The Alliance
for Responsible Atmospheric Policy

April 8, 2020

Dear Chairman Barrasso and Ranking Member Carper:

On behalf of the Alliance for Responsible Atmospheric Policy, we are pleased to submit our written comments on S. 2754, along with an addendum of attachments. Please acknowledge receipt of the documents including the attachments. We look forward to working with the Committee in order to complete this important legislation so that we can begin to achieve the investment, jobs and trade benefits for the US economy.

Please do not hesitate to contact us with additional questions.

Sincerely,

Kevin Fay
Executive Director
Alliance for Responsible Atmospheric Policy

CC:

The Honorable James M. Inhofe
The Honorable Shelley Moore Capito
The Honorable Kevin Cramer
The Honorable Mike Braun
The Honorable Mike Rounds
The Honorable Dan Sullivan
The Honorable John Boozman
The Honorable Roger F. Wicker
The Honorable Richard Shelby
The Honorable Joni Ernst
The Honorable Benjamin L. Cardin
The Honorable Bernard Sanders
The Honorable Sheldon Whitehouse
The Honorable Jeff Merkley
The Honorable Kristen Gillibrand
The Honorable Cory A. Booker
The Honorable Edward Markey
The Honorable Tammy Duckworth
The Honorable Chris Van Hollen

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Testimony of

The Alliance for Responsible Atmospheric Policy

Hearing on S.2754, The American Innovation and Manufacturing Act

Before the U.S. Senate Committee on Environment and Public Works

April 8, 2020

Chairman Barrasso, Ranking Member Carper, and members of the Committee, we are pleased to present testimony on behalf of the Alliance for Responsible Atmospheric Policy (the "Alliance") in support of S.2754, the American Innovation and Manufacturing Act (the "AIM Act").

The Alliance is an organization of industry users and producers of fluorocarbon compounds that was established in 1980 to address concerns of the impacts of these compounds on the Earth's atmosphere, first as ozone depleting substances. Today, the Alliance represents businesses that produce hydrofluorocarbons or HFCs, as well as manufacturers that use HFCs in air conditioning, refrigeration, appliances, foam insulation, foam products, electronics, aerosols, and metered dose inhalers.

Alliance members have worked for three decades to implement Title VI of the Clean Air Act to eliminate the use of ozone depleting substances and to reduce overall environmental impacts. As such, we have worked to introduce compounds and technologies that are more energy efficient, safe, affordable and functional to consumers and to the workers who manufacture these products. These advances have allowed for the continued growth of the global market for these products in the United States and around the globe. These transitions have led us from ozone depleting compounds such as CFCs and HCFCs, to HFC compounds on which we rely today.

Many think that the concern for HFC environmental impacts has only recently emerged. This is not a new issue. HFCs were first commercialized in the early 1990s and became the refrigerant of choice for the air conditioning and refrigeration industry between 2000 and 2010. At the time of commercialization, they were perhaps the most thoroughly studied family of compounds ever introduced. They were the quickest route to replacing the ozone depleting substances. While these compounds provided a quick and safe transition away from ozone depleting substances, it was recognized at that time that HFCs still had a higher global warming potential ("GWP") than was ultimately sustainable. Since then, industry with the support of government, and environmental organizations, have invested and innovated to develop sustainable substitutes for these compounds.

The bipartisan dialogue on what to do about the HFC challenge has been underway for more than a decade, both at the domestic and international level, with particular focus occurring during the administration of George W. Bush, and continuing from then on. As part of this dialogue, in 2013, US industry voluntarily pledged to support policies and take actions to achieve an 80% reduction by 2050 of global emissions of high-GWP HFCs. The dialogue also led to increased research and development as well as examination of policy approaches to achieve the transition to improved, next generation technologies.

U.S. industry, including the fluorocarbon producers, the American HVACR industry, and other use sectors, have now invested billions of dollars in the development of low-GWP compounds and technologies. Industry was also a leading participant in the global development of a policy framework to achieve a cost-effective transition to lower-GWP technologies. That global policy framework is the Kigali Amendment to the Montreal Protocol. It will achieve an 85% reduction of global high-GWP HFC production and consumption by 2047. That framework has now been ratified by 93 countries and the European Union. Every major developed country economy except the United States has adopted programs to achieve this HFC phasedown.

The AIM Act would implement the HFC phasedown in the US, consistent with the global schedule contained in the international agreement that was developed and supported by US industry, as well as government and the environment community. The AIM Act does not ratify the treaty amendment, but it would provide a US policy framework for the investment and implementation of the next -generation technologies that have been developed

The future success of our industries is dependent upon a rational federal transition from HFC refrigerants to new environmentally friendly refrigerants and other use compounds. The Alliance asks for your support of the AIM Act, which facilitates an efficient and cost-effective domestic phase-down of HFCs by providing very narrow authority to the Environmental Protection Agency to transition away from these substances. The most economical transition for manufacturers, distributors, contractors and, ultimately, consumers, is a predictable and rational federal transition.

The AIM Act relies on three key components, a market-based allocation system for the producers of HFC compounds that gradually phases down production and use, a flexible program for user sectors with no impact on existing equipment owners, and a heightened emphasis for improved management of refrigerant substances where relevant.

Industry managed prior efficient and cost-effective federal transitions, which yielded significant consumer cost benefits, while also achieving environmental improvements. The domestic and international phaseout of ozone depleting substances has been one of the most successful policy initiatives in the environmental policy arena. The Montreal Protocol is considered to be one of the most effective treaties ever implemented, and the domestic ODS program was key to that global success, led in part by the effective innovation and implementation from the private sector, and the sensible management of the program by US EPA staff.

The AIM Act builds on this three decades of success, captures what has worked from the Title VI implementation experience and with added improvements and flexibilities based on what has been learned over that time period.

