

STATUS OF PATENTS AND LEGAL CHALLENGES: PATENTS RELATED TO THE USE OF HFO-1234YF IN AUTO AIR CONDITIONING

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Executive Summary

The 2016 Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) phases down the production and consumption of hydrofluorocarbon (HFC) greenhouse gases (GHGs). Since 2016, the vast majority of countries that use and produce HFCs, including the United States (US), China, India, and European nations have agreed to avoid and curtail these potent GHGs. One of the major challenges to transitioning to lower global warming potential (GWP) alternatives identified by Parties to the Montreal Protocol is intellectual property rights (IPR), particularly in the automotive sector (including passenger automobiles, light trucks, and commercial and industrial vehicles used on- and off-road), where low-GWP refrigerant hydrofluoroolefin (HFO)-1234yf has become the predominant solution used in automobiles manufactured or exported to developed countries worldwide. Because a few transnational companies filed a large number of the patents on low-GWP chemical substitutes for HFCs, multiple developing countries (Article 5 Parties under the Montreal Protocol) have raised concerns that these patents could impede their ability to meet HFC reduction goals, significantly increase the costs of doing so, or put their industries at a competitive disadvantage if they do not. Furthermore, because the agreed incremental costs (including IPR) of the Article 5 Parties' transition is paid from the Multilateral Fund for the Implementation of the Montreal Protocol (MLF), there is concern over affordability among Parties from developed countries (non-Article 5 Parties) donating to that fund. This paper addresses

what has been described as a primary concern related to patents: even if chemical companies in Article 5 Parties can develop their own methods of producing HFOs or using them in the products they make, they could be prevented (absent a license) from selling their products at home and in key markets abroad in countries where restrictive patents have been granted to other companies, at least until the time when challenges to patents are decided or these patents expire.

This paper reviews the status of patents granted on HFO-1234yf in automotive air conditioning (AC) in the US, Europe, and China, covering the largest automotive manufacturing regions in the world. This paper primarily focuses on patents on the use of HFO-1234yf in automobiles, as opposed to patents on the manufacture of HFO-1234yf. There are multiple manufacturing pathways for HFO-1234yf which may be reviewed in a future paper. In the US and Europe, most patents on the use of HFO-1234yf in automobile AC systems were invalidated following legal challenge. However, this has not prevented the same chemical manufacturers from gaining or maintaining similar IPR in China, where some of the patents have yet to be challenged or overturned. This raises both legal and diplomatic questions about the validity of such patents, and the environmental, financial, and trade-related benefits that could be realized if legal barriers to unrestricted use were removed.

This paper updates and expands upon a preceding publication co-authored by Stephen Seidel of the Center for Climate and Energy Solutions and Christine R. Ethridge of Eckert Seamans Cherin & Mellott LLC, published in July 2016 and titled "Status of Legal Challenges: Patents Related to the Use of HFO-1234yf in Auto Air Conditioning" (referred to hereinafter as the July 2016 report). The Institute for Governance & Sustainable Development (IGSD) gratefully acknowledges the work of Tianran (T.R.) Yan and Hao Wu of Foley & Lardner LLP who conducted the updated patent search and without whom this paper would not be possible, as well as reviews from mobile AC experts including Professor Jianxin Hu, Peking University; Binbin Yu, Shanghai Jiao Tong University; Ward Atkinson, Sun Test Engineering; William (Bill) Hill, retired-GM; Timothy Craig, Melrose Technologies; and Dwayne Taylor, Denso.

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1. Key Findings

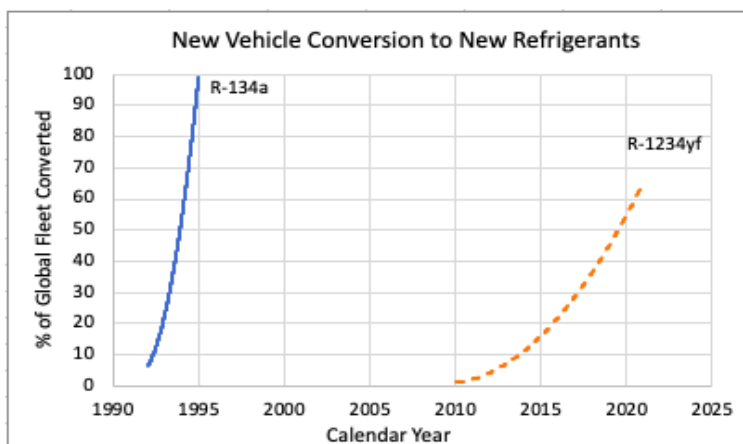
- The majority of patents on HFO-1234yf used in automobile AC systems granted in the US and in Europe have been challenged and/or invalidated.
- The few remaining patents in the EU and the US will expire soon (2023 or 2024).
- Many patents have been granted on HFO-1234yf used in automobile AC systems in China.
- In several cases, patents granted in China contain claims similar to those that were challenged and/or invalidated in the US and/or Europe.
- In some cases, patents granted by other companies in China appear to have dubious or overly broad claims that may not be patentable elsewhere, or may be invalidated in China if challenged.
- Removal of legal barriers through, for example, granting of free license or successful legal challenge, could greatly benefit the global environment and mitigate climate change.

2. Patents Granted on HFO-1234yf in Vehicle AC

This analysis focuses on patents officially granted (as opposed to pending patent applications) in the US, Europe, and China that could apply to the use of HFO-1234yf in automobile AC or heat pump systems. HFO-1234yf is a climate-friendly alternative to HFC-134a, which has a GWP 1,300 times stronger than carbon dioxide (CO₂) over a 100-year period according to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). HFO-1234yf, in comparison, has a GWP of less than 1. When used in automobile AC systems properly designed for it, HFO-1234yf has energy efficiency near or equal to AC systems that use obsolete HFC-134a.

While HFO-1234yf has become the predominant refrigerant used in vehicles manufactured and sold in North America, Europe, and Japan, the vast majority of vehicles manufactured in China continue to use high-GWP refrigerant HFC-134a. This stands in contrast to previous refrigerant transition, where automakers throughout the world switched to a new refrigerant nearly universally within a few years (see figure 1).

Figure 1: Global Vehicle Fleet Transition to New Refrigerants



* The blue line represents the transition from CFC-12 to HFC-134a in new vehicles. The red dotted line shows the slower transition to HFO-1234yf.

This is concerning from a global environmental standpoint, since China has surpassed both Europe and North America to become the world’s largest automotive market. Indeed, the authors estimate that replacing HFC-134a in Chinese-manufactured vehicles with a low GWP alternative could eliminate one-fifth of global HFC-134a emissions and put China on track to meet its HFC phasedown commitments under the Kigali Amendment to the Montreal Protocol. Table 1 lists the patents that were identified as pertaining to the use of HFO-1234yf in automobile AC systems. As the following pages will reveal, most of these patents in Europe and the US have since been invalidated or overturned.

Table 1: List of Granted Patents Relevant to the Use of HFO-1234yf in Automobile AC Systems

United States	European Union	China
US 7,279,451 (expired)	EP 1563032 B (revoked)	CN 102203209 B (expires 2029)
US 7,534,366 (expires 2023)	EP 1716216 B (revoked)	CN 102686695 B (expires 2030)
US 8,033,120 (expires 2023)	EP 1725628 B (revoked)	CN 103146348 B (expires 2025)
US 8,065,882 (expires 2023)	EP 2275509 B (expires 2024)	CN 103215013 B (expires 2024)
US 9,005,467 (expires 2024)	EP 2277970 B (revoked)	CN 103642461 B (expires 2024)
US 9,157,017 (expires 2023)	EP 2277972 B (revoked)	CN 103923610 B (expires 2024)
US 10,781,152 (expires 2023)	EP 2277977 B (revoked)	CN 104164215 B (expires 2025)
	EP 2314654 B (revoked)	CN 104194726 B (expires 2025)
		CN 107011862 B (expires 2026)

* Many patents have been granted on HFO-1234yf in automotive AC systems, but few have survived legal challenge in the US and Europe. The patents in **bold** survived legal challenge, although European Patent (EP) 2275509B is being challenged in opposition proceedings, and the legal challenges against US 7,534,366, US 8,033,120, US 9,157,017, China (CN) 102203209, and CN 107011862 have not reached conclusion as of August 2021. The strikethrough patents have expired or been revoked/invalidated as of August 2021. All of these patents are discussed below.

3. Status of Patents and Legal Challenges

This section discusses patents relevant to the use of HFO-1234yf as an automobile refrigerant in the US, Europe, and China, and describes sixteen legal challenges in these countries of concerns including five US patents (i.e., US 7,279,451; US 7,534,366; US 8,033,120; US 8,065,882; and US 9,157,017), eight European patents (i.e., EP 1563032 B; EP 1716216 B; EP 1725628 B; EP 2275509 B; EP 2277970 B; EP 2277972 B; EP 2277977 B; and EP 2314654 B), and three Chinese patents (i.e., CN102203209B; CN103146348B; and CN107011862B).

