Global Number of Vehicles Using HFO-1234yf Refrigerant

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Executive Summary

This paper quantifies the number of vehicles utilizing HFO-1234yf (R1234yf) mobile air conditioning (MAC) systems throughout the world as of the end of 2022. HFO-1234yf is a low global-warming-potential (GWP) alternative to HFC-134a. HFO-1234yf has a GWP of less than 1. Using vehicle sales and other industry data, this ground-up analysis reveals that close to 200 million vehicles using HFO-1234yf had been sold by the end of 2022. This includes 171 to 180 million in the United States (U.S.) and Europe alone, with additional sales elsewhere throughout the world. Evidence to date demonstrates that automobile manufacturers have mostly continued to use HFC-134a in markets where GWP<150 is not required or incentivized.[1] Despite the gradual transition to HFO-1234yf in places like Europe and North America that require or incentivize refrigerants with GWP<150, most of the world's new vehicles continued to use HFC-134a as of the end of 2022. This is due to ongoing sales of vehicles that use HFC-134a in China and other less-developed countries, including by U.S., European and Asian automobile manufacturers that have already transitioned to low-GWP alternatives for other markets.

Europe: over 100 million vehicles use HFO-1234yf

From 2013-2018, approximately 83 million new passenger vehicles were registered in the European Union (EU).[2] From 2019 to September 2021, an additional 33,471,457 passenger cars and light commercial vehicles were registered in the EU, bringing the total vehicles registered to 112,142,367. Most, but not all, vehicles registered in the EU in this time period used HFO-1234yf. Some Daimler vehicles sold from 2013-2014 for instance used R744.

Directive 2006/40/EC relating to emissions from air conditioning systems in motor vehicles (EU MAC Directive),[3] required vehicles to use a refrigerant with a 100-year GWP <150. It applied to new "type" vehicles at first. After a series of revisions and delays, the law required all vehicles to comply by 1 January 2017:[4]

> *The Directive is being gradually enforced over three phases:*
>
> *Phase 1: From 21 June 2008, car manufacturers have not been able to obtain a type approval for a new type of vehicle if fitted with MACs: containing gases with a GWP higher than 150; leaking more than 40 grams of the refrigerant per year (one evaporator system)**;** or leaking 60 grams of the refrigerant per year (dual evaporator systems).*
> *As of 21 June 2009, this has applied to all new vehicles on the EU market.*

Phase 2: *From 1 January 2011* (delayed to 1 January 2013 due to supply chain issues)[5] *air conditioning systems in new vehicle types must be filled with a refrigerant that has a low impact on the climate. This means that fluorinated greenhouse gases with a GWP of higher than 150 can no longer be used in the MAC systems of newly type-approved vehicles.*

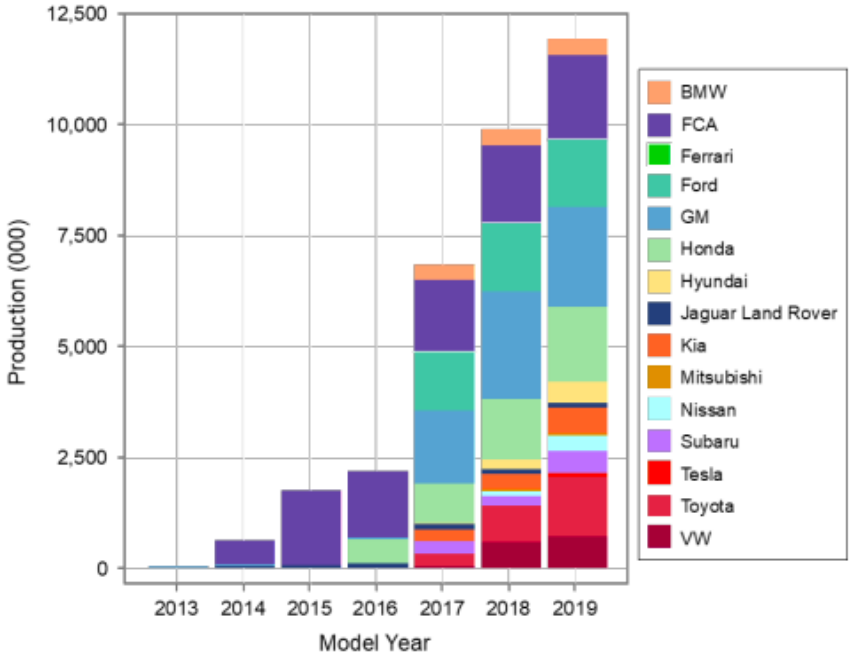
Phase 3: *From 1 January 2017, the use of fluorinated greenhouse gases with a GWP higher than 150 in all new vehicles put on the EU market will be totally banned. New vehicles with MAC systems using these gases will not be registered, sold, or able to enter into service in the EU.*