Lessons Learned

Key lessons from the Title VI program include:

(1) the interrelationship of the allocation phasedown schedule for producers and importers, combined with flexible user sector-based programs, is integral to efficient implementation and maintenance of consumer cost benefits

(2) the gradual phasedown (but not a phaseout) schedule, provides appropriate market signals to producers and users to spur investment and innovation while allowing for more cost-effective implementation and minimizing costly transitions that have little environmental benefit

(3) the flexibility built into the technology transition process, contained in Section 10 of the bill, provides greater relief to those user sectors in identifying a transition path or that may have particular difficulty in identifying alternative technologies

(4) a majority of HFC emissions occur during leaks, service and disposal of equipment, therefore, an effective refrigerant management program is a critical component to deal with the environmental impacts of HFCs

In an independent analysis from the University of Maryland's Interindustry Forecasting program (Inforum,) InForum projects implementation of a federal transition as contained in the AIM Act, will stimulate additional investment by the HVACR industry in the United States, generates an additional 33,000 manufacturing jobs over the first decade, improves the balance of trade by $12.5 billion annually, and increases exports by $5 billion. We are providing these full reports on the economic benefits of AIM Act implementation as well as on the consumer cost impacts, as well as a summary power point, for the record of this hearing.

It is clear that the global transition to next-generation technologies is underway. What is not clear is where the investment will be made, and the efficiency with which the transition occurs. At present, the incentive is to push the investment to countries that have implemented a clear and stable policy framework. What is needed now in the United States is just such a framework that provides the gradual transition schedule and transition to these new technologies. That is the objective of the AIM Act. It builds on the success of the Title VI program, but provides greater flexibilities based on the lessons learned over the past three decades.

Chairman Barrasso has cited three areas of concern with the bill as drafted. These include the authority to accelerate the allocation phasedown schedule, contained in Section 7, the implementation of the technology transition, as contained in Section 10, and the related potential need for essential use exemptions; and the need for Federal preemption of State regulatory programs. The Alliance and its members believe that these issues are manageable and are committed to working with the Committee to address them as part of the overall policy framework that is contained in the legislation. The lessons learned from 30 years of experience from Title VI implementation should allow us to effectively address these issues.

Accelerated Schedule

The Section 7 Accelerated Section authority is designed to allow for adjustments to the schedule that are sensible. The authority could not be utilized prior to the first allocation phasedown period (until 2024), and would require consideration of key economic and technology factors before adoption of any revision. Similar accelerated schedule authority existed in Title VI, and the experience was that the authority was used rarely, and only with industry support, and with the assurance of the availability of alternate technologies that provided users a choice.

Technology Transition/Essential Use Exemptions

As stated earlier, the combination of the technology transition for user sectors along with the producer allocation phasedown schedule is a key element to ensure a rational and cost beneficial transition to new technologies. Section 10 also indicates a strong preference towards a consensus process through negotiated rulemaking with the user sectors, and also encourages flexibility by EPA in determining the speed and coverage of categories within the sector. This flexibility is designed to ensure that transitions occur in as efficient a manner as possible. Under Title VI, this flexibility was limited, and reliance on the Significant New Alternatives Program (SNAP) was more used as a "yes or no" decision. Under Section 10, the agency and the user sectors would be able to fine tune schedule decisions as necessary.

This fine-tuning authority, along with the fact that the reductions are a phasedown, rather than a phaseout, should provide ample protection for users who feel that cost-effective technology solutions are not readily available. The Title VI program also had essential use exemption authority, mostly focused on aerospace, defense, and metered dose inhalers. Over the history of the program, according to EPA data, essential use exemptions never exceeded 1% of the overall baseline. We expect similar results with the HFC phasedown experience.

Based on what is currently known about available substitute technologies, the combination of the residual 15% of baseline between now and 2035 and beyond that date, and the essential use exemption authority should be more than adequate to handle user transition concerns. Since the original basis of the HFC phasedown program was the voluntary effort by the industry to transition to low-GWP technologies, users should be assured of the ability to achieve a transition that is economically and environmentally sensible.

Finally, it is also important to keep in mind that the flexibilities provided in Section 10 are key to integrate with the phasedown schedule and essential use exemption authority contained in Section 6.

Federal Preemption

Our view and experience have been that the most effective preemption is to have a credible national program in place. The AIM Act would establish a uniform Federal program that achieves the technology transition in a consistent, predictable and cost-effective manner. Again, history is relevant, as Title VI contained no specific preemption of state programs, but it did include a short pause in enforcement of state programs. It is our recollection that as many as 20 states had early programs on ozone depleting substances, focused primarily on mobile air conditioning and CFC blown food packaging, but those activities ceased once it was clear that a credible Federal program was in place. In this respect, Title VI has been a great success over the last 30 years.

As we have stated, the first and foremost measure to achieve successful implementation and technology transition is a credible Federal program. Adoption of the AIM Act as proposed would obviate the need for future state programs. We are prepared to work with the Committee and all interested parties in identifying an acceptable path forward

We are appreciative of the efforts by Senators Kennedy and Carper in development of this legislation, as well as the broad bipartisan support from the co-sponsors. Also, the US EPA staff has also provided important technical advice on the legislation and has concluded that the framework is capable of implementation. Recently, EPA staff was invited to testify in a House hearing on H.R. 5544, a bill very similar to the Senate bill being considered today. We are attaching for the record the EPA testimony from that hearing. We encourage continued consultation with EPA officials for technical advice.

Much has been raised about the potential costs associated with implementation of this program. The history of the Title VI program again is relevant. According to previous studies of the effort to accomplish the transition away from ozone depleting substances significant savings were achieved. Industry innovation allowed for the transitions to be made as part of design cycles and changes in conjunction with other programs, such as the Department of Energy efficiency standards programs. We attach for the record EPA's summary of the cost benefits of the Title VI program.