United States

In the US, seven patents were identified pertaining to the use of HFO-1234yf in vehicles from the patent families identified in the July 2016 report. Five Honeywell patents have been challenged in reexaminations and post-grant reviews, among which US 8,065,882 alone has survived reexamination with claims still in force that are relevant to use of HFO-1234yf as an automobile refrigerant. Specifically, all claims of US 7,279,451 were cancelled after reexamination, and this patent is now expired. Further, all claims of US 7,534,366 and US 8,033,120 were rejected in reexamination, a decision that was affirmed by the Patent Trial and Appeal Board (PTAB) and is currently waiting for appeal decision from the US Court of Appeals for the Federal Circuit (CAFC). In addition, all claims of US 9,157,017 were held unpatentable in post-grant reviews, a decision which the CAFC vacated and remanded to the PTAB, and which is currently awaiting further PTAB decision. A number of patent applications containing HFO-1234yf were also identified, and are available upon request. Only granted patents are covered here.

Table 2: Status of Patents Granted in the United States and Legal Challenges

Patent No.	Earliest Claimed Priority Document Nos.	Earliest Claimed Priority Dates	Effective Filing Date	Expiration Date / Status
US 7,279,451 (Honeywell)	US 60/421,435 US 60/421,263 US 10/694,272 US 10/694,273 US 10/695,212	10/25/2002 10/25/2002 10/27/2003 10/27/2003 10/27/2003	10/27/2003	Challenged and now expired due to non-payment of maintenance fees.
US 7,534,366 (Honeywell)	US 60/421,435 US 60/421,263	10/25/2002 10/25/2002	10/27/2003	Estimated 12/7/2023 (Invalidated subject to appeal)
US 8,033,120 (Honeywell)	US 60/421,263 US 60/421,435 US 10/694,273	10/25/2002 10/25/2002 10/27/2003	10/27/2003	Estimated 10/27/2023 (Invalidated subject to appeal)
US 8,065,882 (Honeywell)	US 60/421,263 US 60/421,435 US 10/694,272 US 10/694,273 US 10/837,525 US 11/847,192	10/25/2002 10/25/2002 10/27/2003 10/27/2003 04/29/2004 08/29/2007	10/27/2003	Estimated 10/27/2023 (Patent maintained as amended after reexamination and appeal)
US 9,005,467 (Honeywell)	US 10/695,212 US 10/694,272 US 10/694,273 US 10/837,525 US 60/693,853 US 11/375,826 US 11/385,259	10/27/2003 10/27/2003 10/27/2003 04/29/2004 06/24/2005 03/15/2006 03/20/3006	10/27/2003	Estimated 06/13/2024 (No legal challenge found)
US 9,157,017 (Honeywell)	US 10/694,272 US 10/837,525 US 11/847,192 US 13/844,206	10/27/2003 04/29/2004 08/29/2007 03/15/2013	10/27/2003	Estimated 10/27/2023 (Patent being challenged in reexamination)

Patent No.	Earliest Claimed Priority Document Nos.	Earliest Claimed Priority Dates	Effective Filing Date	Expiration Date / Status
US 10,781,152 (Honeywell)	US 60/421,435 US 60/421,263 US 10/695,212 US 10/694,272 US 10/694,273 US 10/837,525 US 60/693,853 US 11/475,605 US 11/850,025 US 15/675,024	10-25-2002 10-25-2002 10-27-2003 10-27-2003 10-27-2003 04-29-2004 06-24-2005 06-26-2006 09-04-2007 08-11-2017	10/27/2003	Estimated 10/27/2023 (No legal challenge found)

US 7,279,451 (US '451, Honeywell)

This patent issued from an application filed on April 29, 2004. It covers a heat-transfer composition comprising at least one fluoroalkene described by a chemical formula contained in the patent (which includes HFO-1234yf as a subset), and that makes up between 5 and 99 percent by weight of the composition. A request to reexamine this patent was granted by the US Patent and Trademark Office (USPTO) (#95/000,576) resulting in the initial rejection of all pending claims by the examiner. Upon appeal to the PTAB, the previous decision rejecting all claims was affirmed. The patent owner appealed the PTAB decision to the CAFC. On December 11, 2017, the appeal was dismissed as agreed by both Appellant and Appellee. A reexamination certificate was issued accordingly on March 23, 2018, canceling all claims. This patent is now expired due to non-payment of maintenance fees.

US 7,534,366 (US '366, Honeywell)

This patent issued from an application filed on October 27, 2003. It covers a heat-transfer composition for use in an AC system that is comprised of generally at least 50 percent by weight of HFO-1234yf and at least one polyalkylene glycol lubricant. Two reexaminations challenging the patent were initiated (#95/002,189 and #95/002,204) before the USPTO and was then merged together, where all claims were rejected by the examiner. This ruling was appealed to the PTAB, and a decision was handed down on March 20, 2016, affirming the examiner's decision to reject all claims. An appeal of the PTAB decision to the CAFC was filed in May 2016. The CAFC found new grounds of rejection, and therefore vacated and remanded on August 1, 2017. New grounds of an obviousness rejection was then entered by the PTAB on March 22, 2019. After considering the comments by the patent owner, the third-party requester and the Examiner, the PTAB maintained the rejection on May 1, 2020. Shortly thereafter, on July 6, 2020, the patent owner appealed to the CAFC. This appeal (#2020-2023) was consolidated with another one numbered 2020-1991 (discussed below) and is still pending as of August 2021. The patent is estimated to expire in December 2023 even if it survives this legal challenge.

US 8,033,120 (US '120, Honeywell)

This patent issued from an application filed on April 20, 2009. It covers a method of cooling air comprising providing a heat-transfer fluid that includes a lubricant and a fluoroalkene based on a chemical formula contained in the patent (that includes HFO-1234yf as one possible subset). The '120 Patent also was re-examined (#95/001,783) and the examiner's decision to reject all the claims was appealed to the PTAB. The PTAB decision affirmed the rejection of some of the claims by the re-examination examiner and rejected the remaining claims on new grounds, substituting its own modified basis for rejection. As requested by the patent owner, prosecution before the Examiner was re-opened on March 8, 2017 for consideration of new evidence and arguments regarding the new grounds of rejection. However, the new rejection was maintained by the Examiner and affirmed by the PTAB. An Appeal to the CAFC was then filed by the patent owner on July 6, 2020. This appeal (#2020-1991) was consolidated with another appeal

numbered 2020-2023 (discussed above) and is still pending as of August 2021. The patent is estimated to expire in October 2023 even if it survives this legal challenge.

US 8,065,882 (US ‘882, Honeywell)

This patent issued from an application filed on March 26, 2009. It covers several methods relating to automobile AC or cooling air, including a method of transferring heat to or from a fluid or body to provide cooling of air in an automobile with the specifics of the heat-transfer composition described by a chemical formula in the patent. This formula encompasses HFO-1234yf. All claims in the patent were rejected or cancelled during a USPTO reexamination (#95/002,030). On appeal, the PTAB affirmed the rejection of the claims either on the same grounds, or in some cases, on alternative grounds. As requested by the patent owner, prosecution before the Examiner was re-opened on March 8, 2017 for consideration of new evidence and arguments regarding the new grounds of rejection. However, the new rejection was maintained by the Examiner on May 5, 2017. The PTAB initially affirmed the rejection on January 2, 2018, and then denied rehearing and raised new grounds of rejection on March 21, 2019. Prosecution before the Examiner was re-opened again on July 19, 2019, and the Examiner maintained the new rejections on September 16, 2019. However, the PTAB reversed all new grounds of rejection on May 1, 2020. An Appeal to the CAFC was then filed by the third-party requester on June 30, 2020 (#2020-1981), and dismissed on June 15, 2021 upon considering of the joint motion to voluntarily dismiss the appeal. A Notice of Intent to Issue Inter Parte Reexamination Certification was mailed on 7/19/2021, and the claims considered patentable by the PTAB encompass a method for cooling air in an automobile using HFO-1234yf. This patent is estimated to expire in October 2023.

A representative claim of the ‘882 patent relating to HFO-1234yf is provided below:

33. *A method for providing an air conditioning system for conditioning the air in an automobile comprising:*
- (a) providing in the automobile air conditioning system a vapor compression air conditioning system having at least one compressor and at least one condenser; and*
 - (b) providing a refrigerant in said system for cooling the air in the automobile, said refrigerant having no substantial acute toxicity and comprising from about 5 % by weight to about 99% by weight of 1, 1, 1, 2-tetrafluoropropene (HFO-1234yf).*

US 9,005,467 (US ‘467, Honeywell)

This patent covers retrofits of HFC-134a systems to use HFO-1234yf. It was issued on April 14, 2015 and is expected to expire in 2024. No legal challenges have been found as of August 2021. A representative claim of the ‘467 patent relating to HFO-1234yf is provided below:

1. *A method of replacing an existing heat transfer fluid contained in an existing heat transfer system comprising replacing at least a portion of said existing heat transfer fluid with a heat transfer composition comprising HFO-1234yf, wherein said existing heat transfer fluid comprises HFC-134a.*

US 9,157,017 (US ‘017, Honeywell)

This patent issued from an application filed on March 26, 2014. It covers a stable heat-transfer composition comprising HFO-1234yf as the refrigerant for use in an automobile AC system having a condenser operating at about 150 °F. Two post-grant reviews (#PGR2016-00011 and #PGR2016-00012) were instituted on September 2, 2016, raising novelty, obviousness and enablement issues. On August 31, 2017, the PTAB issued a final written decision and deemed all twenty claims unpatentable. After the patent owner appealed to CAFC on November 2, 2017, the Court vacated the PTAB’s final written decision, and the case was remanded to the PTAB and is pending for PTAB’s further decision. This patent is estimated to expire in October 2023 even if it survives this legal challenge.