Assuming all vehicles registered in the European Union complied with the EU MAC Directive as of 1 January 2017, then by the end of 2018, the EU had at least 30,295,464 vehicles on the road using HFO-1234yf (this number includes only newly registered EU vehicles from 2017 to 2018). The actual number of HFO-1234yf vehicles on the road in the EU by the end of 2018 was likely between 48 and 57 million. The EU type approval process is fairly detailed.[6] If half of new vehicles registered in the EU between 2013-2016 used HFO-1234yf, and virtually all vehicles used HFO-1234yf in 2017-2018, the EU will have nearly 57 million HFO-1234yf vehicles on the road by the end of 2018. If one third of new vehicles registered in the EU between 2013-2016 used HFO-1234yf, the total number of HFO-1234yf vehicles in the EU by the end of 2018 is closer to 48 million.[7] Given the uncertainty around the exact number of new type vehicles sold in the EU between the years 2013-2016, an estimate of 48 million is reasonable: approximately 18 million between 2013-2016 (representing approximately a third of new registrations) and 30 million between 2017-2018 (representing virtually all vehicles sold and registered in the EU during those years). According to the European Automobile Manufacturers' Association (ACEA), from 2019 through the end of 2022, approximately 53 million more vehicles were registered in the European Union. Assuming 99% of them used HFO-1234yf, that added another 52.5 million HFO-1234yf vehicles in service.[8] Thus, as of the end of 2022, the total number of vehicles in Europe equipped with HFO-1234yf MAC is estimated to be between 100.5 and 109 million.

United States: approximately 70 million vehicles use HFO-1234yf

Research on model introductions indicates that there has been a standard S-curve adoption, starting off slowly with in model year 2013 (with the first vehicles sold in 2012), and accelerating after the EU MAC Directive entered into full effect 1 January 2017 for all EU models. The 2020 EPA Automotive Trends Report includes a graph and a table on manufacturer adoption of HFO-1234yf in vehicles sold in the USA (see also figures 1 and 2 below).[9] These figures indicate there were 33,304,675 cumulative sales of vehicles using HFO-1234yf through model year 2019.

Figure 1. HFO-1234yf Adoption by Model Year



Source: U.S. Environmental Protection Agency (2021) Figure 5.8.

