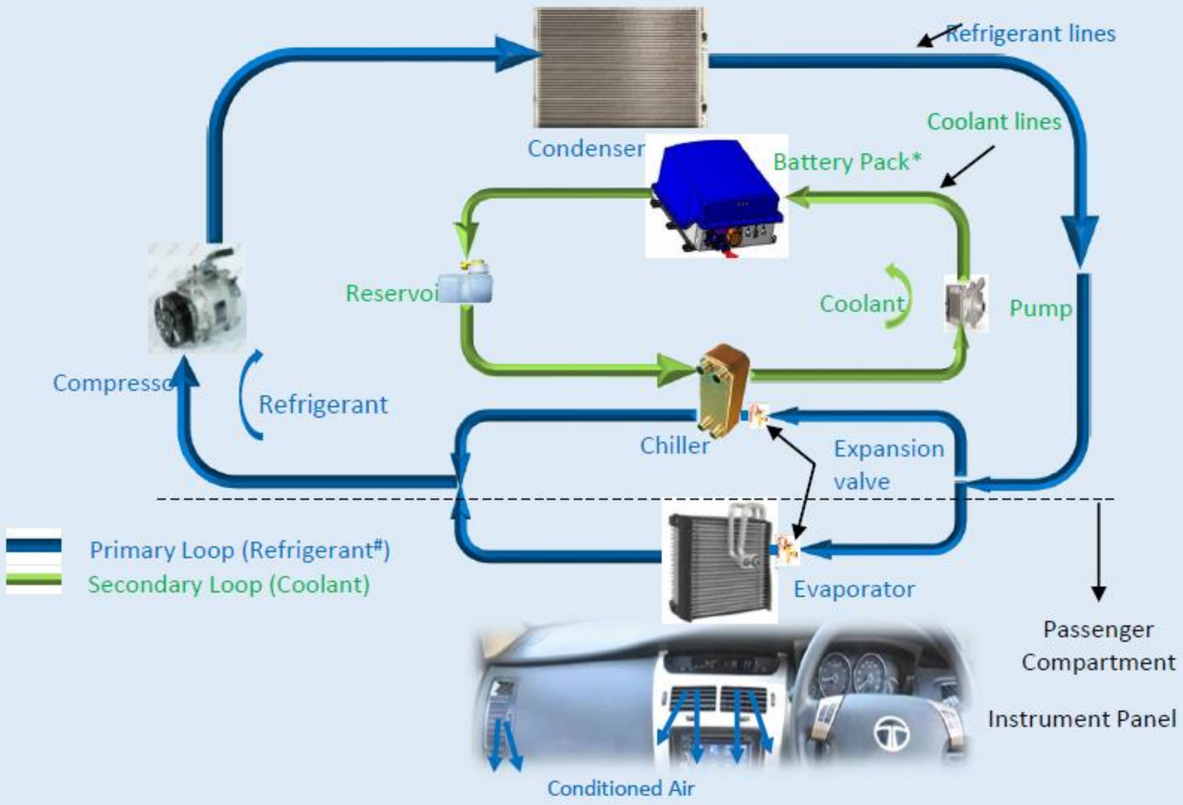
R152a

MOREWHEN ONE

Proposed Layouts in EV’s: Tropical Climate

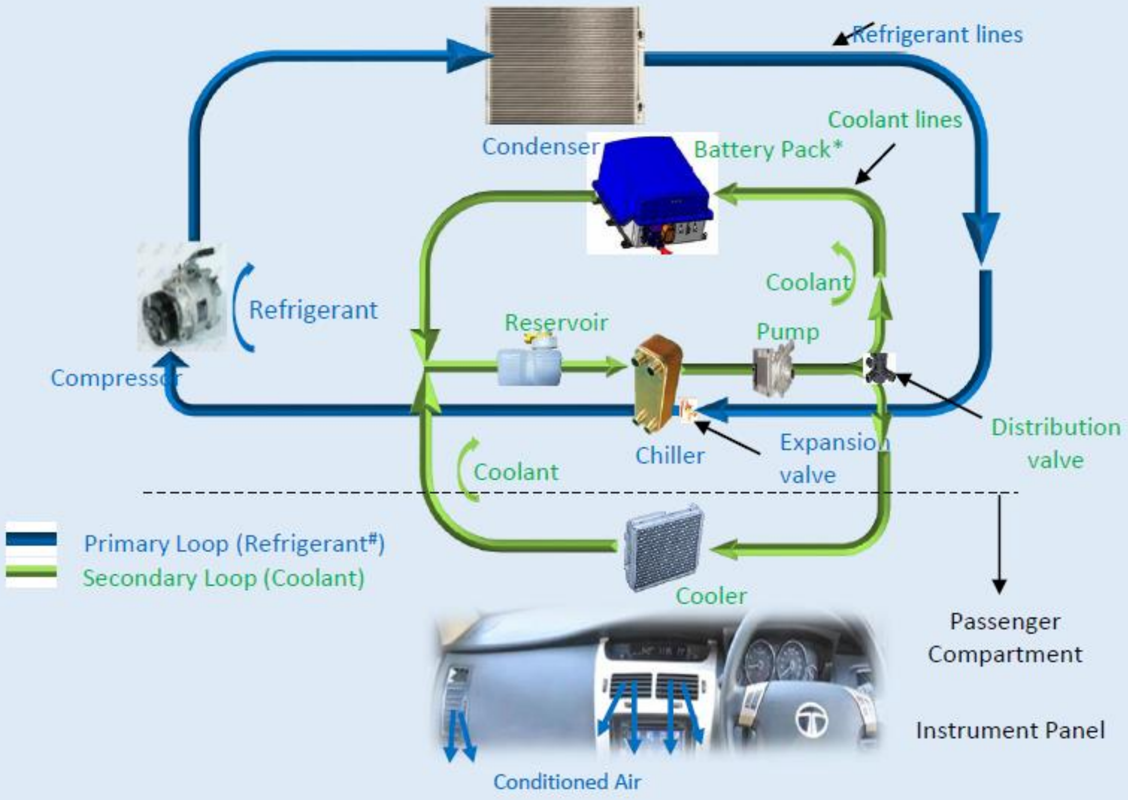
Direct Expansion, DX-AC System

Layout 1: Refrigerant enters passenger compartment



Refrigerant Options: R1234yf (GWP<1)
*Possible location: Engine/Passenger Compartment/Boot

Refrigerant does not enter passenger compartment



Refrigerant Options: R1234yf (GWP<1) /R152a (GWP-124) /R290 (GWP-3)
*Possible location: Engine/Passenger Compartment/Boot

Hot Off the Press: Soon Available …

"History of Industry Leadership in Mobile Air Conditioning"
Case Study of MAC Secondary-Loop Architecture

Vital to Economic and Environmental Performance of All-Electric Vehicles
(for policy makers, regulators, industry professionals and academicians)





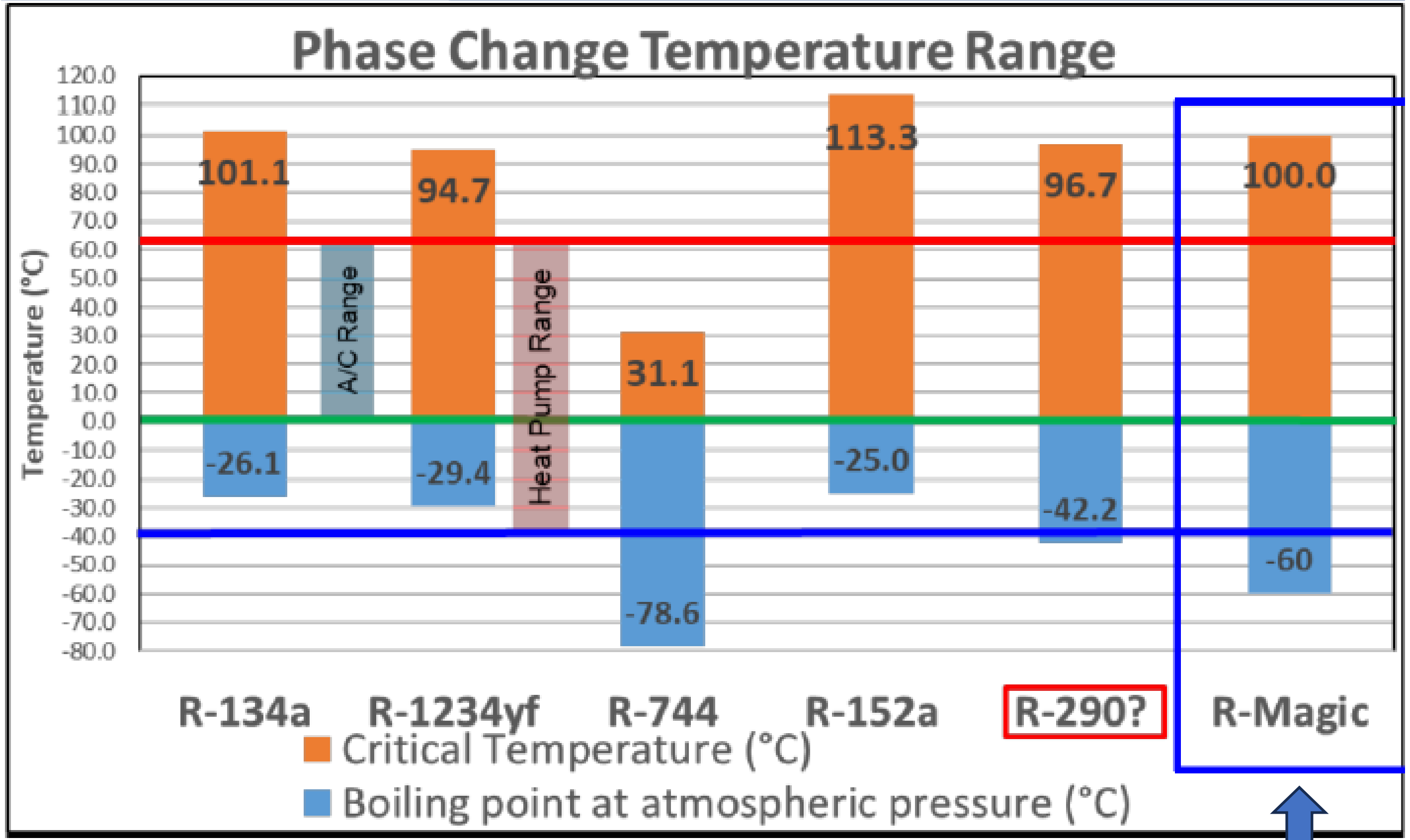

Lead Authors: Stephen O. Andersen, James A. Baker, Timothy D. Craig, Sangeet H. Kapoor, and Steven G. Schaeber Jr. with Sean Dennis Technical Editor

Why R – 290 (Propane)

- It **does not harm 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**, high latent heat of vaporization and thermal conductivity improve heat exchange performance, energy efficient in both heating and cooling - annual energy consumption is 8 to 13% less than for a baseline, direct evaporative R134a system (SAE-TMR CRP results)
- Unlike HFO 1234yf, **it does not degrade into trifluoroacetic acid** (TFA), considered a per- and poly-fluoroalkyl substance (PFAS) commonly knows as "everywhere and forever" chemical, that is eco-toxic and polluting
- It is **inexpensive and naturally occurring** (a hydrocarbon), making it ideal for mass production and developing Lower refrigerant charge needed → **smaller system sizes** and reduced material costs
- Refrigerant grade R-290 is **widely available at competitive price** from the supply chain for refrigerators and stand-alone refrigeration using R-600a (isobutane)
- **No monopoly patents** on refrigerant processing or MAC application
- 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
- Air quality disadvantages of R-290, which is a volatile organic compound (VOC), are mitigated by small leak-tight refrigerant charge, **recovered and recycled**, and destroyed when the vehicle is recycled

Why R – 290 (Propane)

SAE Thermal Management Refrigerant (TMR) Cooperative Research Program (CRP)