A representative claim of the '017 patent relating to HFO-1234yf is provided below:

6. A method of conditioning the air in an automobile using an automobile air conditioning system including at least one compressor, at least one condenser and at least one evaporator, said method comprising:

(a) utilizing in said system a heat transfer composition consisting essentially of:

(i) at least about 50% by weight of a low toxicity refrigerant suitable for use in automobile air conditioning systems, said refrigerant consisting essentially of 2,3,3,3-tetrafluoropropene (HFO-1234yf); and

(ii) lubricant consisting essentially of polyalkylene glycol(s); and

(b) removing heat from said HFO-1234yf by condensing said refrigerant in said condenser when said condenser is operating over a temperature range that includes about 150° F.

US 10,781,152 (US '152, Honeywell)

This patent covers a method for producing an automobile AC system for use with HFO-1234yf. It was issued on September 22, 2020, and is expected to expire in 2023.¹ No legal challenges have been found as of August 2021. Representative claims include:

1. A method for producing an automobile air conditioning system for use with 2,3,3,3-tetrafluoropropene (HFO-1234yf) comprising: (a) providing an automobile vapor compression air conditioning system usable with refrigerant 1,1,1,2-tetrafluoroethane (HFC-134a) and having at least one compressor and at least one condenser; and (b) providing a heat transfer composition in said system, said heat transfer composition consisting essentially of: (i) at least about 50% by weight of HFO-1234yf; and (ii) lubricant consisting essentially of polyalkylene glycol(s), and (c) operating said automobile vapor compression air conditioning system, wherein (1) during at least a portion of said operating step said condenser operates with said refrigerant in a temperature range that includes 150.degree. F.; (2) said HFO-1234yf and said lubricant are stable when in contact in said vapor compression air conditioning system; and (3) said refrigerant has no substantial acute toxicity as measured by inhalation exposure to mice and rats.

5. A method of conditioning the air in an automobile using an automobile air conditioning system including at least one compressor, at least one condenser and at least one evaporator, said method comprising: (a) utilizing in said automobile air conditioning system a heat transfer composition consisting essentially of: (i) a refrigerant comprising at least about 50% by weight of 2,3,3,3-tetrafluoropropene (HFO-1234yf); and (ii) lubricant consisting essentially of polyalkylene glycol(s); and (b) removing heat from said HFO-1234yf by condensing said refrigerant in said condenser when said condenser is operating over a temperature range that includes about 150degrees F., wherein (1) said refrigerant achieves in said system a capacity relative to HFC-134a of about 1 and a Coefficient of Performance (COP) relative to HFC-134a of about 1; (2) said refrigerant has a Global Warming Potential (GWP) of not greater than about 150; and (3) said refrigerant has no substantial acute toxicity as measured by inhalation exposure to mice and rats.

9. A method for providing a system for cooling air in an automobile comprising: (a) providing in the automobile a vapor compression air conditioning system having at least one compressor and at least one condenser; and (b) providing in said system a heat transfer composition consisting essentially of: (i) at least about 50% by weight of 2,3,3,3-tetrafluoropropene (HFO-1234yf); and

¹ A US patent typically expires 20 years from the filing date of the first non-provisional application in its priority chain, plus patent term adjustment and subject to terminal disclaimer if any. In other words, the patent term is not calculated from its grant date, but from the filing date of the first non-provisional application in its priority chain.

(ii) lubricant consisting essentially of polyakylene glycol(s), and (c) operating said vapor compression automobile air conditioning system, wherein (1) said heat transfer composition has no substantial acute toxicity as measured by inhalation exposure to mice and rats; (2) during said operating step said condenser operates with said refrigerant in a temperature range that includes 150.degree. F. and (3) said system achieves a capacity relative to HFC-134a of about 1 and a Coefficient of Performance (COP) relative to HFC-134a of about 1.

Europe

In Europe, eight Honeywell patents were identified pertaining to the use of HFO-1234yf in automobile AC systems from the patent families identified in the July 2016 report. All eight of these Honeywell patents have been challenged in opposition proceedings, and seven of them have been revoked. Specifically, EP 1563032B, EP 1716216B, EP 1725628B, EP 2277970B, EP 2277972B, EP 2277977B, and EP 2314654B were revoked in opposition proceedings with no further appeal available. The remaining patent (EP 2275509B) is currently being challenged in opposition proceedings. A number of patent applications containing HFO-1234yf were also identified, and are available upon request. Only granted patents are covered here.

Table 3: Status of Patents Granted in Europe and Legal Challenges

Patent No.	Earliest Claimed Priority Document Nos.	Earliest Claimed Priority Dates	Effective Filing Date	Expiration Date / Status
EP 1563032 B (Honeywell)	US 60/421,263 US 60/421,435 PCT/US2003/033874	10/25/2002 10/25/2002 10/27/2003	10/27/2003	Revoked
EP 1716216 B (Honeywell)	US 10/837,525 PCT/US2005/014873	4/29/2004 4/29/2005	04/29/2005	Revoked
EP 1725628 B (Honeywell)	US 10/695,212 PCT/US2004/035132	10/27/2003 10/25/2004	10/25/2004	Revoked
EP 2275509 B (Honeywell)	US 10/695,212 PCT/US2004/035132 EP 1725628	10/27/2003 10/25/2004 10/25/2004	10/25/2004	Estimated 10/25/2024 (Patent being challenged in opposition)
EP 2277970 B (Honeywell)	US 10/695,212 PCT/US2004/035132 EP 1725628	10/27/2003 10/25/2004 10/25/2004	10/25/2004	Revoked
EP 2277972 B (Honeywell)	US 60/421,263 US 60/421,435 PCT/US2003/033874 EP 1563032	10/25/2002 10/25/2002 10/27/2003 10/27/2003	10/27/2003	Revoked
EP 2277977 B (Honeywell)	US 10/837,525 PCT/US2005/014873 EP 1716216 EP 2085422	4/29/2004 4/29/2005 4/29/2005 4/29/2005	4/29/2005	Revoked
EP 2314654 B (Honeywell)	US 60/421,263 US 60/421,435 PCT/US2003/033874 EP 1563032	10/25/2002 10/25/2002 10/27/2003 10/27/2003	10/27/2003	Revoked

EP 1563032 B (EP '032, Honeywell)

This patent is derived from the European regional stage of a Patent Cooperation Treaty (PCT) application (published as WO 2004/037913) with an international filing date of October 27, 2003. It covers use as a

heat-transfer composition of a composition comprising at least one HFO-1234 and a polyol ester or polyalkylene glycol lubricant. Opposition to this patent was filed in 2012 and the European Patent Office (EPO) Opposition Division issued a communication revoking the patent on January 15, 2015. This decision was upheld on appeal by the EPO Boards of Appeal. Termination of opposition proceeding with revocation of the patent was then issued on March 5, 2016.

EP 1716216 B (EP '216, Honeywell)

This patent is derived from the European regional stage of a PCT application (published as WO 2005/105947) filed on April 29, 2005. It covers use as a refrigerant of a composition comprising an HFO-1234 in an automobile AC system. The EPO Opposition Division revoked this patent following a hearing. This decision was upheld on appeal by the EPO Boards of Appeal. Termination of opposition proceeding with revocation of the patent was then issued on October 8, 2016.

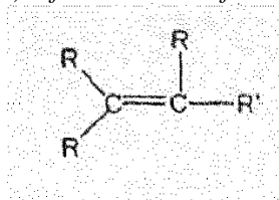
EP 1725628 B (EP '628, Honeywell)

This patent is a European regional stage of a PCT application (published as WO 2005/042663) with an international filing date of October 25, 2004. It covers a liquid composition for use in a compression refrigeration, AC or heat pump system comprising a general formula including at least HFO-1234yf and a polyol ester or polyalkylene glycol lubricant. Several oppositions to this patent were filed in 2012–2013 and the EPO Opposition Division issued a communication revoking the patent on January 15, 2015. An appeal of the revocation to the Boards of Appeal was filed by the patent holder and withdrawn on December 21, 2018. Termination of opposition proceeding with revocation of the patent was then issued on March 24, 2020.

EP 2275509 B (EP '509, Honeywell)

This patent is a European regional stage of a PCT application (published as WO 2005/042663) with an international filing date of October 25, 2004. It covers use in a refrigerant system of a liquid composition comprising a fluoroalkene limited by a general formula and a lubricant. This formula encompasses HFO-1234yf. Several oppositions to this patent have been filed and pending for EPO's decision. This patent is estimated to expire in October 2024 even if it can survive the opposition proceeding. A representative claim of the '509 patent relating to HFO-1234yf is provided below:

1. Use in a refrigeration system of a liquid composition comprising:
 - a) a fluoroalkene of the structure:



wherein each *R* is independently Cl, F, Br, I or H; *R'* is (CR₂)_{*n*}Y; Y is CRF₂; and *n* is 0; and
b) an effective amount to provide lubrication of an essentially miscible organic lubricant comprised of carbon, hydrogen and oxygen and having a ratio of oxygen to carbon which provides a degree of miscibility with said fluoroalkene so that when up to five weight percent of lubricant is added to said fluoroalkene the mixture has one liquid phase at a temperature of at least one between -40 and +70°C, and wherein the lubricant is selected from the group consisting of polyalkylene glycol, polyalkylene glycol ester, polyol ester and vinyl ether lubricants; wherein the refrigeration system is selected from electric refrigerators, chillers, transport refrigeration systems and commercial refrigeration systems.