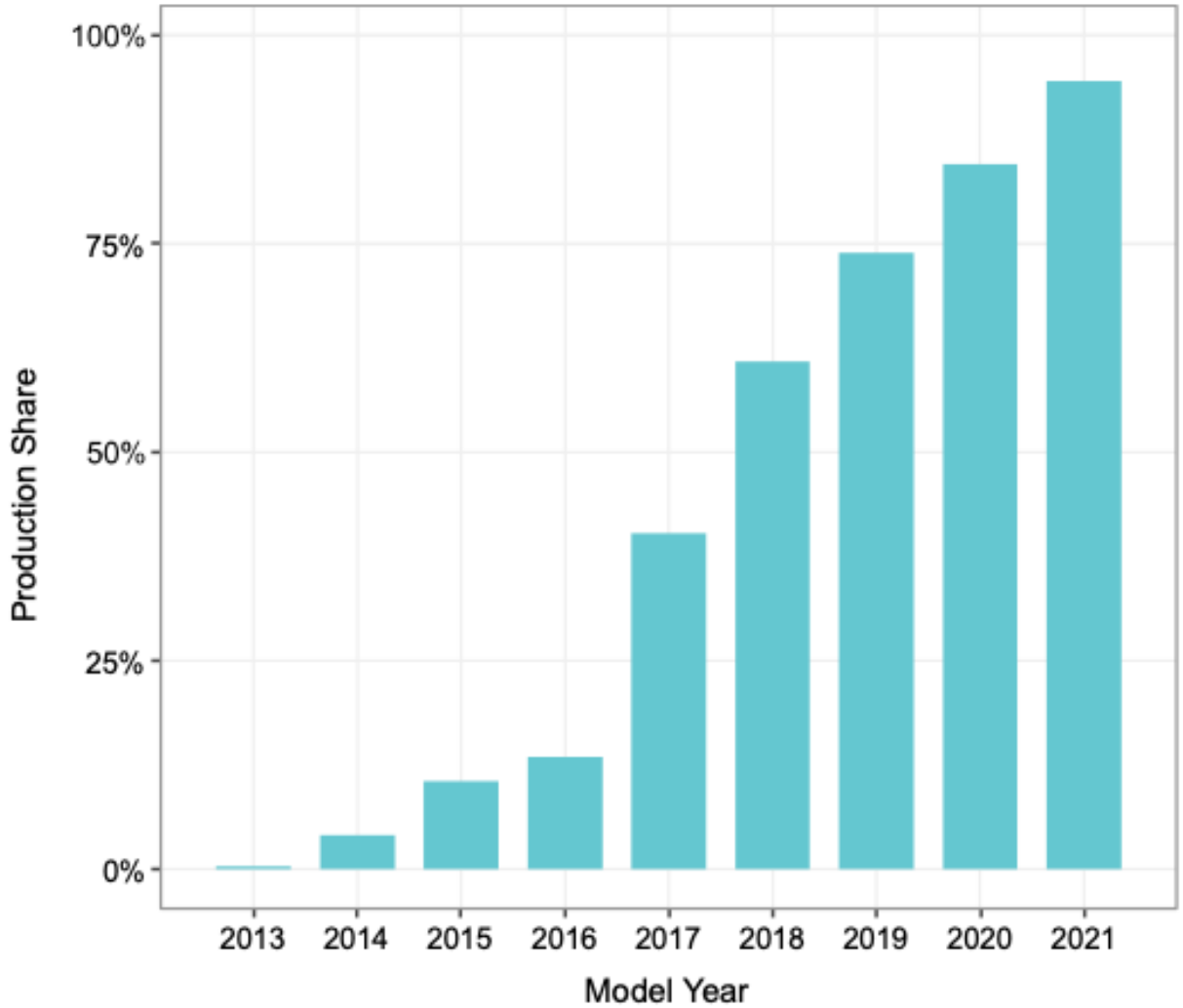
Figure 2. Production of Vehicles with HFO-1234yf MAC by Model Year

Manufacturer	Model Year						
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
BMW	-	-	-	-	334,633	367,072	358,787
FCA	-	540,098	1,683,956	1,504,046	1,633,139	1,750,652	1,906,228
Ferrari	-	-	-	-	1,886	2,559	2,659
Ford	-	-	-	-	1,326,663	1,530,469	1,512,981
GM	41,913	30,652	16,298	32,775	1,632,981	2,433,265	2,242,408
Honda	471	599	-	541,393	897,751	1,368,127	1,698,515
Hyundai	-	-	-	-	14,663	211,969	481,403
Jaguar Land Rover	-	56,604	62,316	114,580	122,586	110,615	105,504
Kia	-	-	-	-	264,353	336,262	580,596
Mazda	-	-	-	-	-	-	-
Mercedes	-	-	-	-	-	-	-
Mitsubishi	-	-	-	-	-	58,968	55,880
Nissan	-	-	-	-	-	94,474	338,942
Subaru	-	-	-	-	292,788	228,363	488,650
Tesla	-	-	-	-	-	-	96,459
Toyota	-	-	-	-	277,645	819,578	1,345,131
VW	-	-	-	-	50,884	588,122	714,364
Volvo	-	-	-	-	-	-	-
All Manufacturers	**42,384**	**627,953**	**1,762,570**	**2,192,794**	**6,849,972**	**9,900,495**	**11,928,507**

Source: U.S. Environmental Protection Agency (2021) Table 5.8.