In the dialogue over the last two years with EPA and other key officials, it is our understanding that analysis prepared by the White House Council of Economic Advisors and the US EPA have concluded that implementation of the program outlined in the AIM Act would be de minimus or even cost beneficial. According to Senators Kennedy and Carper, reports of EPA preliminary analysis have estimated the cost of implementation of the AIM Act over 15 years could result in consumer cost savings of $3.7 billion or more. We believe that this analyses should be included in the record of this hearing if and when it is released.

The AIM Act simplifies a complicated and confusing existing regulatory structure, relies on known policy approaches and makes improvements from lessons learned. The AIM Act advances American-made technology, provides domestic economic benefits and significant job growth, while facilitating American leadership in this industry around the globe.

Additionally, an effective federal program will also curtail illegal dumping of HFCs into the U.S. as is currently occurring, particularly from countries such as China.

The only debate remaining is the timing of the transition in the United States, the efficiency by which it occurs, and whether our industry maintains its global leadership in the $125 billion global air conditioning and refrigeration market; a market that is also expected to double in the next ten years.

While all other developed economies have begun their transitions, the domestic U.S. HVACR industry is lagging and falling behind both the EU and Asia as a result of the lack of a uniform federal policy.

Failure to pass the AIM Act into law will significantly increase our regulatory burden and may potentially lead to a costly localized refrigerant transition. Instead of investments in research and development and productive manufacturing capacity, industry will manufacture redundant product lines, increase our distribution costs and reduce our inventory turns. Failure to pass the AIM Act means inefficiency wins over innovation and American industry, workers and consumers lose to foreign competition.

Conversely, the AIM Act reduces regulation to a single rational, efficient and cost-effective federal program.

We strongly support smart Federal policy that enables American industry to commercialize its next generation technologies here at home and win an increasingly expanding and competitive global market. We believe that is what S. 2754 offers us.

Importantly, the AIM Act is supported by the impacted industries, the National Association of Manufacturers, the U.S. Chamber of Commerce, and the Natural Resources Defense Council (NRDC). We should take advantage of this rare broad-based support. Historically, the Title VI programs have experienced broad bi-partisan support since 1990. A similar legislative proposal in the House, H.R. 5544, currently enjoys bi-partisan support. We hope that this legislation, S. 2754, will also receive bi-partisan support here in the Senate

The AIM Act provides regulatory simplification, implements smart, market-based and flexible approaches that have proved cost-effective over the years and are projected to do so into the future. It is pro-jobs, pro-trade, pro-American technology leadership, and it is pro-environment. It deserves strong bi-partisan support and we hope that you will give it favorable consideration and quick passage.

In summation:

--The policy community and industry recognized the need to address HFC impacts for more than two decades, it is not a new issue

--The AIM Act and the global response was developed and led by American industry beginning with the pledge in 2013 to "support policies and take actions to reduce the global emissions of high-GWP HFCs 80% by 2050"

--The AIM Act is modeled after Title VI of the Clean Air Act, which has enjoyed continuous strong bipartisan support, and with flexibility provisions based on lessons learned over the last three decades

--Independent analysis projects that a uniform Federal policy will create an additional 33,000 US manufacturing jobs, improve the US trade balance by $12.5 billion annually, and increase US share of the global HVACR export market

--Currently, the failure to embrace a uniform Federal policy is causing an inefficient transition in the United States, and tilting the investment benefits towards global competitors, at the expense of American industry, jobs, and consumers

--The government's own analysis continues to confirm that the Title VI program produced $billions in consumer cost savings and benefits, and also projects the AIM Act will produce at least $3.7 billion in consumer cost savings over the next 15 years

In our view, this is not a hard policy decision. Title VI succeeded over the last 30 years because of a strong partnership of US industry with the government and environment groups. That is why the ozone layer is healing and American consumers are saving money with better technologies, and markets are expanding around the globe. The same can happen with the transition from HFCs to US developed next-generation technologies if we maintain that partnership. Every day that we delay in establishing a uniform Federal policy, the tables are titled more in favor of the economic benefits accruing outside our borders.

These are signature American industries and technologies. Federal indecision is threatening the $billions already invested, and the $billions to be invested to provide these technologies to our domestic market and to the expanding global markets. We support the AIM Act because we know it will work. We have done this before and succeeded. The "issues" that have been raised--accelerated schedule, essential use exemptions, and preemption-- are issues with which we have dealt in the last 30 years. They may be issues, but they should not be problems, because we have dealt with them successfully before and will do so again if we can have an effective dialogue.

We urge the Committee and the Congress to take "yes" for an answer. The Aim Act is a bet on American innovation and supports American manufacturing and leadership. Industry needs your support to compete and win globally.

On behalf of the member s of the Alliance, thank you for the opportunity to provide our views. We look forward to answering questions or providing additional information as may be required.

ADDENDUM

“Economic Impacts of U.S. Ratification of the Kigali Amendment.” Industry Forecasting at the University of Maryland (INFORUM) and JMS Consulting, 2019.

“Consumer Cost Impacts of U.S. Ratification of the Kigali Amendment.” Industry Forecasting at the University of Maryland (INFORUM) and JMS Consulting, 2019.

“Economic & Consumer Impacts of HFC Phasedown” Industry Forecasting at the University of Maryland (INFORUM) and JMS Consulting, 2019.

Cindy Newburg (Director of the Stratospheric Protection Division, U.S. Environmental Protection Agency Legislative Hearing). "Statement on H.R. 5544 before the 2020 Subcommittee on Environment and Climate Change House Energy and Commerce Committee” (Date: 01/14/20).

“Overview of CFC and HCFC Phaseout.” U.S. Environmental Protection Agency, 2018.

“History of Title IX Essential Use Exemptions.” Source: Montreal Protocol Secretariat Data Reporting: U.S. EPA Data

“2020 Members of the Alliance for Responsible Atmospheric Policy.” Alliance for Responsible Atmospheric Policy.