EP 2277970 B (EP '970, Honeywell)

This patent is a European regional stage of a PCT application (published as WO 2005/042663) with an international filing date of October 25, 2004. It covers a liquid composition for use in compression refrigeration, AC and heat pump system comprising a fluoroalkene and a lubricant. This formula encompasses HFO-1234yf. Several oppositions to this patent were filed and the EPO Opposition Division issued a communication revoking the patent on November 12, 2018. No Appeal was filed and termination of opposition proceeding with revocation of the patent was then issued on February 21, 2019.

EP 2277972 B (EP '972, Honeywell)

This patent is a European regional stage of a PCT application (published as WO 2004/037913) with an international filing date of October 27, 2003. It covers a refrigerant composition comprising a fluoroalkene limited by a general formula and a polyol ester or a polyalkylene glycol as a lubricant. This formula encompasses HFO-1234yf. Several oppositions to this patent were filed and the EPO Opposition Division issued a communication revoking the patent on May 20, 2020. No Appeal was filed and termination of opposition proceeding with revocation of the patent was then issued on October 1, 2020.

EP 2277977 B (EP '977, Honeywell)

This patent is a European regional stage of a PCT application (published as WO 2005/105947) with an international filing date of April 29, 2005. It covers uses as a refrigerant in an automotive AC system of a composition comprising a fluoroalkene limited by a general formula. This formula encompasses HFO-1234yf. Several oppositions to this patent were filed and the EPO Opposition Division issued a communication revoking the patent on May 11, 2020. No appeal was filed and termination of opposition proceeding with revocation of the patent was then issued on August 24, 2020.

EP 2314654 B (EP '654, Honeywell)

This patent is a European regional stage of a PCT application (published as WO 2004/037913) with an international filing date of October 27, 2003. It covers a refrigerant composition comprising a fluoroalkene limited by a general formula, and polyalkylene glycol as a lubricant. This formula encompasses HFO-1234yf. Several oppositions to this patent were filed and the EPO Opposition Division issued a communication revoking the patent on March 19, 2019. An appeal of the revocation to the Boards of Appeal was filed by the patent holder on May 15, 2019 and withdrawn on May 12, 2020. Termination of opposition proceeding with revocation of the patent was then issued on June 9, 2020.

China

With China's acceptance of the Kigali Amendment to the Montreal Protocol, automakers will need to transition away from HFC-134a refrigerant, which has a 100-year GWP 1,300 times that of CO₂ according to the 5th Assessment Report of the IPCC. China has become the world's largest automobile market, producing between 25 and 30 million vehicles per year over the last five years. Du et al. (2016)² found that in China, life-cycle refrigerant emissions average 1,477 to 1,726 grams per vehicle (including service and accidental emissions). If 90% of vehicles contain HFC-134a, that means each year's vehicle fleet will contribute 33,233 to 46,602 tonnes of HFC-134a refrigerant emissions to the atmosphere. (It is notable that this is consistent with Jianxin Hu and co-authors' prediction³ that HFC-134a emissions from China's automobile AC sector would reach 34,875 tonnes by 2015). In terms of warming potential, these refrigerant emissions are equal to 40 to 60 million tonnes of CO₂ per model year, if 100-year GWPs are used. Using 20-year GWP (relevant given that HFC-134a has an atmospheric life under 20 years), each model year that

² Du L., Meszler D., & Minjares R. (2016) [HFC-134a phase-out in the Chinese light-duty motor vehicle sector](#), White Paper, The International Council on Clean Transportation.

³ Hu J., Wan D., Li C., Zhang J., & Yi X. (2010) [Forecast of Consumption and Emission of HFC-134a Used in the Mobile Air-conditioner Sector in China](#), ADVANCES IN CLIMATE CHANGE RESEARCH, 1(1): 20-26.

China’s auto makers continue to use HFC-134a will result in warming equivalent to 120-180 million tonnes of CO₂ emissions. Indeed, Du and colleagues’ analysis (which used 100-year GWPs) found that phasing out HFC-134a from the Chinese fleet could produce a climate benefit equivalent to reducing CO₂ emissions by 1.5 billion tonnes through 2050, provided that vehicles transition to a low-GWP refrigerant by 2024.⁴

This is concerning from a global environmental standpoint. The United Nations Environment Program has estimated that annual global HFC-134a consumption in Article 5 parties (developing countries) will increase to between 106,731 and 139,547 tonnes per year between 2020 and 2025.⁵ If Du and Hu and colleagues’ HFC-134a estimates for the vehicle sector are accurate, that means that China’s automobile AC sector alone could account for one-third of HFC-134a emissions from Article 5 parties, and up to one-fifth of global emissions. Stated more positively, replacing HFC-134a in Chinese-manufactured vehicles with a low-GWP alternative could eliminate one-fifth of global HFC-134a emissions and put China on track to meet its HFC phasedown commitments under the Kigali Amendment to the Montreal Protocol.

The search of patents granted in China was intentionally broad so as not to miss any potential patent that may restrict the use of HFO-1234yf in automobile AC systems or heat pumps, either used as a single refrigerant composition or in a blend. The patents described in this section include those that definitely apply to the use of HFO-1234yf in vehicles, as well as those such as CN 104164215B and CN 104194762B that have broad scope. One patent, Arkema’s CN 102686695 B, concerned the patent’s technical reviewers, who questioned whether it is legitimate to patent a thought process. Several of these patents may or may not be of interest to the automotive AC community, but for the sake of inclusiveness, they are included in this report. Searches were conducted in multiple databases and included both English-language and Chinese-language searches.

Thus far, two Honeywell patents and one Arkema patent have been challenged in invalidation proceedings. Of these patents, CN 103146348B has survived invalidation (invalidated in part and maintained in part) with claims still in force that are relevant to use of HFO-1234yf as automobile refrigerant. CN102203209B and CN107011862B were invalidated in full; however, the appeal process has not been exhausted for the invalidation of CN102203209B and CN107011862B. A number of patent applications containing HFO-1234yf were also identified, and are available upon request. Only granted patents are covered here.

Table 4: Status of Patents Granted in China and Legal Challenges

Patent No.	Earliest Claimed Priority Document Nos.	Earliest Claimed Priority Dates	Effective Filing Date	Expiration Date / Status*
CN 102203209 B (Arkema)	FR 08.57454 PCT/FR2009/052075	10/28/2008 10/28/2009	10/28/2009	Estimated 10/28/2029 (Invalidated subject to appeal)
CN 102686695 B (Arkema)	US 61/290,690 PCT/US2010/061258	12/29/2009 12/20/2010	12/20/2010	Estimated 12/20/2030*
CN 103146348 B (Honeywell)	US 10/837,525	04/29/2004	04/29/2005	Estimated 04/29/2025*
CN 103215013 B (Honeywell)	US 10/695,212	10/27/2003	10/25/2004	Estimated 10/25/2024*

⁴ Du L., Meszler D., & Minjares R. (2016) [HFC-134a phase-out in the Chinese light-duty motor vehicle sector](#), White Paper, The International Council on Clean Transportation.

⁵ United Nations Environment Programme, [Available Information on HFC Consumption and Production in Article 5 Countries](#), UNEP/OzL.Pro/ExCom/78/4 (6 March 2017).

Patent No.	Earliest Claimed Priority Document Nos.	Earliest Claimed Priority Dates	Effective Filing Date	Expiration Date / Status*
CN 103642461 B (Honeywell)	US 10/695,212 PCT/US2004/035132 CN 200480039094.8	10/27/2003 10/25/2004 10/25/2004	10/25/2004	Estimated 10/25/2024*
CN 103923610 B (Honeywell)	US 10/695,212 PCT/US2004/035132 CN 200480039094.8	10/27/2003 10/25/2004 10/25/2004	10/25/2004	Estimated 10/25/2024*
CN 104164215 B (Honeywell)	US 10/837,525 PCT/US2005/014873 CN 200580013536.6	04/29/2004 04/29/2005 04/29/2005	04/29/2005	Estimated 04/29/2025*
CN 104194726 B (Honeywell)	US 10/837,525 PCT/US2005/014873 CN 200580013536.6	04/29/2004 04/29/2005 04/29/2005	04/29/2005	Estimated 04/29/2025*
CN 107011862 B (Honeywell)	US 60/693,853 PCT/US2006/024886 CN 200680031093.8	06/24/2005 06/26/2006 06/26/2006	06/26/2006	Estimated 06/26/2026 (Invalidated subject to appeal)

*An asterisk indicates our search found no current history of reexamination, invalidation or litigation. However, this does not preclude developing or future legal challenges.

CN 102203209 B (CN ‘209, Arkema)

This patent is a national-stage entry in China of a PCT application (published as WO 2010/061084) by Arkema with an international filing date of October 28, 2009. It covers a heating and/or AC method for a passenger compartment of an automobile, using a reversible cooling loop, in which a coolant flows, comprising a first heat exchanger, an expansion valve, a second heat exchanger, a compressor and means for reversing the direction of flow of the coolant, characterized in that the coolant comprises 2,3,3,3-tetrafluoropropene. The patent was granted on March 12, 2014. An invalidation was requested by Chemours, and a decision was issued on January 7, 2019 by the Patent Reexamination Board invalidating the patent in full. Arkema appealed to the Beijing Intellectual Property Court; however, the invalidation decision was maintained by the Court on December 24, 2020. The patent owner can still appeal the decision to the Supreme People's Court.