By model year 2020, over 80% of new passenger vehicles in the USA were produced with HFO-1234yf AC systems, and by model year 2021 that share had increased to 90% (see figure 3 below). The U.S.-based National Automotive Dealers Association reports that approximately 14.5 million light duty vehicles were sold in the U.S. in 2020, 14.9 million in 2021, and 13.7 million in 2022. Assuming the percentage of vehicles manufactured with HFO-1234yf by model year approximates the percentage of vehicles sold with HFO-1234yf per year, then the U.S. added approximately 11.6 million HFO-1234yf vehicles in 2020, 13.4 million in 2021, and at least 12.3 million in 2022. Adding this to the 33.3 million vehicles produced as of the end of 2019 brings the U.S. total to approximately 70.6 million.

Figure 3: HFO-1234yf Adoption as a Percentage of Production Share in the USA

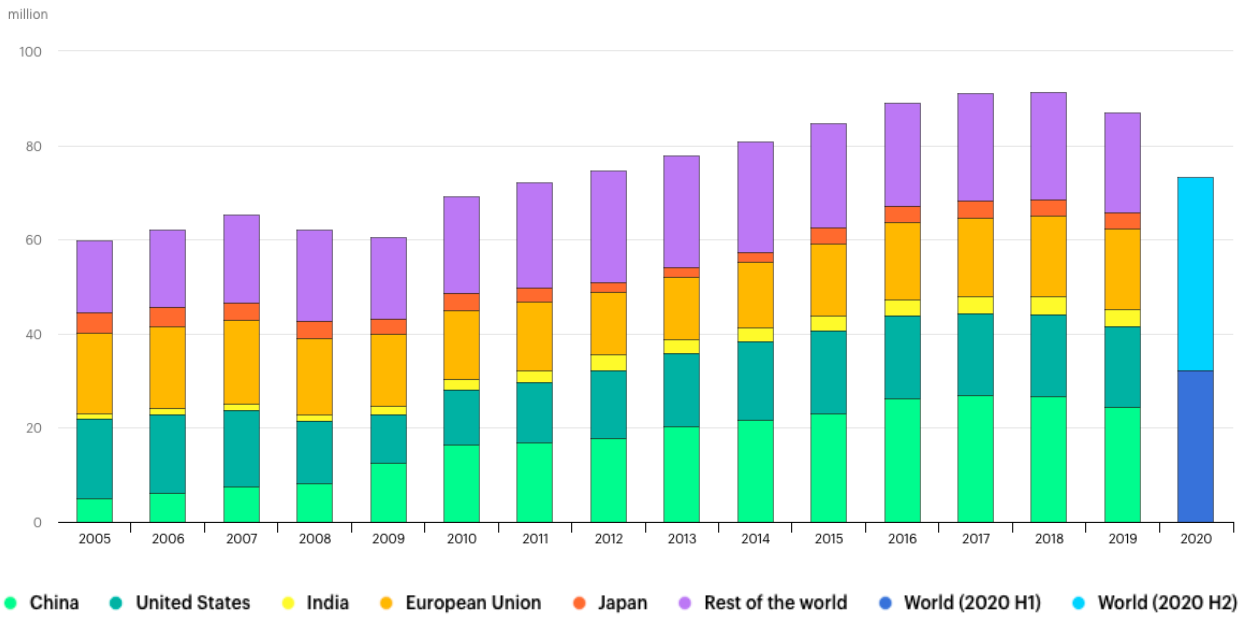


Source: US Environmental Protection Agency (2022) Automotive Trends. Table 5.6.