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INFORUM
Interindustry Forecasting at the University of Maryland

In Partnership with

JMS Consulting

Economic Impacts of a U.S. HFC Phasedown

Report Prepared for the
Air-Conditioning, Heating, & Refrigeration Institute
and the
Alliance for Responsible Atmospheric Policy

December, 2019

Authors' Note:

The following report, originally published in April, 2018 was prepared to explore the economic impacts of an HFC phasedown in the United States. The nominal case for a phasedown was chosen to be the schedule and requirements of the Kigali Amendment to the Montreal Protocol, with which the study interviewees were familiar. The "ratification of Kigali" case is equivalent to a phasedown of HFCs using Kigali's timing, regardless of how implemented. The methodology and conclusions of the study are independent of any other considerations related to actual ratification of the amendment by the United States.

Douglas S. Meade, Ph.D.
Joseph M. Steed, Ph.D.

Final Report

Economic Impacts of a U.S. HFC Phasedown

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Abbreviations

A5	Classification for Developing Economies (Article 5)
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ARAP	The Alliance for Responsible Atmospheric Policy
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
CAA	Clean Air Act
CFC	Chlorofluorocarbon
EC	Economic Census
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HS	Harmonized System
HVACR	Heating, Ventilation, Air-Conditioning, and Refrigeration
INFORUM	Interindustry Forecasting at the University of Maryland
IO	Input-Output
MAC	Mobile Air-Conditioning
NAICS	North American Industry Classification System
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substance
SNAP	Significant New Alternatives Policy (EPA)
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Climate Change Convention

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Executive Summary

Industries based on fluorocarbons play a large role in the U.S. economy. The broad industry using fluorocarbons as a refrigerant includes the Heating, Ventilation, Air-Conditioning, and Refrigeration (HVACR) industry, along with the related industries: household appliances and motor vehicle air-conditioning. HVACR equipment includes commercial and residential HVACR and commercial refrigeration and is the largest manufacturing industry using fluorocarbons. Insulating foams, medical metered-dose inhalers, aerosols, and several other applications, along with the production of the fluorocarbons themselves, comprise the rest of the broad fluorocarbon-based U.S. industry. The HVACR and fluorocarbon technologies used globally today are signature American technologies.

U.S. industry strongly supports ratification of the Kigali Amendment to the Montreal Protocol, followed by domestic implementation. The Kigali Amendment provides a global platform for gradual introduction and commercialization of next generation technologies in the U.S. and in the rapidly expanding global market. Prior transitions under the Montreal Protocol enabled these strong U.S. industries to maintain their technology leadership. The new Kigali Amendment, which creates a clear path toward global adoption, will have a similar effect.

The economic size of the U.S. industries based on fluorocarbons has been analyzed using Economic Census data and economic models. The impact of Kigali was assessed using industry interviews and surveys and additional modeling, based on current industry trends and the experience of prior transitions under the Montreal Protocol.

The economic analysis indicates that U.S. implementation of the Kigali Amendment is good for American jobs. It will both strengthen America's exports and weaken the market for imported products. Finally, it will enable U.S. technology to continue its world leadership role.

Background on the Kigali Amendment

The Kigali Amendment to the Montreal Protocol was agreed upon at a meeting of more than 170 countries in October 2016. It has since been ratified by a sufficient number of countries to enter into effect globally on January 1 2019, but it has not yet been ratified by the U.S. The agreement establishes timetables for all developed and developing countries to freeze and then to reduce their production and use of HFCs, chemicals that are used widely by the U.S. and global industries. HFCs will be eliminated over time for most uses, and they will be replaced with a new generation of alternative chemicals and products that are more climate-friendly and more energy-efficient.

Under the Montreal Protocol, the global fluorocarbon-using industries have undergone two prior transitions. In each case, U.S. industries were able to use their technological strengths to play a major role in defining the new generation technologies. New technology and manufacturing investments were made in the U.S., and U.S. manufacturers led the way as the world moved toward new technologies.

It is important that the transitions have been defined in such a way that older equipment can continue to be serviced with existing fluorocarbons and need not be replaced before the end of its useful life, minimizing consumer impact. In HVACR industries, gains in energy efficiency have helped balance added equipment and refrigerant costs when equipment does need to be replaced, with very short payback times. Kigali adopts the same phased approach.

The Montreal Protocol is recognized as perhaps the most successful global agreement of any kind. It has also been good for the U.S. economy. The Kigali Amendment will continue this economically beneficial effect.

Industry Summary

An analysis has been done of the broad fluorocarbon industries to determine their economic footprint in 2016. All segments of the using and producing industries were assessed, with a focus on HVACR, the largest component. The size of the direct industries is based on Economic Census data and industry interviews. Indirect and induced impacts have been estimated with Inforum economic models. Growth of the industries over time is based on economic models combined with industry input on observed trends. The growth information was used to bring the 2012 Economic Census data forward to 2016.

Fluorocarbon-based **manufacturing** industries in the U.S. include the broad HVACR industry, mobile air-conditioning, home appliances, insulating foams, medical metered-dose inhalers, aerosols, and other segments, plus fluorocarbon manufacture. A number of **downstream** businesses are also fully dependent on these products. HVACR installation and service contracting, distribution, repair, and maintenance comprise the rest of the industries' direct employment. Together, these industries directly employ 589,000 Americans, with a $39 billion per year payroll. Total **direct** output is $205 billion per year in products and services.

Each component of these industries also creates demand for its suppliers' products, resulting in a large supply chain contribution to the economy. These **indirect** effects add 494,000 jobs with a $36 billion per year payroll, and $126.5 billion per year in economic output.

The combined direct and indirect employment creates additional demand that, in turn, leads to additional economic activity. This **induced** economic activity is estimated to employ 1,463,000 people, with an $82 billion per year payroll and an additional output of $290 billion per year.