CN 102686695 B (CN ‘695, Arkema)

This patent is a broad description of a “method of choosing” a refrigerant. Reviews by US technical experts raised questions about the legitimacy or enforceability of a patent on what essentially amounts to a thought process. The anticipated expiration date of this patent is December 2030. A status check by Chinese counsel found no history of reexamination, invalidation or litigation. A translation of a representative claim includes:

1. A method of choosing a refrigerant composition for use in a vapor-compression heat transfer system, the method comprising:
 - a. Determining a relatively low operating temperature range of the evaporator effluent in a vapor-compression heat transfer system at;
 - b. Determining a relatively higher operating temperature range of the compressor discharge in the vapor-compression heat transfer system; and
 - c. Selecting a 1st concentration of a tetra propylene refrigerant, the refrigerant is selected from: 2, 3, 3, 3 - tetrafluoropropene (HFO-1234yf), 1, 3, 3, 3 - tetrafluoropropene (HFO-1234ze), or a mixture thereof; and a 2nd concentration of a lubricant, the lubricant is selected from: a polyalkylene glycol (PAG), wherein said refrigerant and said lubricant are miscible at a first temperature within said lower, evaporator discharge operating temperature range of about -60°

C. to about +25° C., and produce a fluid system having a refrigerant-rich phase and a lubricant-rich phase at a second temperature within said upper, compressor discharge operating temperature range of about +15° C. to about +90° C., provided that said second temperature is higher than said first temperature, wherein the lubricant-rich phase has a higher density than the refrigerant-rich phase at said second temperature and wherein a phase inversion temperature is lower than the compressor operating temperature.

CN 103146348 B (CN ‘348, Honeywell)

Honeywell filed this patent in China on April 29, 2005, claiming priority to US Patent Application No. 10/837,525, *i.e.*, US ‘451 as discussed above. In the US, the corresponding patent was challenged and is currently expired due to nonpayment of fees. Like the expired US patent, this Chinese patent covers a heat transfer composition for use in an automobile AC system and apparatus, the heat transfer composition comprising: (i) a refrigerant, comprising at least 50 weight % of 2, 3, 3, 3-tetrafluoropropene (HFO-1234yf); and (ii) a lubricant, selected from the group consisting of polyoxyalkylated glycol (PAG) and/or a polyol ester (POE). The patent was granted on January 13, 2016. Arkema filed a request for invalidation. On January 22, 2017, the Patent Reexamination Board of the China National Intellectual Property Administration (CNIPA) issued a decision indicating the patent is partially invalidated. Both Honeywell and Arkema appealed to the Beijing Intellectual Property Court; however, the Court affirmed the Board’s decision of partial invalidation on October 17, 2019. China’s Supreme People’s Court further affirmed the decision of the Beijing Intellectual Property Court in November 2021. Claims 10, 12, 26, 28, 42 and 44 of the patent survived this legal challenge, which cover a heat transfer composition comprising HFO-1234yf and a lubricant selected from PAG and/or POE, and are estimated to expire on April 29, 2025.

For the ease of review, translation of the surviving/maintained claims is listed below with the corresponding invalidated independent claims (struck through).

~~(Cancelled) 1. A heat transfer composition for use in an automobile AC system and apparatus, the heat transfer composition comprising:~~

~~—— (i) a refrigerant, comprising at least 50 weight % of 2, 3, 3, 3-tetrafluoropropene (HFO-1234yf); ; and~~

~~—— (ii) a lubricant, selected from a polyoxyalkylated glycol (PAG) and/or a polyol ester (POE).~~

(Maintained) 10. The heat transfer composition for use of claim 1, wherein the refrigerant consists of HFO-1234yf.

(Maintained) 12. The heat transfer composition for use of claim 1, wherein ODP of the heat transfer composition is 0 and GWP is not higher than 75i, and wherein the refrigerant consists of HFO-1234yf.

~~(Cancelled) 17. A heat transfer system, comprising: a heat transfer composition of the system, the heat transfer composition comprising: (i) a refrigerant, comprising at least 50 weight % of HFO-1234yf; and (ii) a lubricant comprising a polyoxyalkylated glycol and/or a polyol ester, wherein the heat transfer system is an automobile AC system.~~

(Maintained) 26. The heat transfer system of claim 17, wherein the refrigerant consists of HFO-1234yf.

(Maintained) 28. The heat transfer system of claim 17, wherein ODP of the heat transfer composition is 0 and GWP is not higher than 75i, and wherein the refrigerant consists of HFO-1234yf.

~~(Cancelled) 33. A method of transferring heat to fluid or an object or from fluid or an object, comprising contacting the fluid or object with a composition, wherein the composition comprises~~

~~—— (i) a refrigerant, comprising at least 50 weight % of 2, 3, 3, 3-tetrafluoropropene (HFO-1234yf); and~~

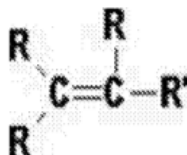
~~—— (ii) a lubricant selected from a polyoxyalkylated glycol and/or a polyol ester, wherein the contacting step comprises circulating the composition in an automobile air conditioner.~~

(Maintained) 42. The method of claim 33, wherein the refrigerant consists of HFO-1234yf.
(Maintained) 44. The method of claim 33, wherein ODP of the heat transfer composition is 0 and GWP is not higher than 75i, and wherein the refrigerant consists of HFO-1234yf.

CN 103215013 B (CN '013, Honeywell)

This patent covers a liquid composition for use in a compression refrigeration, AC and heat pump system, wherein the composition comprises a fluorinated olefin that encompasses HFO-1234yf. It is expected to expire in 2024. No legal challenges have been disclosed as of August 2021. Translation of representative claims:

1. A liquid composition for use in a compression refrigeration, AC and heat pump system, comprising: a) a fluorinated olefin comprising 3 carbon atoms, wherein the fluorinated olefin has the following structure:



wherein each R is independently F or H; R' is $(CR_2)_nY$; Y is CRF_2 , and n is 0; and
b) an effective amount of miscible organic lubricant to provide lubrication, comprising carbon, hydrogen and oxygen, and having an oxygen to carbon ratio effectively in providing a certain miscibility with the fluorinated olefin, such that when the at most 5 weight % of the organic lubricant is added to the fluorinated olefin, the composition is in a liquid phase in at least one of the temperature between -40 and $+70$ °C, wherein the organic lubricant is selected from a polyalkylene glycol, a polyalkylene glycol ester and a polyol ester for uses in a compression refrigeration, AC and heat pump system.

...
24. A method of refrigeration, comprising condensing a refrigerant composition, comprising... and subsequently evaporating the composition near the object to be refrigerated.

...
35. A heating method, comprising condensing a refrigerant composition near the object to be heated, the composition comprising ... and subsequently evaporating the fluorinated olefin composition.

CN 103642461 B (CN '461, Honeywell)

This patent covers a composition for use in a compression refrigeration, AC and heat pump system, wherein the composition comprises a refrigerant that encompasses HFO-1234yf. It is expected to expire in 2024. No legal challenges have been disclosed as of August 2021. Translation of representative claims:

1. A composition for use in a compression refrigeration, AC and heat pump system, the composition comprising:

(A) a refrigerant comprising a fluorinated olefin selected from trans - 1, 3, 3, 3 - tetrafluoropropene or 2, 3, 3, 3 - tetrafluoropropene; and

(B) a lubricant selected from a polyalkylene glycol and a polyol ester, wherein the lubricant at 37 °C has a 10 - 200 centistokes of viscosity, and wherein the lubricant has a certain miscibility with the fluorinated olefin, such that when the at most 5 weight % of the organic lubricant is added to the fluorinated olefin, the composition is in a liquid phase in at least one of the temperatures between -50 and $+70$ °C.

9. A composition for use in a compression refrigeration, AC and heat pump system, the composition comprising:

(A) a refrigerant comprising a fluorinated olefin selected from trans - 1, 3, 3, 3 - tetrafluoropropene or 2, 3, 3, 3 - tetrafluoro olefin; and

(B) a polyalkylene glycol lubricant, wherein the lubricant comprises at least two flexi group of homopolymer or copolymer having a straight-chain or branched chain, and

wherein the lubricant at 37 °C has a 10 - 200 centistokes of viscosity, and wherein the lubricant has a certain miscibility with the fluorinated olefin, such that when the at most 5 weight % of the organic lubricant is added to the fluorinated olefin, the composition is in a liquid phase in at least one of the temperatures between -40 and + 20 °C.

CN 103923610 B (CN ‘610, Honeywell)

This patent covers a composition for use in a compression refrigeration or AC system, wherein the composition comprises a refrigerant that encompasses HFO-1234yf. It is expected to expire in 2024. No legal challenges have been disclosed as of August 2021. Translation of representative claims:

1. A composition for use in a compression refrigeration, or AC system, the composition comprising: (A) a refrigerant comprising a fluorinated olefin selected from trans - 1, 3, 3, 3 - tetrafluoropropene or 2, 3, 3, 3 - tetrafluoropropene; and

(B) a polyalkylene glycol lubricant, wherein one or both of the terminal hydroxy group comprises a 1 - 10 carbon atom long alkyl-terminus, wherein the lubricant at 37 °C has a 10 - 200 centistokes of viscosity, and wherein the lubricant has a certain miscibility with the fluorinated olefin, such that when the at most 5 weight % of the organic lubricant is added to the fluorinated olefin, the composition is in a liquid phase in at least one of the temperature between -50 and + 70 °C.