R290 properties are closer to ideal target

The 'Main Challenge' is to overcome the added thermal resistance of the secondary loop system to achieve performance and Coefficient of Performance (CoP)

GOAL: Investigate alternatives to Improve/optimize Electrified Vehicle Thermal Management System's efficiency (COP)

- Operating range and conditions
  - Heat Pump operation at low ambient (-40°C)
  - Maintain A/C efficiency (COP) at ambient temperature (45°C)
  - Vehicle unplugged with no preconditioning at -20°C and 45°C

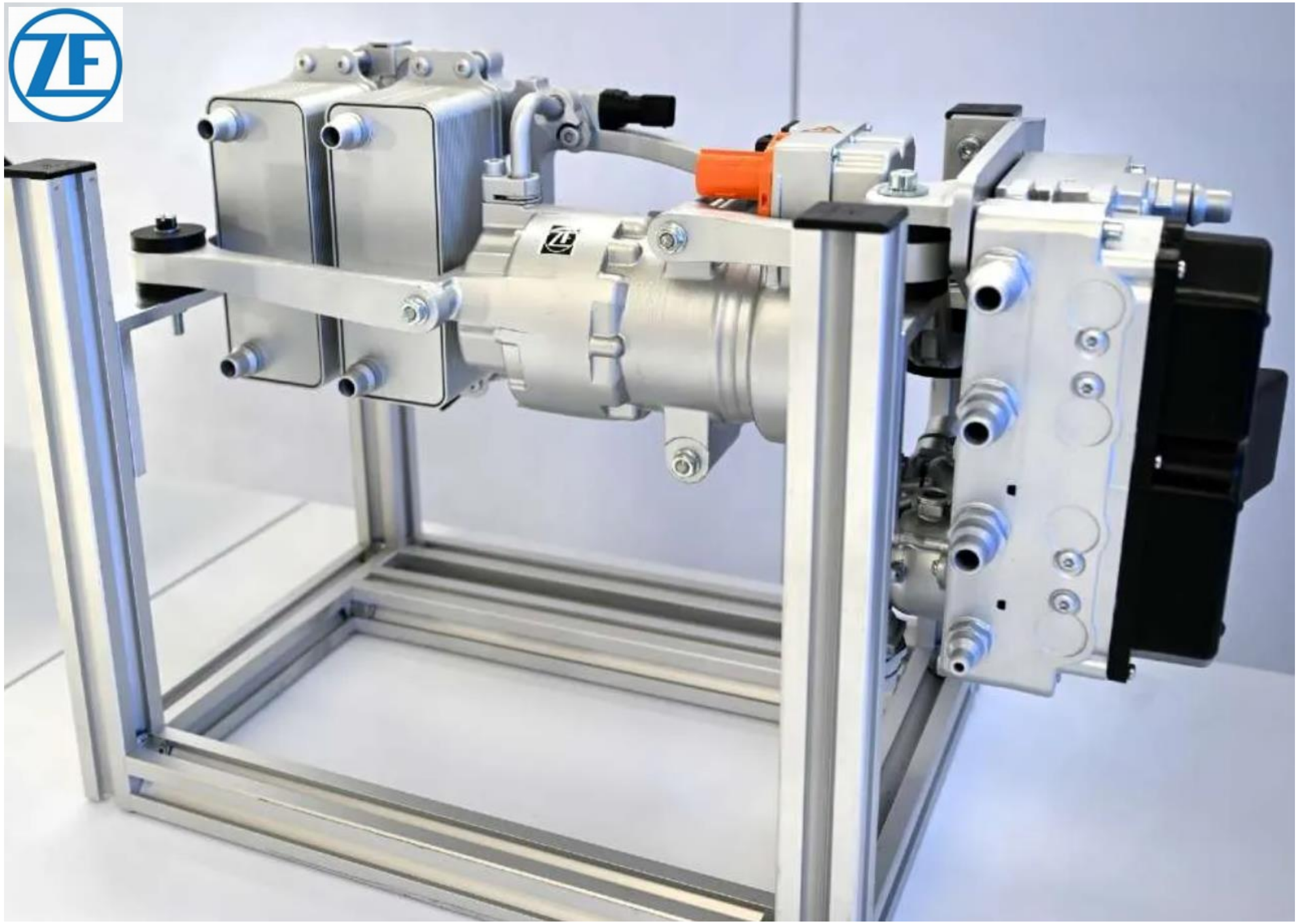
- Explore refrigerants and optimized hardware options
  - Life Cycle Climate Performance (LCCP) model system approach

- Establish the best option(s) initially with a long-term goal of establishing best option(s) for global regulatory approval and for updating SAE Standards

- Develop an LCCP model for EV Thermal Management Systems/Heat Pumps

- Target ready for implementation by 2025

Movement in the Auto Industry … An example of Vendor Preparedness



R-290-based thermal management system for electric vehicles

Photo credit: ZF, Natural Refrigerants News and Marketplace

R-290 Thermal Management System **improves EV Range** by up to 30% compared to HFO1234yf

While the system is not yet commercially available, it is “ready for the market” **pending regulatory approval for the use of propane in mobile air-conditioning (MAC) applications**

The fully integrated system improves EV efficiency via optimized thermal management and **better use of waste heat from the vehicle’s drivetrain (energy efficient)**

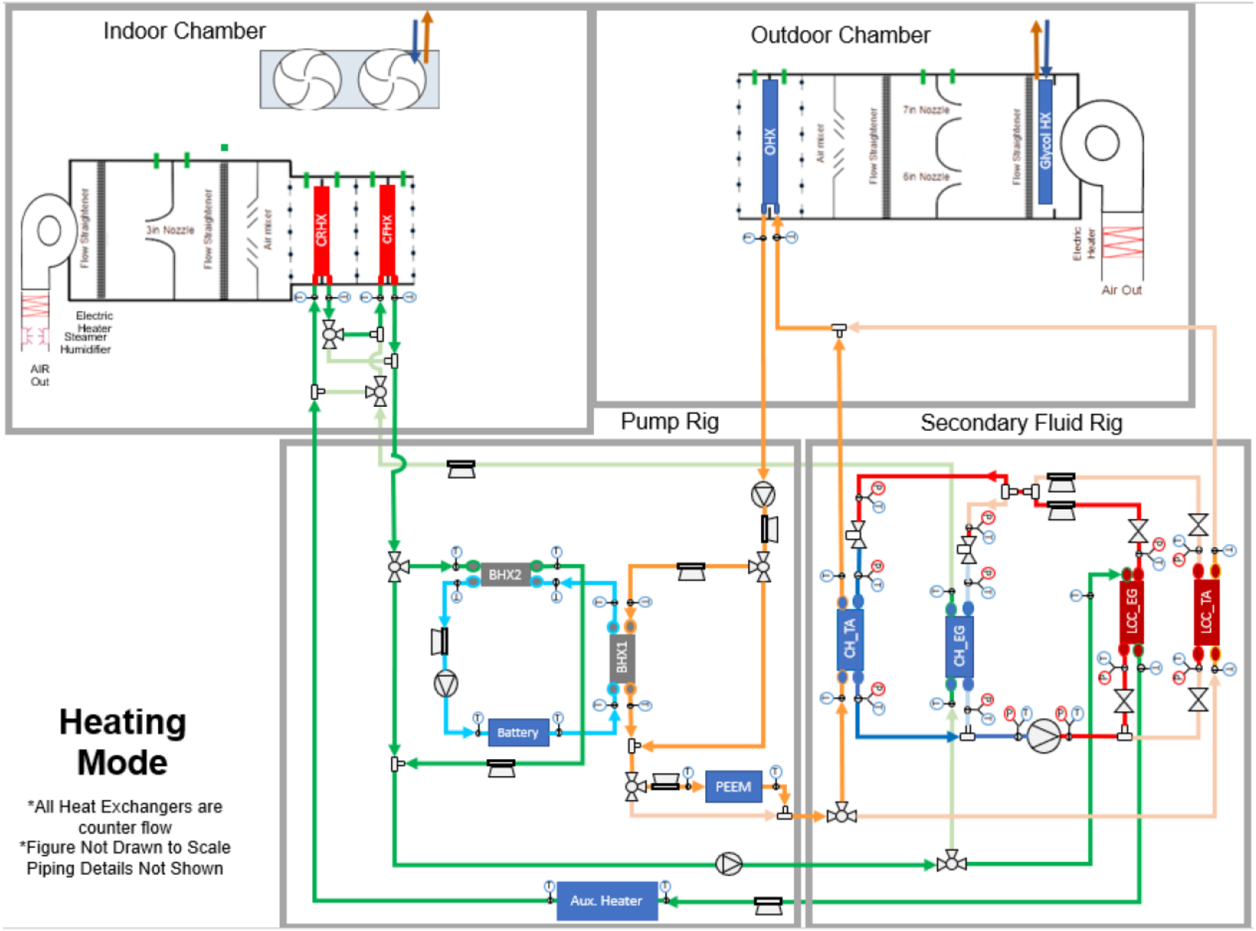
The first version of this system was deployed in a prototype EV in 2023. Since then, by reengineering the system, **refrigerant charge is reduced from 290g to 150g (enhancing safety)**

TATA Motors 2025 R-290 Demonstration Project

- Successful build and **demonstration of R-290 MAC** system on **2 Proof of Concept (PoC) Vehicles** - one passenger EV and one small commercial EV (from green to greener). Component design and engineering
- The commercial vehicle Proof of Concept (PoC) employs a **conventional secondary loop** air conditioning layout, while the passenger vehicle PoC utilizes a **secondary loop, heat pump** air conditioning (HP-AC) system
- These PoC's will demonstrate the **safe use of HC-290 in MAC systems** under typical Indian climatic conditions. Test and Validation
- **Milestone reports** on thermal performance, energy efficiency, durability, and safety
- Recommended **best practices and standard operating procedures** for safe use of R-290 in MAC systems operating in the Indian subcontinent
- Beyond technical innovation, the project seeks to **create enabling conditions** for widespread adoption through the development of **design standards and safety guidelines**
- Findings to be shared with Society of Indian Automobile Manufacturers (SIAM) and the Indian automotive industry to guide the Ministry of Environment Forests and Climate Change (MoEFCC) in developing an India-specific **roadmap for HFC phasedown**
- The knowledge generated will also contribute to **regional replication**, particularly in South and Southeast Asian countries with **similar climatic and regulatory contexts**
- Furthermore, it demonstrates the role of **public-private partnerships**, technological **innovation**, and **regulatory alignment** in achieving sustainable **industrial transformation**