Figure E.1 Total Employment, 2016
Units: Thousand Persons

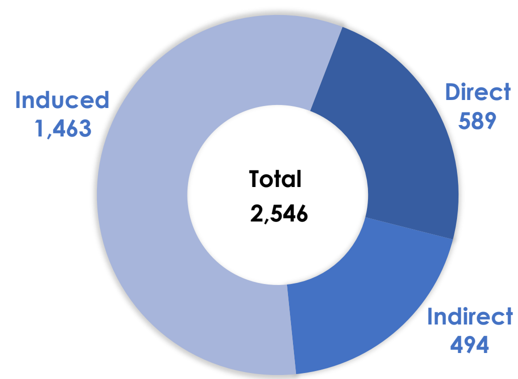
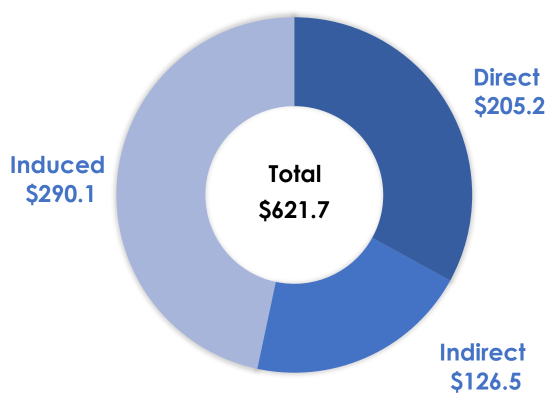


Figure E.2 Total Output, 2016
Units: Billion $



In **total**, the direct manufacturing and downstream industries, along with their indirect and induced contributions, account for more than 2.5 million U.S. jobs and a total economic output of $621 billion per year.

For manufacturing alone (excluding downstream businesses), the total direct, indirect, and induced contributions are 671,000 jobs with an economic output of $178 billion per year.

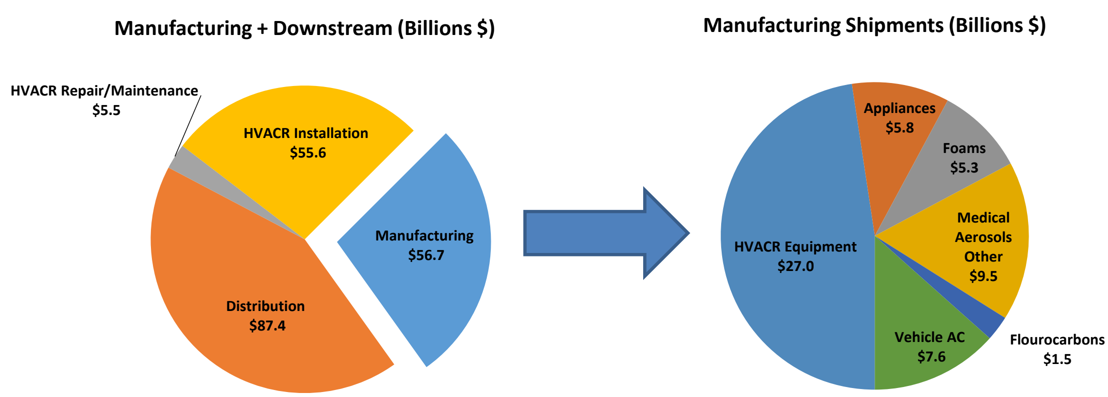
Industry Segments

The direct manufacturing output of the broad fluorocarbon industries is $56.7 billion per year in goods and services. Downstream distribution, installation contracting, repair, and maintenance are almost three times the manufacturing contribution and make up the remainder of the total direct output of $205 billion per year. All of the downstream industries provide services in support of HVACR equipment, vehicle AC, and appliances and can be considered part of a network of industries relying on fluorocarbons.

Within the manufacturing component, HVACR equipment contributes $27.0 billion, almost half the total. Manufacturing output of HVACR and related equipment – that is, including vehicle AC and appliances – is $40.4 billion, more than 70 percent of the total.

Fluorocarbons typically represent only a small, if essential, part of manufactured products, and their contribution is $1.5 billion. Insulating foams add $5.3 billion, and output of all other products is $9.5 billion.

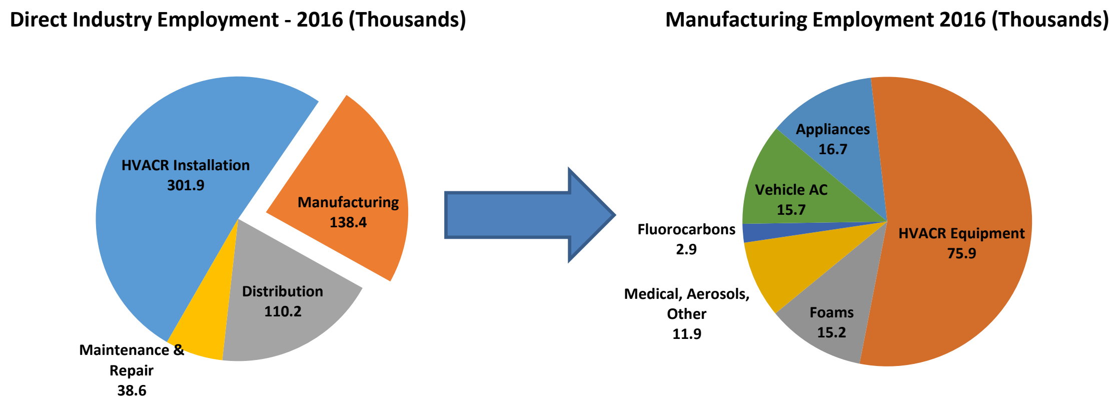
Figure E.3 Manufacturing and Downstream Output, 2016



Direct employment is distributed similarly. Manufacturing employs 138,400 Americans, with the downstream HVACR components adding 450,700 more. Most of the downstream jobs are in the labor-intensive HVACR installation contractor segment.