CN 104164215 B (CN ‘215, Honeywell)

This patent covers a heat transfer composition comprising HFO-1234yf. It is expected to expire in 2025. No legal challenges have been disclosed as of August 2021. Translation of representative claims:

1. A heat transfer composition for use in an automobile AC system and device, the heat transfer composition comprising at least 50 weight % of 2,3,3,3-tetrafluoropropene (HFO-1234yf) and having a GWP of no more than 150.

14. A heat transfer composition for use in an automobile AC system and device, the heat transfer composition comprising at least 50 weight % of 2,3,3,3-tetrafluoropropene (HFO-1234yf)

CN 104194726 B (CN ‘726, Honeywell)

This patent covers a heat transfer composition comprising HFO-1234. It is expected to expire in 2025. No legal challenges have been disclosed as of August 2021. This patent specifies automobile applications as well as other applications. Translation of representative claims:

1. A heat transfer composition for use in a commercial or home refrigerating system, the composition comprising:

(i) at least 50 weight % of HFO-1234; and

(ii) a polyol ester or polyalkylene glycol as a lubricant, wherein the composition has a GWP of no more than 1000.

26. A heat transfer composition for use in a refrigerating system, the composition comprising:

(i) at least 50 weight % HFO-1234;

(ii) one or more of: difluoromethane (HFC-32), ...; and

(iii) a polyol ester or polyalkylene glycol as a lubricant, wherein the composition has a GWP of no more than 1000.

CN 107011862 B (CN ‘862, Honeywell)

Honeywell filed this patent in China on June 26, 2006, claiming priority to US Provisional Patent Application No. 60/693,853 filed on June 24, 2005. It covers a composition for use as a substitute for an existing refrigerant in cooling an electrical or electronic component, the composition comprising at least one fluoroolefin, such as HFO-1234yf, and having a GWP of no more than 500. The patent was granted on March 10, 2020. A request for invalidation was filed by Zhiqiang Wang. On April 6, 2021, the CNIPA Patent Reexamination Board issued a decision invalidating the patent, and setting a time frame for appealing before the Beijing Intellectual Property Court, *i.e.*, until July 6, 2021. No record of any appeal has been made available to the public as of August 2021.

Translation of a representative claim of CN ‘862 relating to HFO-1234yf is provided below:

1. A method of cooling an electronic or electrical component comprising contacting, directly or indirectly, a composition comprising at least one fluoroolefin selected from trans-1-chloro-3, 3, 3-trifluoropropene (trans hydrochlorofluoroolefin (HCFO)-1233zd), cis-1-chloro-3, 3, 3-trifluoropropene (cis HCFO-1233zd), trans-1, 3,3, 3-tetrafluoropropene (trans HFO-1234ze), cis-1, 3,3, 3-tetrafluoropropene (cis HFO-1234ze), 2,3,3, 3-tetrafluoropropene (HFO-1234yf), or combinations thereof, with the electronic or electrical component, wherein the composition has a GWP of no greater than 500.

Other Patents Granted in China that are Possibly of Interest

The following patents were identified as potentially, but not necessarily, pertinent to the use of HFO-1234yf in vehicles, including in certain blends.

Table 5: Other Patents Possibly of Interest

Patent	Description	Expiration
CN 102791840 B (Idemitsu)	Lubricant composition with HFO-1234yf	2031
CN 109072895 B (Hitachi)	Electric compressor for use with HFO-1234yf	2037
CN 103765129B (Arkema)	Use of tetrafluoropropene in the supercritical state for the use of heating a fluid or a body	2032
CN 102482561B (Arkema)	Binary composition consisting of HFO-1234yf and difluoromethane for use as a heat transfer fluid	2030
CN 105567171B (Daikin)	Refrigerant composition with HFO-1234yf used in a variety of applications including vehicle AC	2031
CN 110628388 B (Gree)	Blends of refrigerant including a variety of HFCs and HFOs	2039
CN 109810674 B (Tianjin University and Gree)	A composition in blend comprising HFO-1234yf, R161 and HFC-134a	2039
CN 110845996 B (Gree)	Blend comprising HFC-134a or R227ea, HFO-1234yf, R152aand HFO-1234ze(E)	2039
CN 110591649 B (Gree)	Blend comprising HFC-134a, HFO-1234yf, R227ea and an optional HFO-1234ze(E)	2039
CN 110343509 B (Jiangxi Tianyu Chemical Co)	Blend comprising HFC-134a, HFO-1234ze(E) and HFO-1234yf	2038

CN 102791840 B (CN '840, Idemitsu)

This patent covers a lubricant composition and specifies refrigerator applications, but we are including it here in case it may be relevant. This patent covers a lubricant composition comprising a refrigerant containing HFO-1234yf. This patent is expected to expire in 2031. No legal challenges have been disclosed as of August 2021. Translation of representative claims includes:

1. A lubricant composition for use in a refrigerator, the lubricant composition comprising a refrigerant containing at least one fluorine-containing compound having the following molecular formula of (A), or a combination of the fluorine-containing compound and a saturated fluorinated hydrocarbon compound, wherein the composition further comprises a base oil and at least one sulfur-containing aromatic compound selected from a diphenyl sulfide, a dioctyl diphenyl sulfide, a benzothiophene, or a dibenzothiophene,

CpOqFrRs...(A)

wherein in the formula, R represents any one of Cl, Br, H and I; p is an integer from 1 to 6, q is an integer from 0 to 2, r is an integer from 1 to 14, s is an integer from 0 to 13; wherein when q is 0, p is from 2 to 6, and the compound comprises 1 and more carbon-carbon unsaturated bond.

4. The composition for use of claim 1, wherein the compound described with the molecular formula of (A) is selected from at least one of the following fluorine-containing compounds: an unsaturated fluorinated hydrocarbons compound, a fluorinated ether compound, a fluorinated alcohol compound and a fluorinated ketone compound.

6. The composition for use of claim 4, wherein the said unsaturated fluorinated hydrocarbons compound is selected from at least one of 1,2,3,3,3-pentafluoro-1-propene HFO1225ye, 1,3,3,3-tetrafluoropropene HFO1234ze, and 2,3,3,3-tetrafluoroopropene HFO1234yf.

CN 109072895 B (Hitachi)

This patent covers an electric compressor to compress a refrigerant comprising HFO-1234yf. It is expected to expire in 2037. No legal challenges have been disclosed as of August 2021. Translation of a representative claim:

1. An electric compressor comprising;
in a sealed container, a compression mechanism to compress a refrigerant and an electric motor to drive the compression mechanism, wherein the refrigerant contains more than 20% by weight of hydrofluoroolefin comprising at least one of 2, 3, 3, 3, - tetrafluoropropene, 1, 3, 3, 3- tetrafluoropropene, a trifluoroethylene and 3, 3, 3 - trifluoropropylene,
wherein a refrigerator oil stored in the sealed container contains:
a polyvinyl ether as a base oil,
an alicyclic epoxy compound in an amount of more than 0.1% by weight and less than 2.0% by weight relative to the base oil,
an aliphatic epoxy compound in an amount of more than 0.1% by weight and less than 2.0% by weight relative to the base oil, and
tertiary phosphate in an amount of more than 0.1% by weight and less than 2.0% by weight relative to the base oil l.

CN 103765129B (CN '129, Arkema)

This patent covers a tetrafluoroopropene in the supercritical state for the use of heating a fluid or a body. It is expected to expire in 2032. No legal challenges have been disclosed as of August 2021.

Translation of representative claims:

1. A method for heating a fluid or a body by means of a vapor compression circuit containing a heat-transfer fluid comprising a tetrafluoropropene, the method comprising successively and cyclically, evaporation of the heat-transfer fluid, compression of the heat-transfer fluid, cooling of the heat-transfer fluid and expansion of the heat-transfer fluid, characterized in that the heat-transfer fluid is in the supercritical state at the outcome of the compression, wherein the fluid or body is heated at a temperature higher than or equal to 100 °C.

8. A heat pump apparatus, which comprises a vapor-compression circuit, and a heat transfer fluid comprising tetrafluoroethane and in the vapor-compression circuit, wherein the vapor-compression circuit comprises an evaporator, a compressor, an expansion valve and a cooling device, wherein the heat transfer fluid is in a supercritical state in at least one part of the circuit, and wherein the heat transfer fluid suitable for heating a fluid or a body at a temperature higher than or equal to 100 °C.

13. Tetrafluoroethane in the supercritical state for the use of heating a fluid or a body, wherein the fluid or the body is heated at a temperature higher than or equal to 100 °C.

CN 102482561B (CN ‘561, Arkema)

This patent covers a binary composition consisting of HFO-1234yf and difluoromethane for use as a heat transfer fluid. It is expected to expire in 2030. No legal challenges have been disclosed as of August 2021. Translation of a representative claim:

1. A binary composition consisting of 2, 3, 3, 3-tetrafluoropropene and difluoromethane for use as a heat transfer fluid in a compression-type refrigeration system with an exchanger operating in countercurrent mode or in crossed-current mode with countercurrent tendency, wherein the composition consists of 70-90% by weight of 2, 3, 3, 3-tetrafluoropropene and 10-30% by weight of difluoromethane.

CN 105567171B (CN ‘171, Daikin Industries)

This patent covers uses of a refrigerant composition comprising HFO-1234yf. It is expected to expire in 2031. No legal challenges have been disclosed as of August 2021. Translation of a representative claim:

1. The use of a refrigerant composition, wherein the use is provided in the refrigerant composition to prevent heat exchange efficiency from decreasing due to a temperature glide in a heat exchanger, The refrigerating device for industrial air conditioner, domestic air conditioner, for vehicle air conditioner, heat pump for an automatic vending machine, refrigerator, used for marine transportation container interior cooling refrigerator, turbo-refrigerator, water heating equipment, floor heating equipment or snow melting equipment, Said refrigerant composition comprising difluoromethane HFC32 and 2, 3, 3, 3 - tetrafluoropropene HFO-1234yf, in order to HFC-32 and HFO-1234yf total is 100% when the quality, HFC-32 content is 30 - 50% by weight, HFO-1234yf content is 50 - 70% by weight.