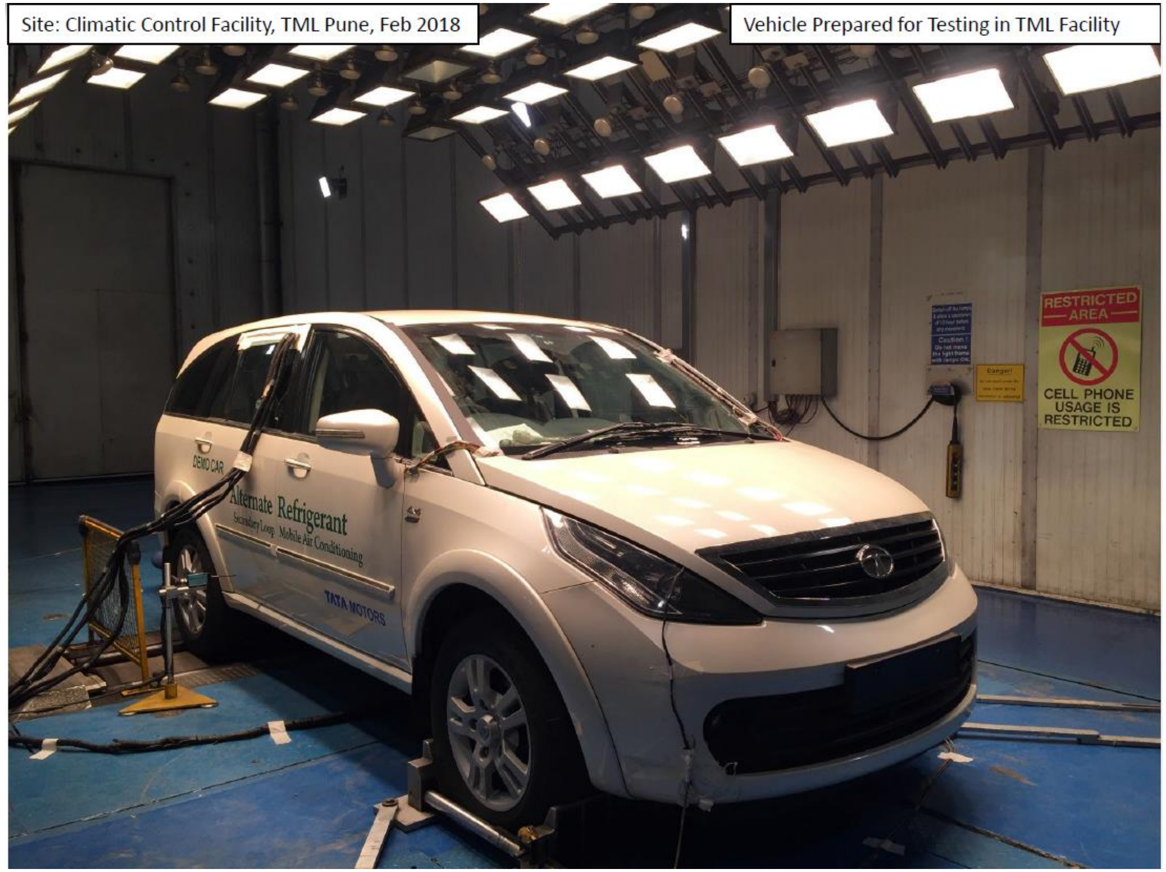
TATA Motors 2025 R-290 Demonstration Project

HVAC System Bench



Each fluid/system is tested at typically 21 test points (11 AC and 10 HP) ranging in ambient temperatures from 45C to -40C (most testing stops at -30C) and testing as a HP fluid is ended when the compressor suction pressure reaches 0 gauge or atmospheric pressure. Cooling and heating capacity, power consumption and critical temperature and pressure data is generated and used for analysis and system optimization

Full Vehicle



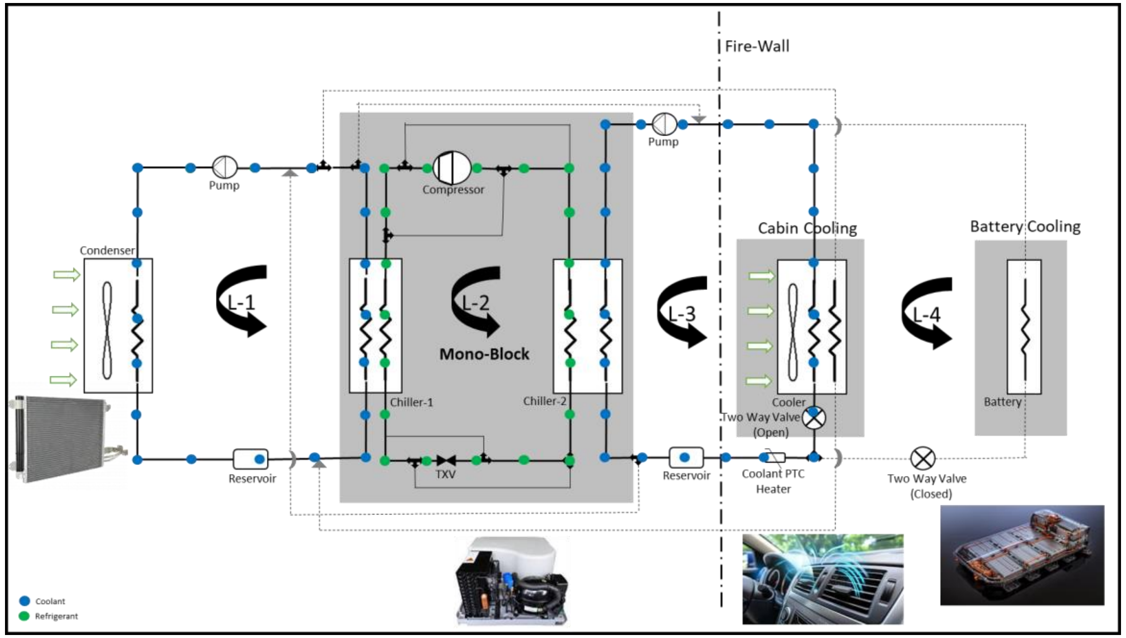
Tata Motors Full Vehicle Environment Trest Facility

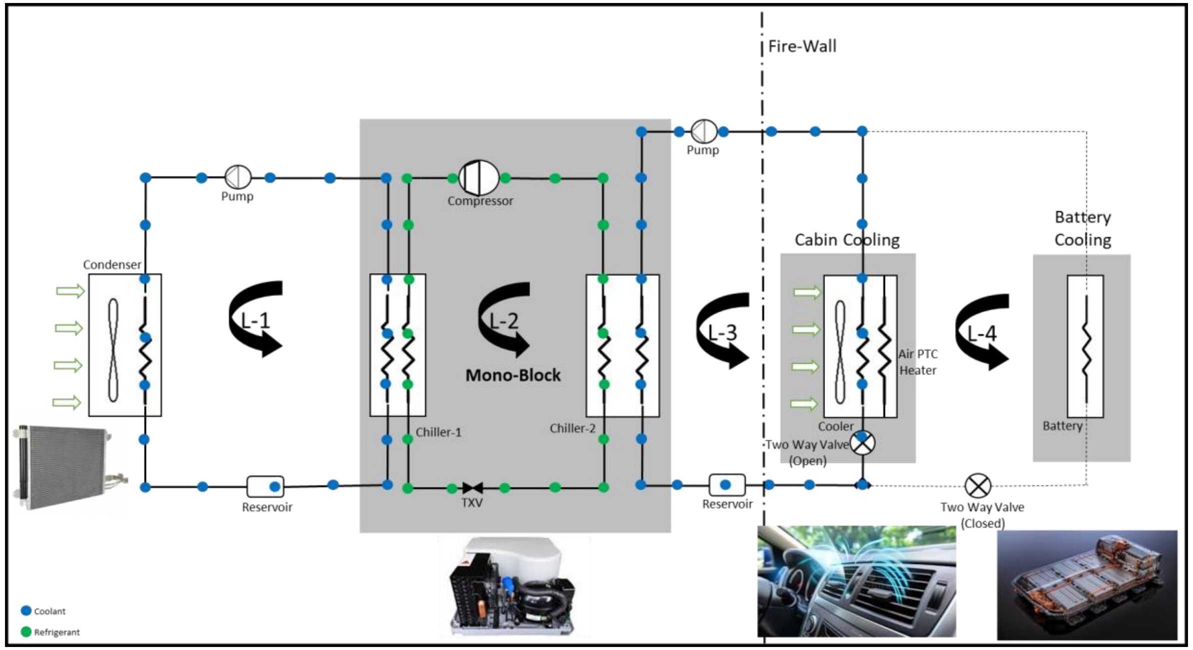
Cooling and heating performance trials are performed at moderate and severe ambient conditions ranging from -25C to 55C and matching solar load. The vehicle under test is subjected to a recipe of city and highway cycles. Cool down, heat up, thermal comfort and vehicle interior air quality is captured at multiple locations using thermocouples, mannequins and real world humans