Within manufacturing, HVACR equipment, vehicle AC, and appliances together employ 108,400 of the 138,400 thousand total manufacturing employees. The manufacture of insulating foams employs 15,200, and fluorocarbon manufacture and specialized uses employ the remaining 14,800.

Figure E.4 Manufacturing and Downstream Employment, 2016



Industry Trends

Most of the fluorocarbon-based industries have significant growth opportunities in global markets. In particular, the international market for HVACR is expected to more than double over the next ten years, for a cumulative output of more than $1 trillion, driven by expanded use of cooling and refrigeration in the developing world.

Most developed countries are already transitioning to new technologies consistent with Kigali Amendment requirements. Developing countries, under the Montreal Protocol's staggered implementation, will be completing their transition away from ozone-depleting substances. This transition will be at its peak between now and 2047. The result is a large market opportunity for new technologies.

From the time of its creation, the U.S. HVACR industry has led global innovation. The industry's new technology capabilities enabled it to lead previous transitions under the Montreal Protocol, spreading U.S. technology throughout the world. Commercialization of next generation technologies is essential to complete the Montreal Protocol and Kigali Amendment transitions. With a typical design cycle of 5-10 years, decisions are being made now.

Investments in next generation refrigerants and equipment technologies are already underway. In 2015, members of the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), representing 90% of U.S. HVACR manufacturing, committed $5 billion through 2025 in R&D and capital investment to commercialize high efficiency equipment using next generation refrigerants. American investments in R&D and capacity for Kigali-related growth will generate 1,400 jobs and $1 billion in capital investment if Kigali is ratified. These jobs and investment are at risk if the U.S. government fails to act. Without ratification by the U.S., manufacturing and R&D for new technologies will move to the international markets where local demand for the new technologies justifies the investment.

To be competitive in growing international markets, American industry must again lead the transition to new technologies. Without the regulatory certainty of a firm Kigali timetable, any transition in the U.S. will likely be delayed, allowing others to move into leadership roles or driving U.S. industry toward offshore rather than domestic investment and employment in order to stay competitive.

Impact of Kigali Ratification

The U.S. HVACR industry is expected to experience very different levels of economic growth and revenues depending on whether the U.S. ratifies the Kigali Amendment. To examine the impact of the decision of whether or not to ratify, the industry analysis has been carried forward to 2027, again based on both economic models and industry interviews, along with industry surveys. Two cases were examined: with Kigali ratification and without.

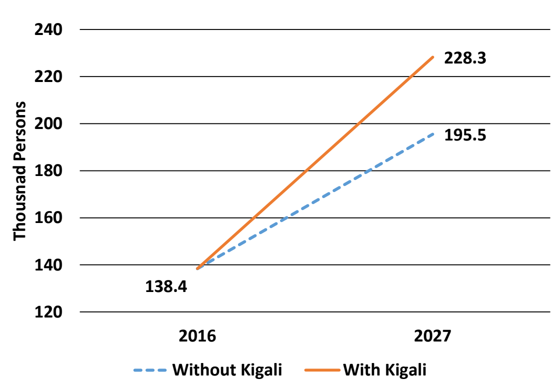
Ratification of Kigali will provide regulatory stability and long-term market information to support domestic investment in new technologies to serve both domestic and global markets. Implementation in the U.S. will support significantly increased exports to growing global markets. Similarly, the market for imported, mostly older technology will have limited growth. The improvement in net trade compared with a "without Kigali" forecast will lead to additional economic growth if Kigali is ratified.

Jobs and Economic Output

Global industry growth will drive an increase in U.S. jobs, even without Kigali ratification. The 138,000 direct manufacturing jobs in 2016 would grow to 195,000 by 2027. However, with U.S. ratification of Kigali, we expect that an additional 33,000 jobs would be created, for a total of 228,000. Adding in the indirect and induced effects to estimate the total impact, the number of additional jobs gained with Kigali ratification would rise to 150,000.

Although not included in the overall analysis, reclaimed refrigerants would also benefit from Kigali ratification. Reclaimed HFCs, now much lower in volume than older refrigerants, would become an important part of servicing existing equipment. Reclaim sales are estimated to increase by $0.8 billion per year with Kigali, adding another 4,000 jobs. The manufacturing and reclaim jobs are in addition to the 1,400 research and development jobs expected for the U.S. if Kigali is ratified.

Figure E.5 Direct Manufacturing Employment
Units: Thousand Persons

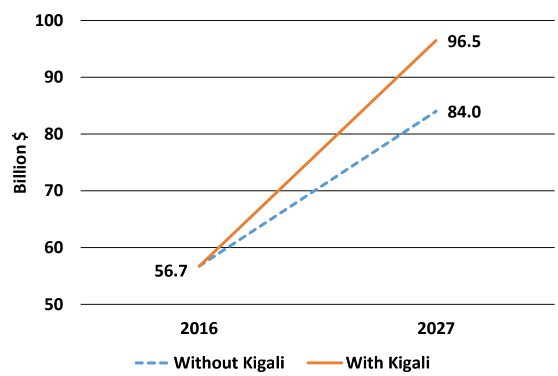


Job growth is driven by similar growth in economic output. Direct manufacturing output of $56.7 billion per year is expected to grow to $84 billion even without ratification. Kigali ratification would add $12.5 billion per year in direct output, bringing the total to $96.5

billion. When the indirect and induced impacts are included, the benefit of Kigali ratification would rise to $38.8 billion per year in additional economic output.