CN 110628388 B (CN ‘388, Gree Electric Appliances Inc. of Zhuhai)

This patent covers a composition in blend comprising R227ea, R1243zf, and either HFC-134a or R152a; or a composition in blend comprising HFC-134a, R1243zf, and HFO-1234ze(E). It is expected to expire in September 2039. No legal challenges have been disclosed as of August 2021. Translation of a representative claim:

1. A working composition suitable for a scroll type compressor, characterized in that said working composition is a near-azeotropic mixture and comprises a first component, a second component and a third component, wherein the first component is 4-44% by weight of either 1,1,1,2,3,3,3-heptafluoropropane (R227ea) or 1,1,1,2-tetrafluoroethane (HFC-134a), the second component is 4-84% by weight of 3,3,3-trifluoropropene (R1243zf), and the third component is 4-84% by weight of one of 1,1,1,2-tetrafluoroethane (HFC-134a), 1,1-difluoroethane (R152a) and trans-1,3,3,3-tetrafluoropropene (HFO-1234ze(E)); wherein when the first component is 1,1,1,2,3,3, 3-heptafluoropropane (R227ea), the third component is either 1,1,1,2-tetrafluoroethane (HFC-134a) or 1,1-difluoroethane (R152a); when the first component is 1,1,1,2-tetrafluoroethane (HFC-134a), the third component is one of trans-1,3,3,3-tetrafluoropropene (HFO-1234ze(E)).

CN 109810674 B (CN ‘674, Tianjin University and Gree Electric Appliances Inc. of Zhuhai)

This patent covers a composition in blend comprising HFO-1234yf, R161 and HFC-134a. It is expected to expire in January 2039. No legal challenges have been disclosed as of August 2021.

Translation of a representative claim:

1. A novel refrigerant replacing HFC-134a characterized by a ternary mixture composed of HFO-1234yf, R161 and HFC-134a, the sum of the concentrations in weight percentages of the components in the mixed refrigerant is 100%, in said mixed refrigerant, HFO-1234yf is 30-60%, R161 is 1-30%, and HFC-134ais 20-50%.

3. A novel refrigerant replacing HFC-134a characterized by a ternary mixture composed of HFO-1234yf, R161 and HFC-134a, the sum of the concentrations in weight percentages of the components in the mixed refrigerant is 100%, in said mixed refrigerant, HFO-1234yf is 70%, R161 is 20%, and HFC-134ais 10%.

CN 110845996 B (CN ‘996, Gree Electric Appliances Inc. of Zhuhai)

This patent covers a composition in blend comprising HFC-134a or R227ea, HFO-1234yf, R152a and HFO-1234ze(E). It is expected to expire in October 2039. No legal challenges have been disclosed as of August 2021. Translation of a representative claim:

1. An environment-friendly refrigerant characterized in that said environment-friendly refrigerant comprises a first component, a second component, a third component and a fourth component, wherein the first component is 28-46% by weight of 1,1,1,2-tetrafluoroethane (HFC-134a), the second component is 1-70% by weight of 2,3,3,3-tetrafluoropropene (HFO-1234yf), the third component is 1-70% by weight of 1,1-difluoroethane (R152a), and the fourth component is 1-60% by weight of trans-1,3,3,3-tetrafluoropropene (HFO-1234ze(E)); wherein the weight percentage is based on the total weight of all components of said environment-friendly refrigerant; and wherein GWP of the environment-friendly refrigerant is less than or equal to 600, and the ODP is 0.

4. An environment-friendly refrigerant characterized in that said environment-friendly refrigerant comprises a first component, a second component, a third component and a fourth component, wherein the first component is 8-17% by weight of 1,1,1,2,3,3,3-heptafluoropropane (R227ea), the second component is 1-90% by weight of 2,3,3,3-tetrafluoropropene (HFO-1234yf), the third component is 1-90% by weight of 1,1-difluoroethane (R152a), and the fourth component is 1-90% by weight of trans-1,3,3,3-tetrafluoropropene (HFO-1234ze(E)); wherein the weight percentage is based on the total weight of all components of said environment-friendly refrigerant; and wherein GWP of the environment-friendly refrigerant is less than or equal to 600, and the ODP is 0.

CN 110591649 B (CN ‘649, Gree Electric Appliances Inc. of Zhuhai)

This patent covers a composition in blend comprising HFC-134a, HFO-1234yf, R227ea and an optional HFO-1234ze(E). It is expected to expire in September 2039. No legal challenges have been disclosed as of August 2021. Translation of a representative claim:

*1. A near-azeotropic working composition characterized in that the near azeotropic working composition comprises four components, wherein
the first component is 30-43% by weight of 1,1,1,2-tetrafluoroethane (HFC-134a);
the second component is 36-68% by weight of 2,3,3,3-tetrafluoropropene (HFO-1234yf);
the third component is 1-22% by weight of trans-1,3,3,3-tetrafluoropropene (HFO-1234ze(E));
the fourth component is 1-6% by weight of 1,1,1,2,3,3,3-heptafluoropropane (R227ea); wherein the weight percentage is based on the total weight of all components of the near-azeotropic working composition.*

*2. A near-azeotropic working composition characterized in that the near azeotropic working composition comprises three components, wherein
the first component is 1-43% by weight of 1,1,1,2-tetrafluoroethane (HFC-134a);
the second component is 56-98% by weight of 2,3,3,3-tetrafluoropropene (HFO-1234yf);
the third component is 1-13% by weight of 1,1,1,2,3,3,3-heptafluoropropane (R227ea); wherein the weight percentage is based on the total weight of all components of the near-azeotropic working composition.*

CN 110343509 B (CN ‘509, Jiangxi Tianyu Chemical Co., Ltd.)

This patent covers a composition in blend comprising HFC-134a, HFO-1234ze(E) and HFO-1234yf. It is expected to expire in April 2038. No legal challenges have been disclosed as of August 2021. Translation of a representative claim:

*1. A non-flammable refrigerant composition with an ODP of 0 and a GWP of 286 or above, characterized in that said refrigerant composition comprises the following components in percentages by weight: 10-22% HFC-134a, 25-69.8% HFO-1234ze(E) and 18.9-65% HFO-1234yf;
said refrigerant composition is a non-flammable azeotropic or near-azeotropic refrigerant mixture.*

Manufacturing Patents

In addition to the patents focusing on use of HFO-1234yf as refrigerant in automobile AC systems, patents have been granted in China covering various routes of manufacturing HFO-1234yf. These manufacturing patents do not directly prevent a company from utilizing HFO-1234yf as refrigerant in automobile AC systems. Legal challenges to patents on the manufacture of HFO-1234yf are discussed briefly here, and may be the topic of a future paper. As manufacturing patents expire, the market price is expected to approach the cost of production through normal competitive forces. Sherry et al. (2017) estimated that production costs could range from US\$13,650 to \$39,025/tonne in contrast to the 2017 market price of US\$80,000/tonne. Costs would decline with expiration or invalidation of patents, economies of scale, process optimization, and integration with production of other fluorinated chemicals.

Example production methods include preparing and further processing one or more of the following intermediate products: Hexafluoropropylene (HFP), 1,1,2,3-tetrachloropropene (1230xa), HCFC-1233xf, HFC-245eb, HCC240db, HCC240aa, 2,3-Dichloro-1,1,1-Trifluoropropane, Chlorotrifluoroethylene and methyl halide, 2-chloro-1,1,1,2-tetrafluoropropane, 1,1,1,2,2-pentafluoropropane, and HCFC-244bb. Exemplary patents include:

- CN 101395108 B (Honeywell; invalidated in full and subject to appeal)
- CN 101415664B (DuPont; estimated to expire in March 2027)
- CN 101535227 B (DuPont; estimated to expire in September 2027)
- CN101550062B (Honeywell; estimated to expire in April 2029)
- CN101684060B (Honeywell; estimated to expire in May 2029)
- CN101772480B (Honeywell; estimated to expire in August 2028)
- CN 101962312 B (Arkema; estimated to expire in July 2030)
- CN101962313B (Arkema; estimated to expire in July 2030)
- CN 101979364 B (Huanxin; partially invalidated and subject to appeal; estimated to expire in September 2030)
- CN102076643B (Arkema; estimated to expire in June 2029)
- CN 102216245B (Arkema; estimated to expire in November 2029)
- CN 102282113 B (Arkema; estimated to expire in January 2030)
- CN102448921B (DuPont; estimated to expire in June 2030)
- CN 102603462 B (DuPont; estimated to expire in November 2026)
- CN102958880B (DuPont; estimated to expire in July 2031)
- CN 103180275 B (Arkema; estimated to expire in October 2030),
- CN 104010999 B (Arkema; estimated to expire in November 2032)
- CN 104136404 B (Honeywell; estimated to expire in February 2033)
- CN104781219B (Chemours; estimated to expire in February 2033)

Besides large international corporations such as Honeywell, Arkema and DuPont, Chinese local companies have joined legal battles in China over the IPR relating to manufacturing HFO-1234yf. One example is Zhejiang Huanxin Fluoro Material Co., Ltd. (referred to herein as Huanxin), which holds a manufacturing patent, CN 101979364 B, as well as at least one pending patent application, CN112778079A.