Proof of Concept Demonstrators

Nexon EV

Ace EV

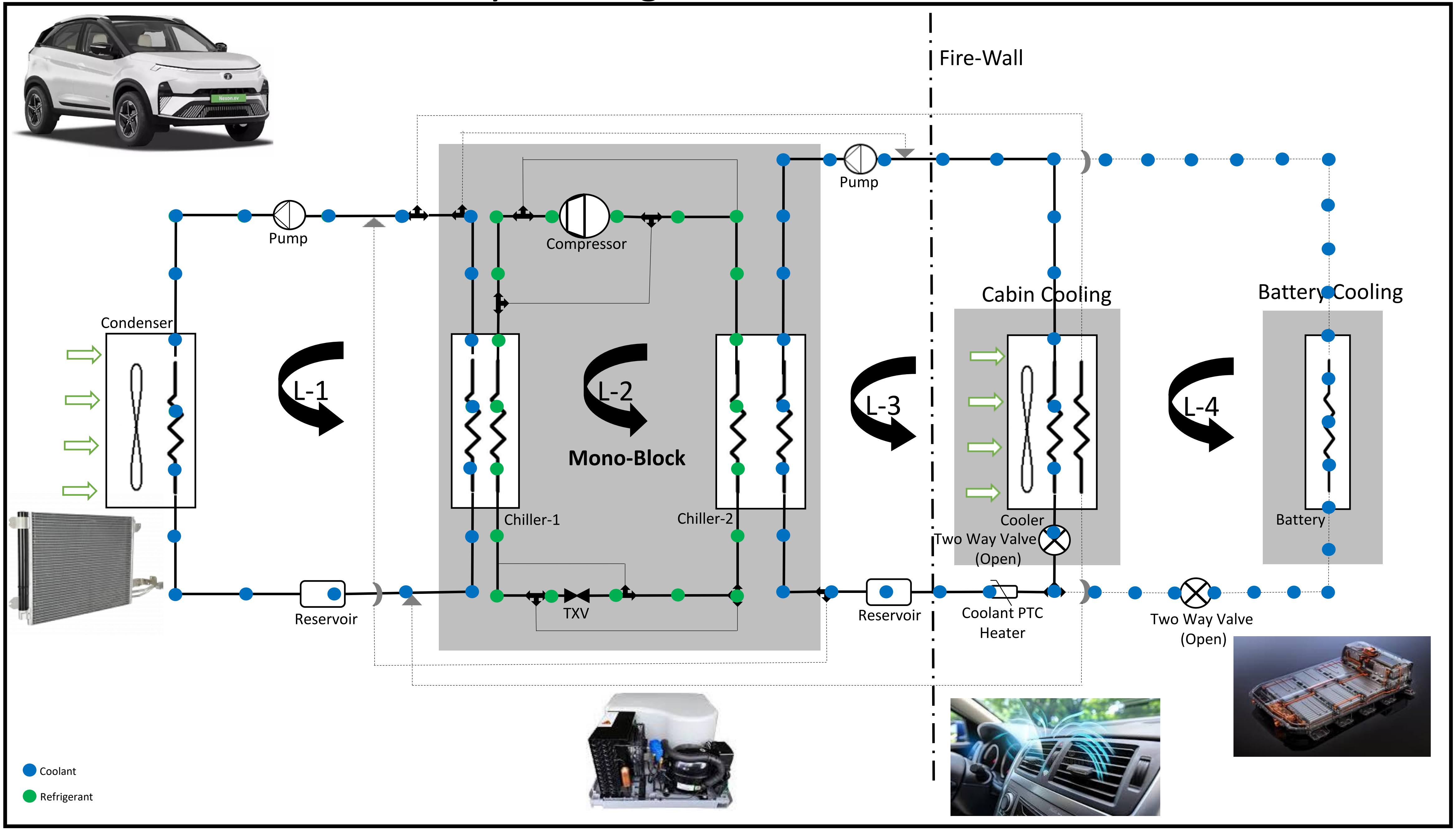




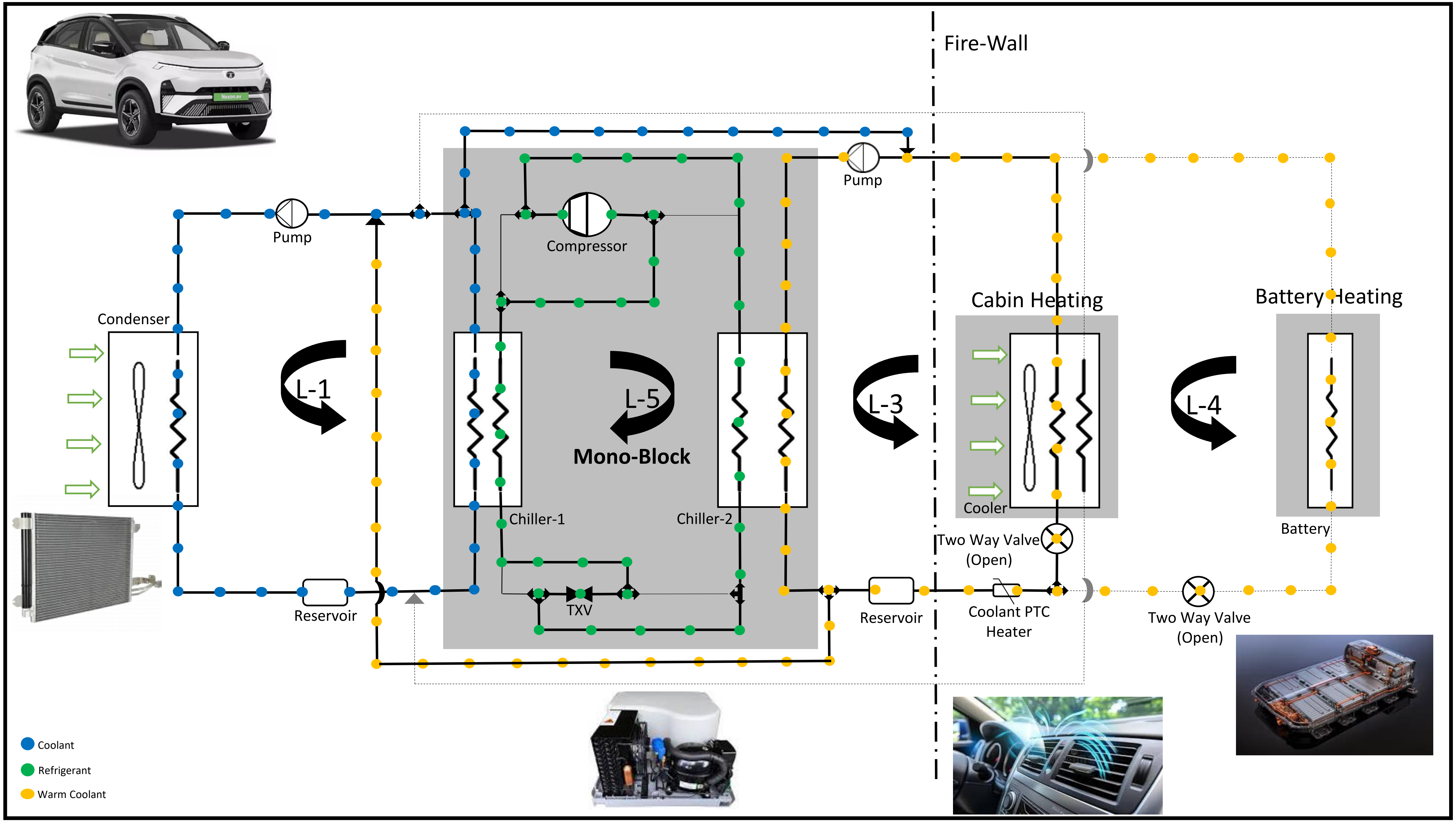
Schematics

Schematics

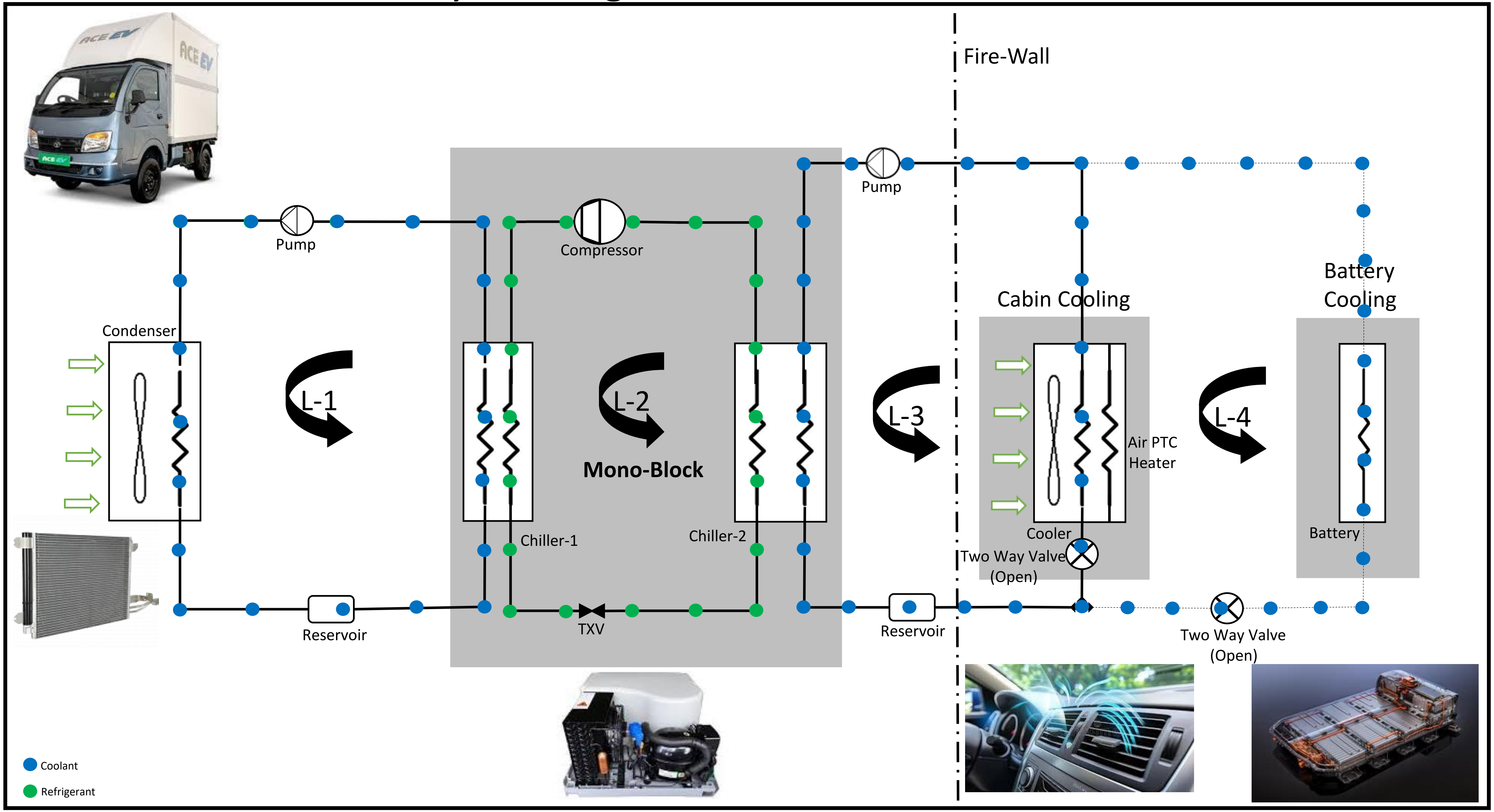
Nexon EV: Cabin + Battery Cooling



Nexon EV: Cabin + Battery Heating



Ace EV: Cabin + Battery Cooling



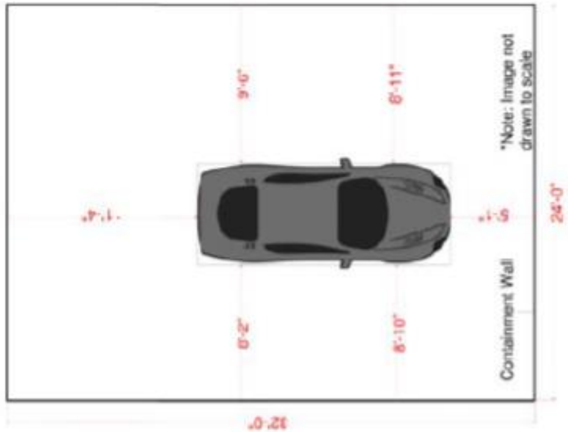
R-290 Use Cases and Potential Risk of Thermal Incidence

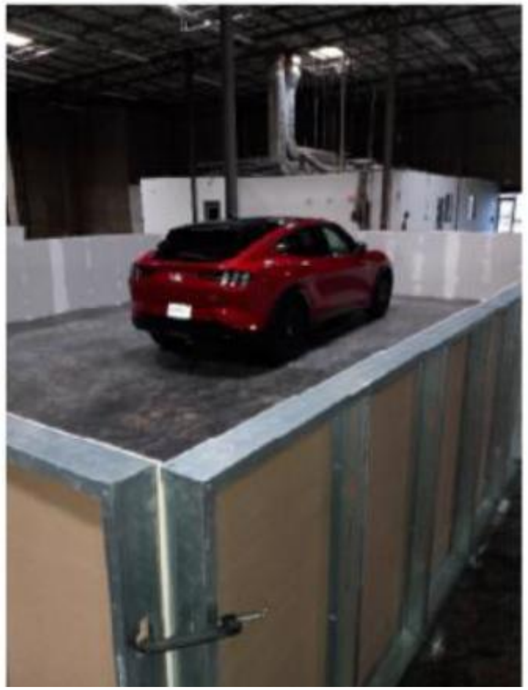
Sr. No.	Risk Scenarios	Potential Causes
1	Normal Use	Fast leak - damaged seals, charge port valves, pipe fatigue failure, rupture of rubber hoses due to high pressure • Sparks from relays, fuse, switches, static electricity, wiring components, other electronic devices & gadgets • Battery cell overheating • Overheating of AC compressor
2	Crash Events	A crash could lead to a sudden release of propane from HVAC aggregates, exposing to heat or electrical sparks • Frontal crash • Side impact crash • Vehicle rollover
3	Vehicle Parked (Garage or Outside)	Fast leak - damaged seals, charge port valves, pipe fatigue failure, rupture of rubber hoses due to high pressure • Lighting firecrackers near the vehicle during festival seasons and other celebrations • A person is smoking a cigarette near the vehicle and throws it close to the vehicle • Electrical short circuit/ fire incident in the vehicle parking area
4	Vehicle Parked (HV Fast Charging)	• Battery Control System (BCS) failure during extreme temperatures, overheating, internal short circuits • AC pre-cooling stage - refrigerant leakage due to high pressures due to failure of cooling module or other faults in the AC system
5	After Sales Service	• Incorrect procedures/ poor ventilation during venting out the gas, refrigerant charging • Improper R290 cylinder storage and handling could cause propane to accumulate and ignite • AC maintenance/ repair near hot work areas ignition sources including static sparks, water heaters and small electrical devices such as an electric drill or the like • Unauthorized modifications or retrofit systems

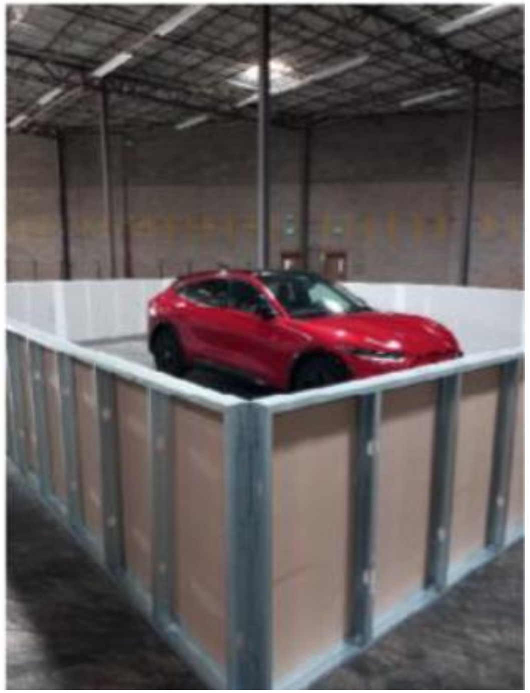
Note: These are only some real world conditions, additional potentially hazardous conditions continue to be identified