Figure E.6 Direct Manufacturing Output

Units: Billion $



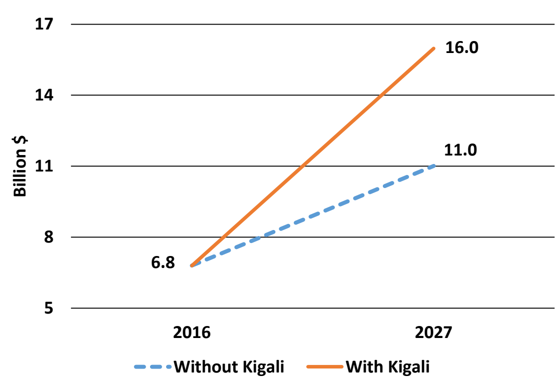
Global Trade

Kigali ratification in the U.S. will support domestic investment in HVACR not only to serve U.S. markets, but also to participate more fully in global market growth through exports. Global customers will be more eager to buy from the market's technology leaders as they make their transitions. U.S. industries will leverage their domestic investments to supply both local and export markets.

In 2016, U.S. exports of HVACR and related equipment and services totaled $6.8 billion. Without Kigali, overall market growth would drive an increase to $11.0 billion per year by 2027, although the U.S. share of the global export market would decline. Exports with Kigali will grow to $16.0 billion per year, a benefit of $5.0 billion from ratification.

Figure E.7 U.S. HVACR and Related Equipment Exports

Units: Billion $

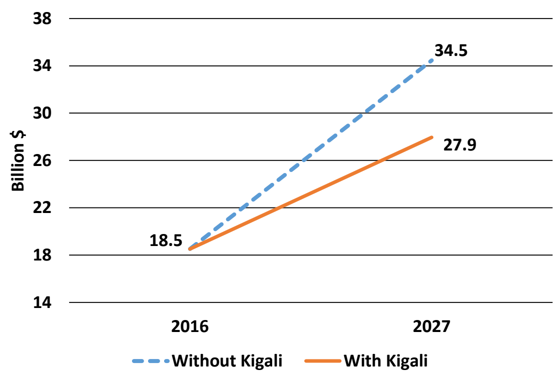


There is an even larger effect on imports. The U.S. in 2016 imported $18.5 billion worth of HVACR and related equipment. A significant part of the imports is made up of old technology products, which are lower in energy efficiency and will soon to be phased out in developed countries that have ratified Kigali. Without Kigali ratification, those imports would grow to $34.5 billion in 2027.

Kigali ratification will inhibit import growth, with imports reaching only $27.9 billion by 2027, for a benefit of $6.5 billion in reduced imports. U.S. manufacturers will reap that benefit in additional sales to keep the U.S. market fully supplied.

Figure E.8 U.S. HVACR and Related Equipment Imports

Units: Billion $



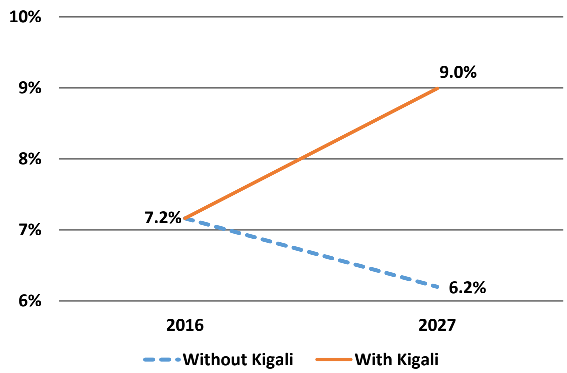
Although impacts on fluorocarbon manufacture were not included in the jobs and economic output numbers, this segment is also expected to experience a trade benefit through increased exports of new technology refrigerants and decreased imports of old technology products. The net improvement in trade balance is estimated to be $1.0 billion per year.

The total improvement in U.S. trade balance with Kigali ratification would be more than $12.5 billion per year.

Increased participation in global export markets is an important factor in maintaining the technological and economic strength of the U.S. HVACR industry. The export market will grow by 6 percent per year over the next decade to meet the needs of China, India, Latin America, and Africa. The U.S. share of that market is currently 7.2 percent as the use of old technology has continued to grow. Without Kigali ratification, the U.S.'s global market share will slip to 6.2 percent over the next decade.

Domestic investments in new technology to meet Kigali requirements will enable the U.S. to outperform in the export market, increasing the U.S. global export market share to 9.0 percent.

Figure E.9 U.S. Share of World HVACR and Related Equipment Export Markets



Conclusion

The manufacturing and service industries dependent upon fluorocarbons have been built on signature American technologies and have a history of leadership in global markets. Together they make large and important contributions to U.S. employment and economic output.

Like the Montreal Protocol, the Kigali Amendment will create demand for another new generation of technology. This is especially true for HVACR, which is experiencing significant global growth as developing countries around the world increasingly employ cooling and refrigeration.

The U.S. industry historically has been the global leader, building on a strong domestic base and expanding the use of new technology globally. The changes driven by the Montreal Protocol have strengthened and expanded that U.S. leadership. But now, the ratification of Kigali is crucial to continuing that pattern and maintaining U.S. leadership. Without Kigali ratification, growth opportunities will be lost along with the jobs to support that growth, the trade deficit will grow, and the U.S. share of global export markets will decline.

1. Introduction

The Montreal Protocol is an international treaty designed to protect the ozone layer. Taking effect in 1989, the agreement required the phase-out of chlorofluorocarbons (CFCs). Hydrofluorocarbons (HFCs) were originally introduced in order to achieve a rapid response as a replacement for ozone-depleting substances. In subsequent years, however, the science and technology communities shared concerns regarding the potential impacts of HFCs on the atmosphere and expressed the desire to replace them with next generation technologies.

On October 15, 2016, representatives from more than 170 countries met in Kigali, Rwanda, to develop the Kigali Amendment to the Montreal Protocol. The aim of the Amendment is to reduce worldwide use of HFCs. Under the agreement, developed countries would begin reducing their use of HFCs by 2019, while developing countries would start their reductions by 2024. The goal is to reduce HFC use by 85 percent by 2047 and replace them with hydrofluoroolefins (HFOs), which have far less impact on the atmosphere.