A request for invalidating Huanxin's CN 101979364B was filed by an individual, Dongyang Miao, and later on January 21, 2021, the CNIPA Patent Reexamination Board issued a decision in which this patent was invalidated in part and maintained in part. No record of any appeal has been made available to the public as of August 2021. Additionally, Huanxin successfully invalidated one of Honeywell's manufacturing patents - CN 101395108 B- in full recently. On September 2, 2021, the CNIPA Patent Reexamination Board issued this invalidation decision, and setting a time frame for appealing before the Beijing Intellectual Property Court, *i.e.*, until December 2, 2021.

4. Summary & Conclusions

Replacing HFC-134a refrigerant in Chinese-manufactured vehicles with a low GWP alternative could eliminate up to one-fifth of global HFC-134a emissions, eliminate 1.5 billion tonnes of CO₂-equivalent by mid-century, and put China on track to meet its HFC phasedown commitments under the Kigali Amendment to the Montreal Protocol. In North America and Europe, most vehicles use low-GWP refrigerant HFO-1234yf instead of HFC-134a. However, in China and developing countries, patent-related concerns have contributed to the slower transition to climate friendly refrigerant alternatives. In Europe, most of the patents filed by Honeywell on HFO-1234yf were challenged and ultimately invalidated. Some corresponding US patents have been similarly challenged and are currently under appeal. In China, by comparison, relatively few patents on HFO-1234yf have been challenged. A summary of the status of legal challenges is presented in Table 5. If remaining legal barriers to the cost-effective use of HFO-1234yf were to be removed, through legal challenge, granting of free license, or otherwise, China and the world could benefit from more rapid transition to climate-friendly refrigerants and cleaner vehicles.

Table 6: Summary of Legal Challenges on Granted Patents Related to Use of HFO-1234yf in Vehicle AC

Patent No.	Initial Challenge	Appeals	Current Status
US 7,279,451	PTO re-examination – all claims rejected.	PTAB affirmed rejections. Appealed to US Court of Appeals for the Federal Circuit (CAFC) – case dismissed as agreed by both Appellant and Appellee.	All claims cancelled, and patent expired.
US 7,534,366	PTO re-examination – all claims rejected.	PTAB affirmed rejections and issued new rejection. Appealed to CAFC.	Waiting for appeal decision from CAFC.
US 8,033,120	PTO re-examination – all claims rejected.	PTAB affirmed rejections and issued new rejection. Appealed to CAFC.	Waiting for appeal decision from CAFC.
US 8,065,882	PTO re-examination – all claims rejected.	PTAB affirmed rejections and issued new rejections in 1 st appeal. PTAB reversed all rejections in 2 nd appeal. Appealed to CAFC – case dismissed as agreed by both Appellant and Appellee.	Patent maintained as amended, with claims relevant to use of HFO-1234yf still in force.
US 9,157,017	Post-grant reviews instituted.	PTAB held all claims unpatentable. Appealed to CAFC, which vacated the decision and remanded the case to PTAB.	Waiting for further PTAB decision in remand.
EP 1563032 B	EPO Opposition Division revoked patent.	EPO Boards of Appeal upheld revocation.	Patent revoked
EP 1716216 B	EPO Opposition Division revoked patent.	EPO Boards of Appeal upheld revocation.	Patent revoked
EP 1725628 B	EPO Opposition Division revoked patent.	Appeal to EPO Boards of Appeal was filed and withdrawn.	Patent revoked
EP 2275509 B	Oppositions filed.	-	Waiting for decision from EPO Opposition division
EP 2277970 B	EPO Opposition Division revoked patent.	-	Patent revoked
EP 2277972 B	EPO Opposition Division revoked patent.	-	Patent revoked
EP 2277977 B	EPO Opposition Division revoked patent.	-	Patent revoked
EP 2314654 B	EPO Opposition Division revoked patent.	Appeal to EPO Boards of Appeal was filed and withdrawn.	Patent revoked
CN 102203209 B	Patent Reexamination Board invalidated the patent in full.	Beijing Intellectual Property Court affirmed the Board’s decision. Patent owner may still appeal to the Supreme People’s Court.	n/a

Patent No.	Initial Challenge	Appeals	Current Status
CN 103146348 B	Patent Reexamination Board invalidated the patent in part.	Beijing Intellectual Property Court affirmed the Board's decision.	Patent invalidated in part and maintained in part, with claims relevant to use of HFO-1234yf still in force.
CN 107011862 B	Patent Reexamination Board invalidated the patent in full.	Patent owner may still appeal to Beijing Intellectual Property Court.	n/a

Appendix A: Patent Review Methodology—China

The search and review of Chinese patents focused on compositions of HFO-1234yf, HFO-1234yf plus a lubricant, or HFO-1234yf plus R-32, as well as their uses as refrigerant in automobile AC. Multiple searches in different databases and based on different languages were performed, among which, two sets of results are considered as most relevant to the targeted subject matter and thus have been further reviewed. In particular, *de novo* searches were performed for Chinese patents relevant to the use of HFO-1234yf as refrigerant in automobile AC, which are not covered by the 2016 report. The English patent search engine, Total Patent One®, was used to search for patents and applications published by the CNIPA having HFO-1234yf in claims as well as AC and automobile or an equivalent term thereof mentioned across the publication. The search query is provided below resulting in 457 hits.

Search string (457 hits):

CLM:(1234 OR tetrafluoropropene) AND FT:(tetrafluoropropene OR 1234yf OR "1,1,1,2-tetrafluoropropene" OR "2,3,3,3-tetrafluoropropene") AND FT:("air conditioning" OR "refrigerant" OR "heat pump") AND FT:("auto" OR "car" OR "automobile")

In collaboration with qualified patent attorneys in China, two additional searches were performed in Chinese language using the CNIPA's database. A specific IPC class was covered in the searches, *i.e.*, C09K5, drawn to heat-transfer, heat-exchange or heat-storage materials, *e.g.*, refrigerants and materials for the production of heat or cold by chemical reactions other than by combustion. The first search for HFO-1234yf and AC or an equivalent term thereof in the claims, resulting in 561 hits. The search further focused by requiring mentioning of automobile or an equivalent term thereof in the patent description, resulting in 292 hits.

Search string (561 hits):

(International Patent Classification (IPC):(C09K5) OR CLMS:(空调 OR 制冷 OR 热泵 OR 传热)) AND CLMS:(HFO-1234yf OR HF0-1234yf OR 1,1,1,2-四氟丙烯 OR 2,3,3,3-四氟丙烯 OR R1234yf OR R-1234yf)

Search string (292 hits):

(IPC:(C09K5) OR CLMS:(空调 OR 制冷 OR 热泵 OR 传热)) AND CLMS:(HFO-1234yf OR HF0-1234yf OR 1,1,1,2-四氟丙烯 OR 2,3,3,3-四氟丙烯 OR R1234yf OR R-1234yf) AND DESC:(汽车 OR 车辆)

All of the granted Chinese patents listed in the search results were reviewed, including about 154 out of 457 hits from the English-language search results and about 226 out of 561 hits from the Chinese-language search results. Chinese patents most relevant to the use of HFO-1234yf as refrigerant in automobile AC are contained in this report.

Acronyms

AC	air conditioning or air conditioner
CAFC	Court of Appeals for the Federal Circuit (US)
CFC	chlorofluorocarbon
CN	China
CNIPA	China National Intellectual Property Administration
CO ₂	carbon dioxide
COP	coefficient of performance
EC	European Commission
EP	European Patent
EPA	Environmental Protection Agency
EPO	European Patent Office
EU	European Union
FCCC	Framework Convention on Climate Change
GHG	greenhouse gas
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HCFO	hydrochlorofluoroolefin
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin
IGSD	Institute for Governance & Sustainable Development
IPC	International Patent Classification
IPCC	Intergovernmental Panel on Climate Change
IPR	intellectual property rights
ODP	ozone-depletion potential
ODS	ozone-depleting substance
PAG	polyalkylene glycol or polyoxyalkylated glycol
PCT	Patent Cooperation Treaty (WIPO)
POE	polyol ester
PTAB	Patent Trial and Appeal Board
PTO	Patent and Trademark Office (US)
R	refrigerant (as in R-134a)
CNIPA	China National Intellectual Property Administration
UNEP	United Nations Environment Programme
US	United States
USPTO	United States Patent and Trademark Office
WIPO	World Intellectual Property Organization
WMO	World Meteorological Organization

Key References

Seidel, Stephen and Christine R. Ethridge. 2016. Status of Legal Challenges: Patents Related to the Use of HFO-1234yf in Auto Air Conditioning. Center for Climate and Energy Solutions and Eckert Seamans Cherin & Mellott. <https://www.c2es.org/wp-content/uploads/2016/07/status-legal-challenges-patents-related-hfo1234yf-auto-ac.pdf>.

Sherry, David, Maria Nolan, Stephen Seidel, and Stephen O. Andersen. 2017. HFO-1234yf: An Examination of Projected Long-Term Costs of Production. Center for Climate and Energy Solutions – C2ES; Nolan Sherry & Associates – NSA; and Institute for Governance & Sustainable Development – IGSD. <https://www.c2es.org/wp-content/uploads/2017/04/hfo-1234yf-examination-projected-long-term-costs-production.pdf>.