SAE Thermal Management CRP: Concentration Testing

- Testing conducted with R-290
- 28 sensors were placed around the vehicle
- 19 test scenarios from calm to windy
- Hood seal intact and removed
- Hood down and up (buckled)
- Recirc on and off
- 600-gram releases – severed line
- The report is under preparation







Source: SAE International Team Entropy Report

TATA Motors 2025 R-290 Demonstration Project

Milestone	Activity	Start Date	End Date
1	Project Definition, Scope including Success Criteria, Budgeting, Kick off Concept Selection and Technology Integration	Dec-2024	May-2025
2	Final Data Judgement, Proto Development, Component and Vehicle Level Thermal Validation and Optimization	Jun-2025	May-2026
3	Vehicle Level Crash Safety Assessments, IPR	Dec-2025	May-2026
4	Concluding Outcome, Final Report Preparation and Release	Mar-2026	Aug-2026
5	Publications, Guidelines and Standards Development, Special Mention and Acknowledgement	Jun-2026	Nov-2026

R-290 Standards Development – A Roadmap at SAE International

- General Approach
  - Goal: Standards are performance and metric based with minimum prescriptive requirements to allow innovation
  - SAE J639 is the umbrella MAC Design for Safety standard; will reference R290 standards
  - Multiple new and revised standards specific to R290 in work (see list)

- All New R290 Standards
  - J3343 – Vehicle level safety at full system level
  - J3342 – Module or Monoblock safety for unit with refrigerant charge
  - Target complete date: December 2025
  - SAE standards inform the US EPA regulatory effort under the SNAP program

SAE INTERNATIONAL

SURFACE VEHICLE STANDARD	J639™	NOV2020
	Issued 1953-04 Revised 2020-11 Superseding J639 DEC2011	

(R) Safety and Design Standards for
Motor Vehicle Refrigerant Vapor Compression Systems

SAE Interior Climate Control Committee J-Standards Needed for R290

CLEAR FILTERS to include Low Priority items

Committee	Task Force Lead	Standard	Priority	Name
OEM Committee Chair: Aamir Khawaja Vice-Chair: David Cosgrove	Chair: Martin Mann Vice Chair: Jing He	J3343	**HIGH**	Safety and Design Standards for Motor Vehicle Thermal Systems using A3 Refrigerants
	Tim Craig: current updates Martin Mann: R290 Update	J639	**MED-HIGH**	Safety and Design Standards for Motor Vehicle Refrigerant Vapor Compression Systems
Supplier Committee Chair: Yevgeniy Beygel VIce-Chair: Rachel Dill	Chair: Rachel Dill	J3324	**HIGH**	Design Standards for Motor Vehicle Refrigerant Vaopor Compression and Expnansion Systems Access Port Assemblies and Interfaces
	Chair: Takayuki Watanabe (Nabe) Vice Chair: Dana Nicgorski	J3342	**HIGH**	Safety and Design Requirements for A3 Refrigerant Thermal Management Modules
Fluids Committee Chair: Angelo Patti	Chris Seeton	New	**HIGH**	R290 Purity Spec
Service Committee Chair: Mark McMasters Vice-Chair: Steve Schaeber	TBD	J2845	**HIGH**	Technician Training for Service an Containment of Refrigerants used in Mobile AC systems
	TBD	J2851	**MED-HIGH**	Recovery Equipment for Contaminated R134a or R1234yf
	TBD	New	**MED-HIGH**	Similar to J2913 R290 Refrigerant Electronic Leak Detectors, minimum performance Criteria

Matrix of R290 Related SAE Standards

Source: SAE ICCC

Potential Challenges in Servicing R-290

- Regardless of refrigerant, **professional service is required** for reliability, energy efficiency, and environment (the unorganized service sector is a challenge even today)
- R-290 has the **challenge of high flammability** and local air pollution from VOC characteristics
- A: Only allow **service as a Monoblock**, remove and return defective Monoblock for repair
- B: Allow only very **minor refrigerant system service** such as seal replacement (O-ring) but not HX or compressor
- C: Define **full scope** of allowable service **in detail**
- KEY: New **technician certification** necessary
- The challenge is to **embrace service discipline** for safety and environment to contain, recover, and recycle or destroy a gas that has very low price and is inconspicuous when intentionally vented
- Any accidents with flammable refrigerants in stationary or mobile applications will **risk public rejection of the technology** desperately needed to avoid irreversible climate tipping points
- Small charge and near-zero leaks can only be achieved by engineering, secondary-loop, and quality control

Take-home Message, Way Forward

- Low GWP and **flammable refrigerants** like R-290 are **low cost and easily available**, hence can be considered as alternates to currently used R-134a, by mitigating the flammability risk **thru architectural changes in EV's**
- Along with the primary concern of safety, discussions on **energy efficiency**, availability of **standards**, training of **service professionals** are equally important in developing a **robust business case**
- Investments in technical know how will have to be made in R&D, this **will require funding for research**. A good example of this is the UNIDO-CCAC-TATA Motors 2025 **R-290 Demonstration Project** – the outcomes of which will benefit OEM's, AC system vendors, refrigerant manufacturers and other stakeholders on safe use of R290 in their respective product portfolios
- **Government support** in the form of **permitting** safe use of **flammable refrigerants**, **subsides** on equipment, carbon credits can provide a thrust to the **faster adoption** of low GWP refrigerants like R-290

- In the interim, **HFO 1234yf based MAC Systems** made available 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 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**. **Patent** related concerns can contribute to the **slower transition** to climate friendly refrigerant alternatives like HFO 1234yf

- There is an urgent need to enhance **collaborative efforts by all stakeholders** including policy makers, regulatory authorities, OEM's, refrigerant and HVAC system manufacturers, training establishments, for ensuring a **smooth phasing** down of HFC's as per committed milestones, thereby achieving a much-needed **sustainable industrial transformation**

“Assessing the Use of R-290 in MAC Sector”

End of Report

Thank You for your Time and Attention

Am happy to take Questions …

Images: Internet

Back Up

R-290

Why R – 290 (Propane)

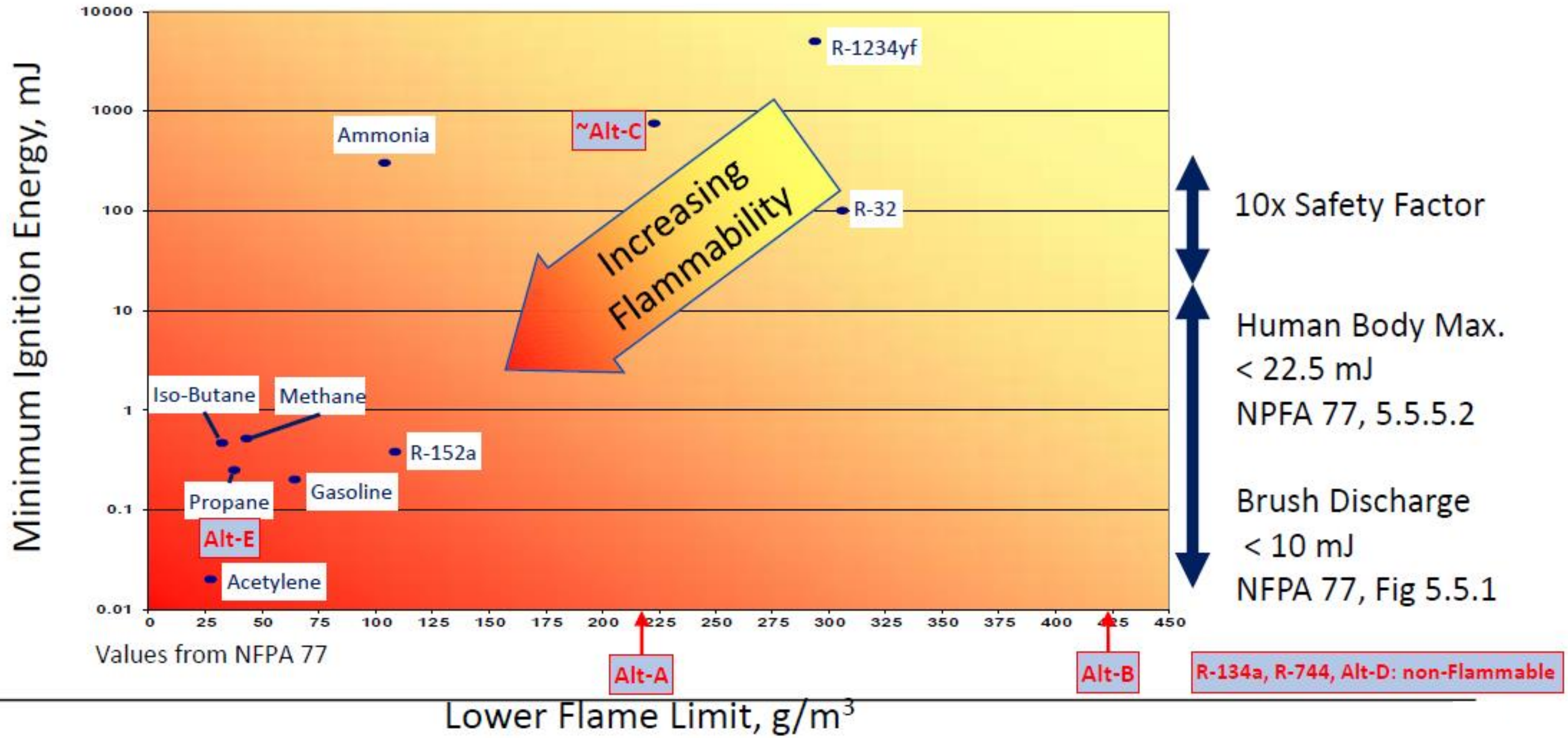
R290 outperforms **R1234yf** and **R134a** in terms of **latent heat**, **enthalpy of vaporization**, and **thermal conductivity**, leading to better energy efficiency
R290 is highly flammable, **R1234yf** has low flammability, while **R134a** is nonflammable
R290 is a new entrant and currently being investigated in North America, Europe and India
R1234yf is used by every major original equipment manufacturer in North America and Europe from 2020 onwards

Property	R290 (Propane)	R1234yf	R134a
Molecular Weight	44.1 g/mol	114.04 g/mol	102.03 g/mol
Boiling Point (at 1 atm)	42.1°C	29.5°C	26.3°C
Critical Temperature	96.7°C	93.3°C	101.1°C
Critical Pressure	42.5 bar	33.4 bar	40.6 bar
Density (at 0°C and 1 atm)	0.493 kg/m^3	0.273 kg/m^3	0.397 kg/m^3
Enthalpy of Vaporization	**356 kJ/kg**	245 kJ/kg	246 kJ/kg
Specific Heat Capacity (Liquid, at 25°C)	2.44 kJ/kg·K	1.52 kJ/kg·K	1.47 kJ/kg·K
Thermal Conductivity	**0.12 W/m·K**	0.097 W/m·K	0.078 W/m·K
Latent Heat of Vaporization	**384 kJ/kg**	217 kJ/kg	247 kJ/kg
Flammability	**Highly flammable (A3)**	Low flammability (2L)	Nonflammable (A1)

Alternative Comparison - Flammability

Flammability is evaluated by ‘Chance of Flame occurring’ and ‘Impact of Flame’