Rest of World: Most new vehicles continue to use HFC-134a

Nearly 1 billion light duty vehicles (including passenger cars, sport utility vehicles and trucks) have been manufactured globally since 2013, when HFO-1234yf refrigerant was first commercially introduced in vehicles.[10] Most light duty vehicles were equipped with air conditioning. If approximately 200 million vehicles worldwide are equipped with HFO-1234yf systems, it follows that up to 800 million –approximately 80%--of vehicles manufactured since 2013 continued to use HFC-134a. Europe and North America, where HFO-1234yf MAC systems are common, accounted for less than half of the world's automobile sales over the last decade. As shown by the International Energy Agency in figure 4, China is now the world's largest automobile market. Chinese, India, and other less-developed country automobile manufacturers still use HFC-134a. As of the end of 2022, most of the global auto manufactures identified in figure 1, below, continued to use HFC-134a when they were manufacturing or selling vehicles in countries that have not established rules or incentives to transition away from high-GWP refrigerants.

Figure 4: Global Light Duty Vehicle Sales by Key Markets.



Source: International Energy Agency (IEA), Global Car Sales by Key Markets

Conclusion

Globally, the number of vehicles sold using HFO-1234yf refrigerant was approaching 200 million by the end of 2022. Over 170 million vehicles using HFO-1234yf have been sold in the US and Europe alone as of the end of 2022. Other markets have adopted HFO-1234yf in automotive air conditioning systems too, including Japan and South Korea. However, vehicles with HFC-134a MAC systems continued to be produced and sold in China (the world's largest automotive market), India, Brazil, and other countries as of 2022. Significant reduction in global production, consumption, and emissions of HFCs could be achieved by transitioning the rest of the world's vehicles to climate-friendly refrigerants.

References

[1] Kristen N. Taddonio, Nancy J. Sherman, and Stephen O. Andersen. (2019) *Next Generation Refrigerant Transition: Lessons Learned from Automotive Industry Experiences with CFC-12, HFC-134a and HFO-1234yf*, SAE Technical Paper 2019-01-0909, doi:10.4271/2019-01-0909.

[2] European Automotive Manufacturers' Association (ACEA), *Vehicle registrations* (*last accessed* 13 February 2023). (83,037,413 to be precise; the number rises to 85,879,074 if non-EU members Iceland, Norway and Switzerland are included). Subtracting Daimler vehicles sold from 2013-2014, which sometimes used R744 refrigerant, reduces the number to 81,670,910

[3] Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 Relating to Emissions from Air Conditioning Systems in Motor Vehicles and Amending Council Directive 70/156/EEC, 2006 O.J. (L 161) 12.

[4] European Commission, *Mobile air-conditioning systems (MACS)* (*last accessed* 16 February 2023).

[5] Honeywell (12 December 2012) *MAC Refrigerant HFO-1234yf: Meeting the MAC Directive on 1 January 2013*, Presentation.

[6] European Commission, *Type Approval of Vehicles* (*last accessed* 12 December 2021).

[7] In the EU, 30,295,464 new passenger vehicles were registered between 2017-2018 and 52,741,949 were registered between 2013-2016, but not all used HFO-1234yf. Assuming half used HFO-1234yf, that would be 30,295,464 + 26,370,975 = 56,666,439 vehicles in the EU using HFO-1234yf by the end of 2018. If only a third of vehicles sold between 2013-2016 used the new refrigerant, then there will be approximately 47,846,114 vehicles in the EU using HFO-1234yf by the end of 2018. These numbers assume all new passenger vehicles were equipped with AC.

[8] ACEA. Vehicle registration data for the EU. 13 February 2023.

[9] U.S. Environmental Protection Agency (2021) THE 2020 EPA AUTOMOTIVE TRENDS REPORT.

[10] Statista. (2023). Estimated Worldwide Motor Vehicle Production. See also International Energy Agency (IEA), Global Car Sales by Key Markets, 26 October 2022.