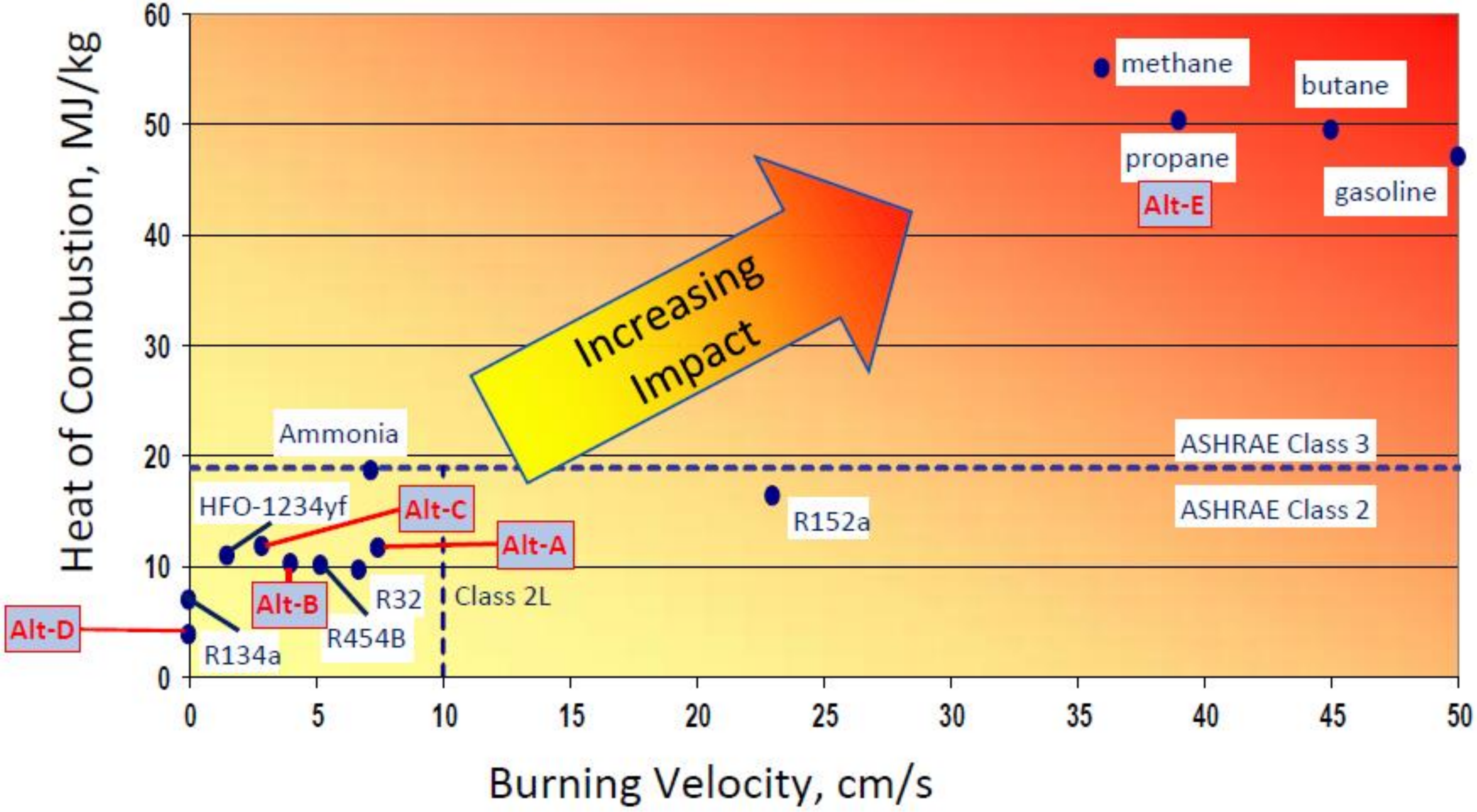
- The chance of flame occurring is dependent on: Lower Flame Limit, Minimum Ignition Energy



Alternative Comparison - Flammability

Flammability is evaluated by 'Chance of Flame occurring' and 'Impact of Flame'

- Impact of Flame is dependent on: Burning Velocity, Heat of Combustion

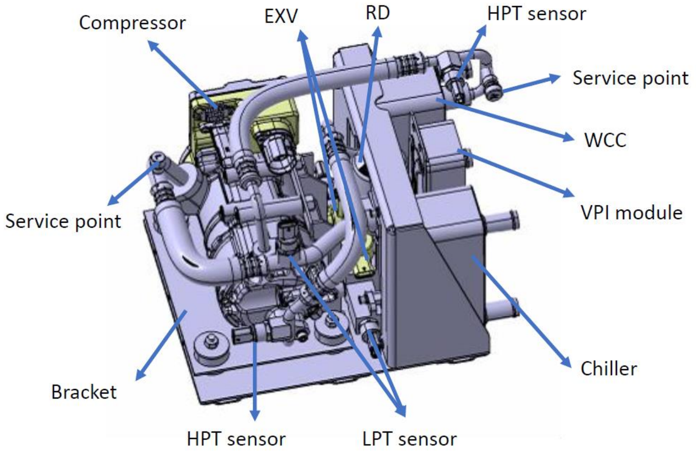


TATA Motors 2025 R-290 Demonstration Project

TATA Motors 2025 R-290 Demonstration Project

1. **Compressor Selection**
    - **Low Oil Content Compressors**:
        - Compressors with **reduced oil volume** are preferred.
        - Reason: Oil dissolves refrigerant; higher oil volume leads to higher effective refrigerant charge.
        - Example: Configuration RC821 used a **horizontal scroll compressor with low oil content**, achieving better performance with reduced charge.
2. **Heat Exchanger Design**
    - **Smaller Internal Volume**:
        - Plate heat exchangers (PHEs) with fewer plates and **lower refrigerant side volume** reduce total charge.
        - Charge reduction is directly correlated with minimized internal volume.
3. **Symmetric vs Asymmetric PHEs**:
    - Though **asymmetric** designs are common for charge reduction, this study found that:
        - Asymmetric PHEs caused **flow maldistribution** and **vapor quality imbalance**.
        - This **increased required charge** due to inefficiencies.
    - Thus, the authors recommend careful evaluation or **avoiding asymmetric PHEs** in low charge R290 designs.
4. **Oil Sump and Compressor Design**
    - **Oil Sump Location**:
        - The **location of the oil sump** inside the compressor affects how much refrigerant gets absorbed.
        - Placing it in low pressure regions leads to **more refrigerant dissolution** in oil.
        - Design should **minimize refrigerant oil interaction** to reduce required charge.
5. **Overall System Layout**
    - **Compact Component Arrangement**:
        - Shorter pipes and compact layout **reduce system volume**, minimizing refrigerant charge.
        - This also reduces pressure drop and improves COP.

Compact Monoblock Unit

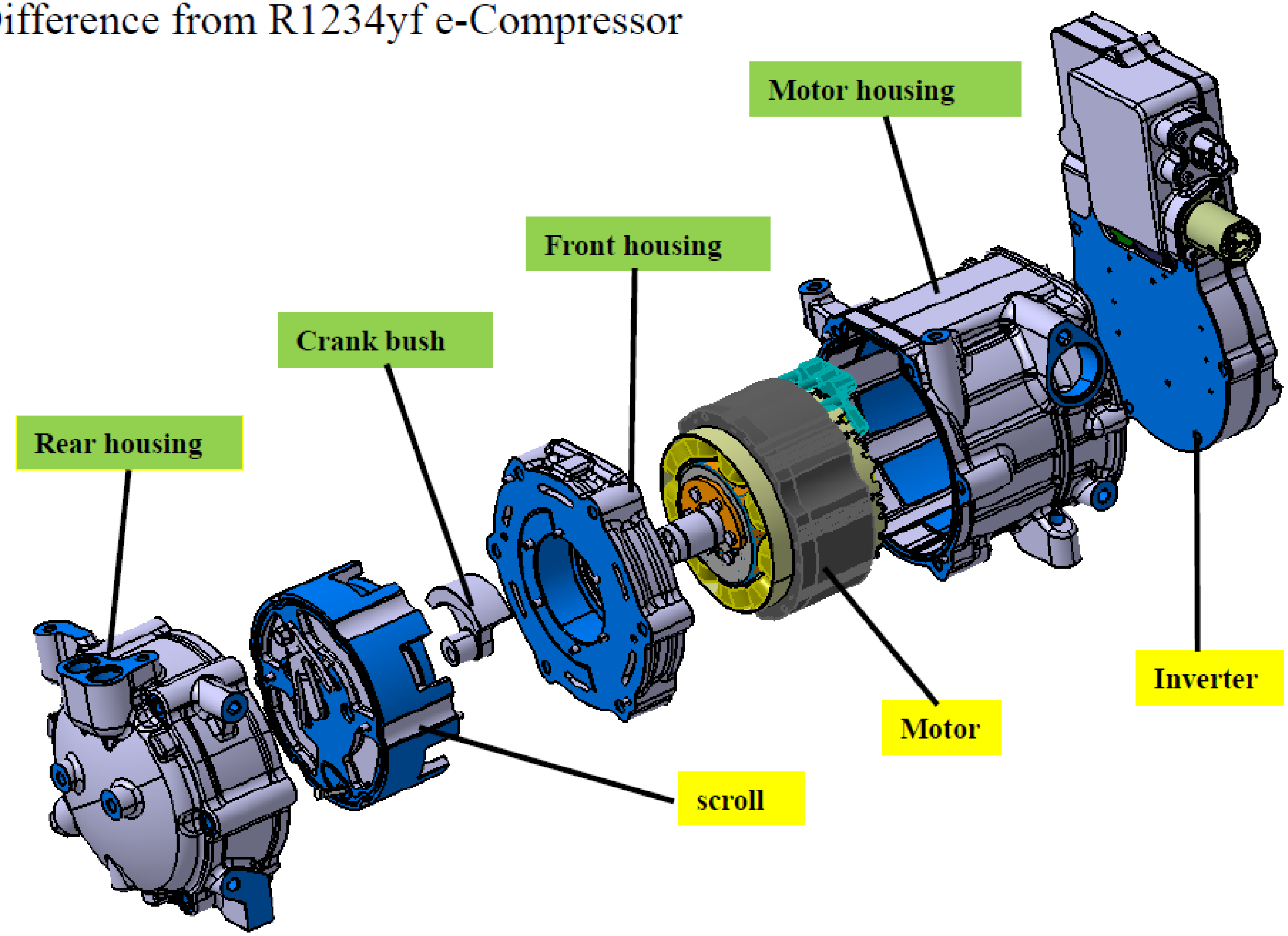


Source: Component Selection & Modifications for R290 (as per Schnabel et al., 2023)

TATA Motors 2025 R-290 Demonstration Project

e-Compressor Design for R290

Difference from R1234yf e-Compressor



Shared parts with R1234yf

Unique for R290

1.Scroll

◆ Improved robustness

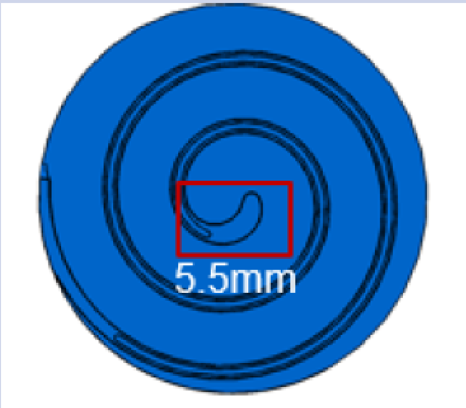
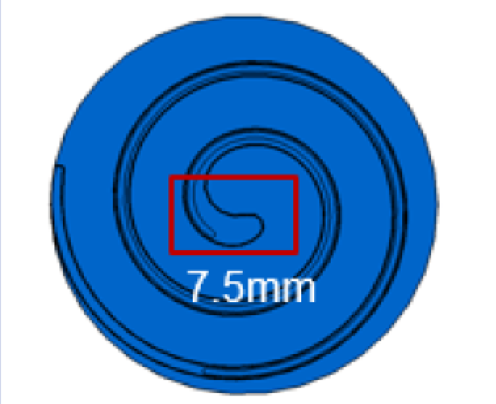
2.Motor

◆ Higher torque & power

3.Inverter

◆ Higher power

TATA Motors 2025 R-290 Demonstration Project

	R1234yf /R134a		**R290**	
Scroll Profile				
Displacement	34cc	45cc	34cc	45cc
Scroll thickness	3.6mm	5.5mm	4.3mm	7.5mm
Motor Max Power (kw)@650V	6.5	13	10	13
Motor Max Torque (N.m)	7.1	10.5	11	13.5
Motor Speed (rpm)	800-8500	800-12000	800-8500	800-8500
Motor Stator(mm)	Φ94X37	Φ112X45	Φ94X51.5	Φ112X45
Motor Rotor Magnet	N42SH	N42SH	N42SH	N48SH
Oil	POE/PVE	POE/PVE	POE/PAG	POE/PAG
Suction/Discharge Seal	Single seal	Single seal	Double seal	Double seal

Mitigating the Flammability Risk

- **Leak Detectors**
  - Monitor for refrigerant leaks in critical areas.
  - Triggers system shutdown in case of leak detection.
- **Ventilation or Containment Systems**
  - In EVs or enclosed systems, special design features vent or isolate leaks safely.
- **Secondary Loop Architecture**
  - Keeps R290 in a sealed loop outside the passenger cabin.
  - Uses a separate loop (with water glycol or CO_2) to transfer cooling inside.
- **Explosion Proof Electrical Components**
  - Fans, relays, and switches are designed to prevent ignition.
- **Explosion Proof Enclosure:**
  - Designed to withstand **internal explosions** and prevent the escape of gases or flames.
  - Typically made from **steel or aluminum** with sealed joints to contain any potential sparks or flames.
  - **IP rated** for dust and water ingress, commonly rated as **IP65** or higher.

- **Leak Prevention & Detection:**
  - The refrigerant circuit must have **enhanced sealing technology** to minimize leakage risk.
  - A **leak detection system** should be integrated to alert users and prevent unsafe accumulation of R290.
  - **Automatic shut-off valves** should be installed to contain refrigerant in case of a leak.
- **Ventilation & Safety Design:**
  - The HVAC system should have **adequate ventilation mechanisms** to prevent R290 build up inside the vehicle.
  - Electrical components near refrigerant lines must be **spark-free** and comply with **relevant standards** for explosive atmospheres.
- **Fire and Explosion Prevention:**
  - The system must adhere to SAE J639, and IEC 60335-2-40 safety standards for flammable refrigerants.
  - A risk assessment (HAZOP/FMEA) should confirm the HVAC system meets the required flammability safety margin.

Source: UNIDO - CCAC - TML Milestone 1 Report

R-290 Leak Detection Sensors

Semiconductor (MOS)

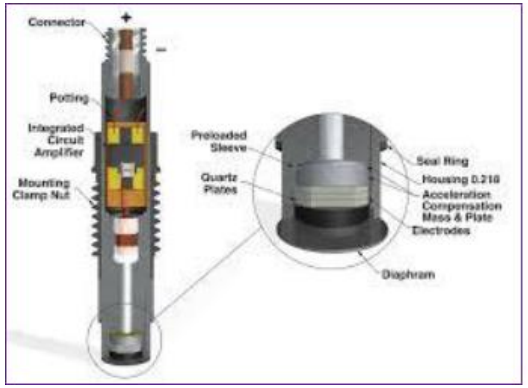
Infrared (NDIR) Sensors

Photoionization Detectors (PIDs)

Catalytic Bead Sensors

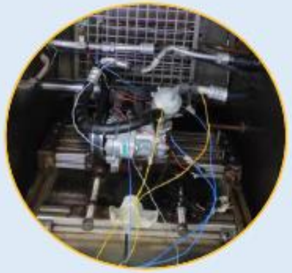
OEM Photoionization Sensor (PID Sensor) - 2 ppm - PID-2

R-290 Piezo Electric Pressure Sensor



Validation Matrix and Timeline: For Changing Refrigerant

Component level performance and durability tests



Compressor test bench

Condenser test bench

HVAC unit test bench

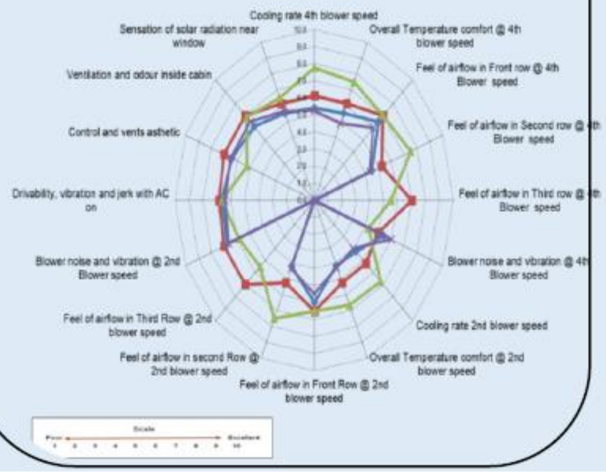
Pipes and hoses tests

System level performance tests on bench

Test in Full Vehicle Environment Test Facility

Durability tests and road trials

Subjective thermal comfort trials



Lead Program once identified ~ 6 to 9 months depending on complexity, carry over content, new component development

TATA Motors 2025 R-290 Demonstration Project

Outcomes

- Developing design specifications for R-290 systems and key components for building the demonstration vehicle
- Prototyping two demonstrator vehicles, a passenger vehicle with Air-Conditioning and Heat Pump (AC-HP) architecture and a small commercial vehicle with Secondary Loop (SL-MAC) architecture
- Validate cooling, heating, energy efficiency vs the success criteria and identify performance gaps if any, make system modifications to close the performance gaps
- Development of guidelines for standard operating procedures on safe use of HC-290 in MAC application for vehicles operating in typical Indian ambient conditions for industrial level

Benefits

- This project supports the Kigali Amendment to the Montreal Protocol by identifying a suitable alternate, non-HFC, low GWP refrigerant that can safely be used in the vehicle sector
- It will demonstrate how R290 refrigerant can be used in two types of air conditioning architectures for providing year around comfort and optimum battery performance, under Indian climatic conditions
- The lessons learnt, guidelines and key takeaways from this study will benefit OEM’s, AC system vendors, refrigerant manufacturers and other stakeholders on safe use of R290 in their respective product portfolios
- It will expose the stakeholders of the auto industry to evaluate the pros and cons on use of non-HFC refrigerants and compatible technologies in the vehicle sector (particularly e-compressors, advanced heat exchangers, sensors, valves)
- These learnings can possible also benefit other sectors such as room and building air conditioning.

SL-MAC

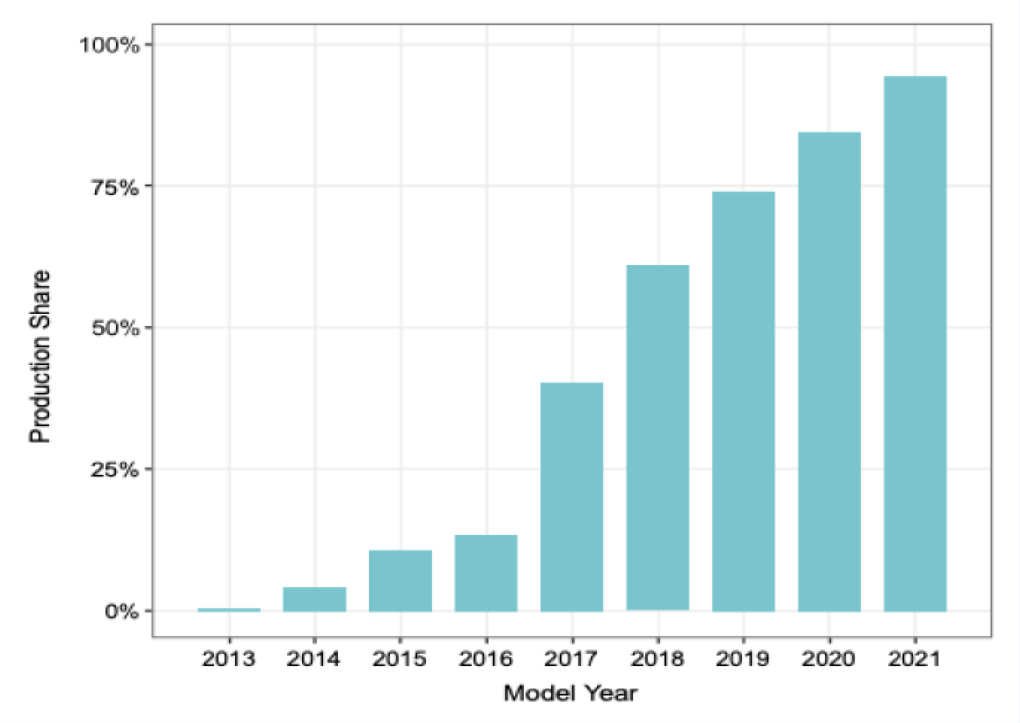
Key Takeaways from MAC Secondary Loop Success

- 90% of Secondary Loop components are base content in EVs
- Other Benefits
- Measurable but not noticeable lag in vehicle cooling, from hot soak
- Faster cooling and heating comfort after short stop
- Prolonged idle-stop with cooling and heating comfort
- No loss of cooling and heating during heavy traction loads with compressor off
- Priority cooling and heating dispatch to battery, inverter, and cabin
- Integrated with regenerative braking when battery is fully charged
- Low cost of cooling/heating points for precise satisfaction of demands
- Super-cooled or super-heated secondary fluid as thermal ballast with outlet temperature automatically controlled by fan speed and vents
- Strategic use of thermal storage to increase efficiency

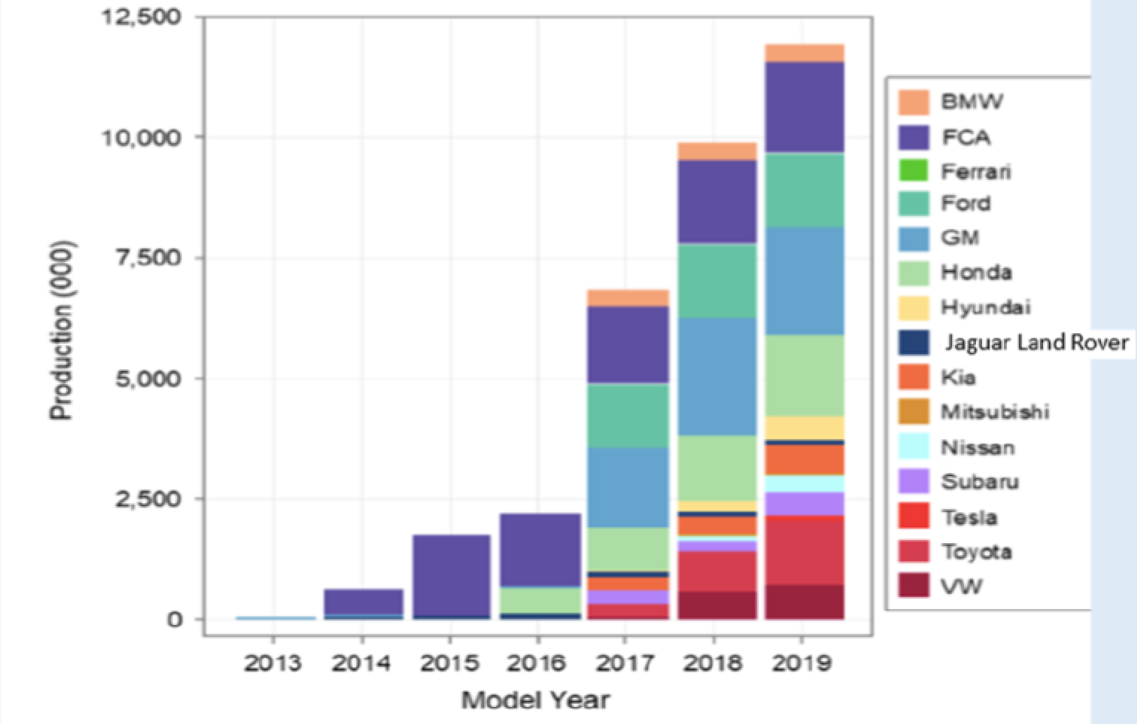
HFO 1234yf

Status of HFC134a Replacement for Sales in Non Article 5 Markets

HFO-1234yf Adoption by Manufacturer



HFO-1234yf Adoption by Manufacturer

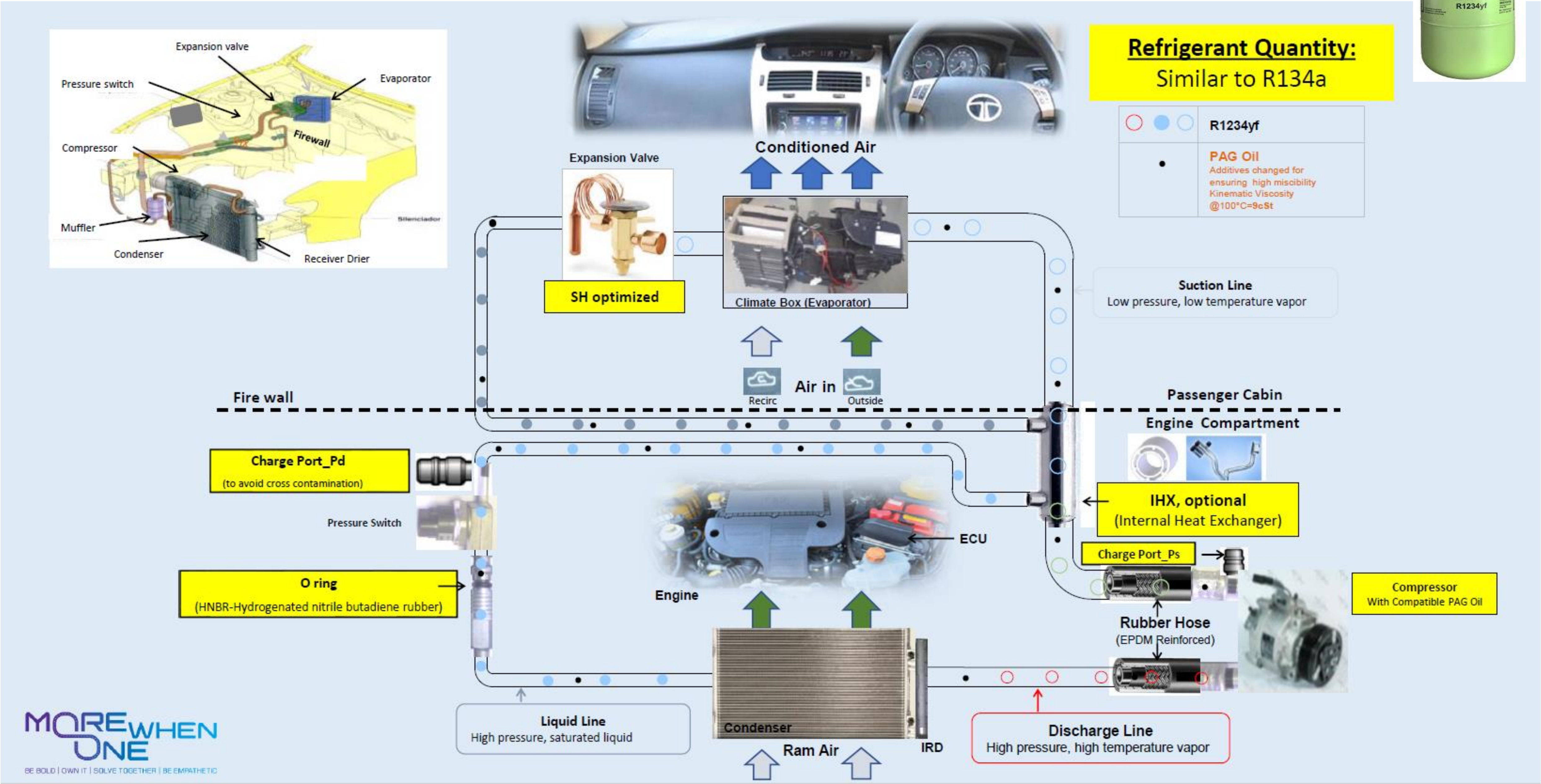


- ✓ Every major manufacturer that sells cars in North America and Europe had switched production to HFO-1234yf (source: EPA Automotive Trends Report, 2020)
- ✓ As of the end of 2021, approximately *150 million* vehicles have been sold worldwide that use HFO-1234yf.
- ✓ As of the end of 2021, US production of vehicles using HFO-1234yf was approaching 100%

MORE WHEN ONE

Source: http://www.igsd.org/wp-content/uploads/2021/12/Global-Number-of-Vehicles-Using-HFO-1234yf.pdf

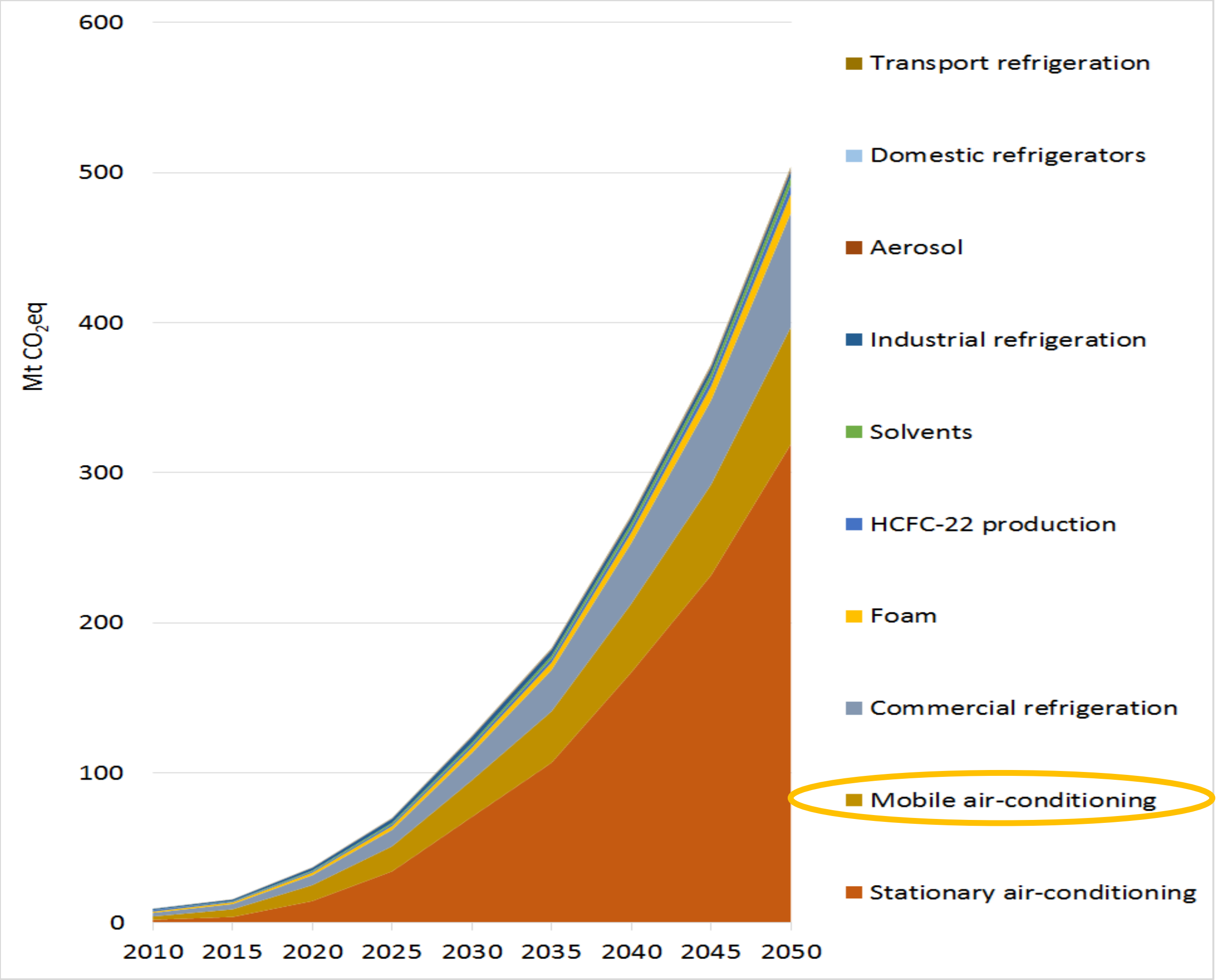
HFO1234yf: Gap Analysis as a 'Drop In' in a DX System



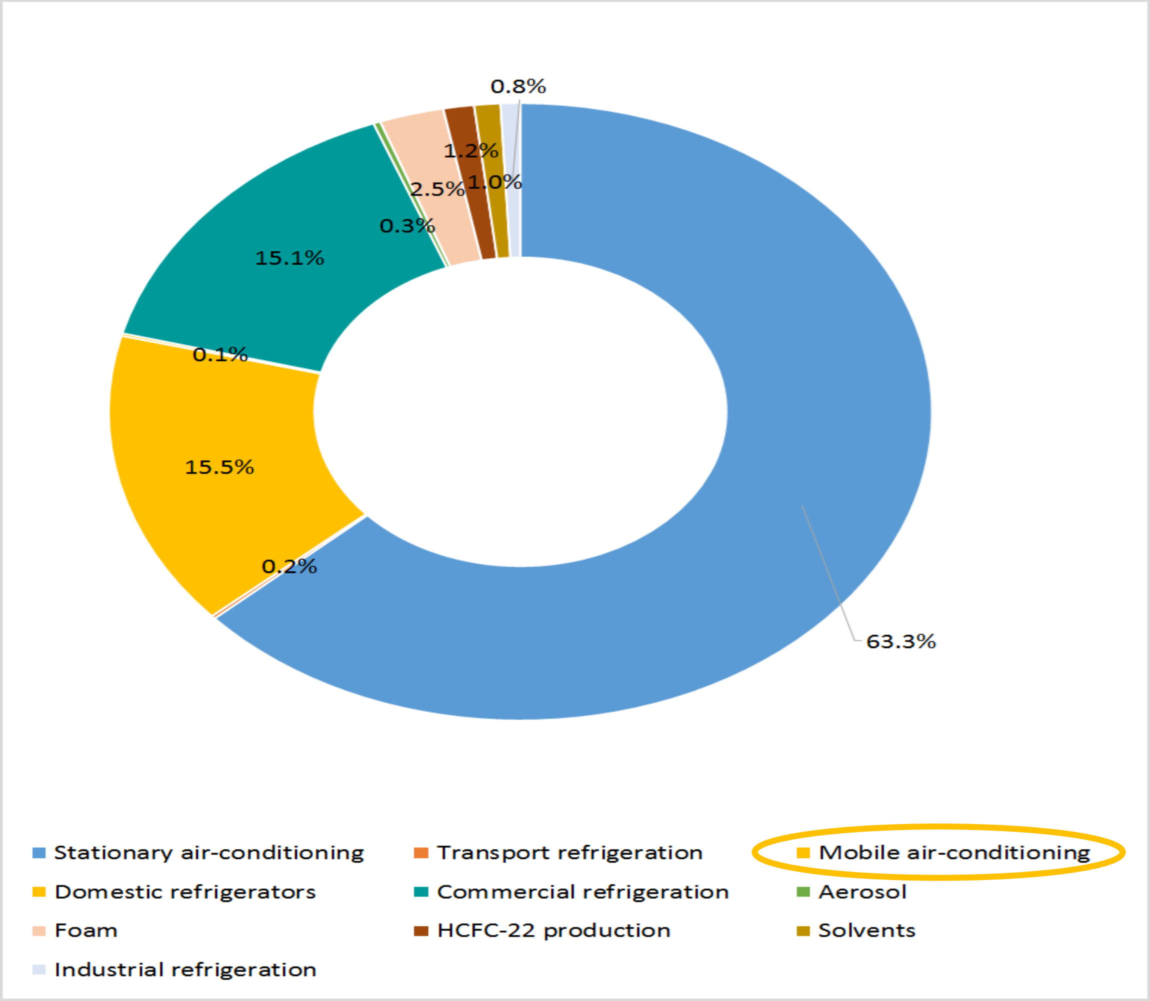
India – Sectorial Emissions

India Sectoral HFC Emissions 2010–2050

Sectoral development of HFC emissions



HFC emissions in 2050 by sector



An initiative supported by

Source: Purohit, Höglund-Isaksson, et al. 2016