This Amendment is subject to Senate ratification in the U.S. but will formally take effect globally on January 1, 2019 whether or not the U.S. ratifies. Canada announced in November 2017 that it would join more than two dozen other countries in backing the agreement. Another significant signatory country is the UK, which ratified the amendment in October 2017.

The transition from CFCs to HFCs resulted in a 90 percent reduction of global warming potential (GWP). Replacing HFCs with next generation technologies such as HFOs is expected to reduce global warming potential an additional 90 percent.[1] Some concerns exist that replacement HFOs will cost more than the HFCs they are replacing.[2] However, history and past experience with these types of technology transitions in the U.S. demonstrate that, for most uses, the cost increase will be a marginal part of product cost, and that the costs will come down over time. Furthermore, because this is a phase-down transition rather than a phase-out, consumers will have significant latitude in choosing when to replace older equipment. The newer models of air conditioners, refrigerators, and other equipment will save money in other ways, such as reduced energy use.

1.1 Study Objectives

This study has two main objectives:

1. Establish the economic "footprint" of the fluorocarbon and refrigerants industries, as well as the industries that comprise the fluorocarbon "network" of industries, including HVACR equipment, vapor-compression home appliances (refrigerators, freezers, water heaters), mobile air conditioners (MACs), foams, and other specialized uses, such as aerosols and MDIs. We also look at the downstream industry impacts,

[1] See UNEP (2017).
[2] For example, Michaels (2018).

including wholesale distribution, repair and maintenance, and installation contractors.
2. Perform a scenario analysis of the potential impacts of the U.S. ratification of the Kigali Amendment. This scenario analysis will develop a "without Kigali" case that represents a continuation of current policy in the U.S. In this scenario the U.S. does not ratify, but the rest of the world implements Kigali. We contrast this with a case including Kigali adoption, which will be called "with Kigali". The driving assumption is the effects of Kigali ratification on enabling an increase in the U.S. exports of HVACR equipment and fluorocarbons, and a reduction in the share of imports.

In many ways, the achievement of the first objective sets the stage for the second, as it is through understanding and quantifying the current economic situation in the relevant industries that we can intelligently construct alternative scenarios.

1.2 Background

Although the goals of the Kigali Amendment are laudable, policymakers in the U.S. would like to understand better the economic consequences of Kigali ratification. The current study applies historical data from the U.S. Bureau of Census and the Bureau of Economic Analysis (BEA) to understand the current economic contribution of the fluorocarbon, HVACR, and related industries to the U.S. economy.

We then apply input-output (IO) tools developed by Inforum to project how these industries may change over a 10-year (or longer) period, with and without Kigali ratification.

JMS Consulting has extensive experience in working with the chemicals and HVACR industries. A study completed in 2013[3] provided an earlier analysis of the economic impact of the network of industries related to fluorocarbon production.

Inforum specializes in input-output and industry modeling at the national and regional levels, and also has extensive experience in international trade analysis. Inforum maintains a large database of bilateral imports and exports by Harmonized System (HS) 4-digit products, which is used for the Inforum bilateral trade model of the largest world economies. Inforum recently worked with the Center for Manufacturing Research of the National Association of Manufacturers to complete an industry analysis at the national and regional level for the Air-Conditioning, Heating, & Refrigeration Institute (AHRI).[4]

1.3 Footprint, World Trade, and Scenario Analysis

The footprint analysis, described in section 2, proceeds by first compiling Census data on the various focus industries classified in the manufacturing, wholesale trade, repair and maintenance, and contracting sectors. These data are based primarily on the 2012 Economic Census. We then construct a time series of compatible data, using annual data available from the Bureau of Census and the BEA. Most of these data have been

[3] See Steed (2013), *Fluorocarbon Industry Economic Analysis*,
[4] Center for Manufacturing Research and Inforum (2017).

compiled into a database for a large IO model developed by Inforum named *Iliad* that contains 352 industries comprising the U.S. economy. This model shows the sources of demand for each industry, as well as what they buy from upstream or supplier industries.

In section 3, we investigate patterns of world trade in fluorocarbons and HVACR equipment, primarily using data available from the United Nations (UN) Comtrade database. The goal in this analysis is to understand world trade patterns by country, particularly in relation to the U.S. This knowledge helps inform the development of the scenario analysis, in which changes in world trade are the driving factor.

The framing and execution of modeling the scenarios is described in section 4. We develop alternative trade scenarios based on interviews and conversations with industry economists from relevant producing companies. We then apply the key findings of these interviews to the construction of two alternative scenarios, "without Kigali" and "with Kigali", and calculate the total economic impact using IO analysis.

2. Current Economic Footprint

This section describes the set of manufacturing industries that produce and use fluorocarbons and other refrigerants. Manufacturing industries that are important users of fluorocarbons and refrigerants include:

- Refrigeration and air-conditioning equipment
- Household refrigerators and home freezers
- Water heaters
- Motor vehicle air conditioners
- Polystyrene and polyurethane foam
- Medical MDIs (Metered dose inhalers)
- Aerosols
- Fluoropolymers and process agents

The economic footprint also includes the important downstream industries that owe their existence to these manufacturers, such as wholesale trade, maintenance and repair, and installation and service contractors. The footprint measures the economic activity of these focus industries by several metrics. Economic activity can be measured as output (production), employment, payroll, and total value added.

2.1 Overview

This section provides important background information for the industries considered as part of the *fluorocarbon network*, which is defined as the industries that produce fluorocarbons and other refrigerants, the products that rely on fluorocarbons as an important and necessary component, and the downstream industries that sell, maintain, and install equipment. Section 2.2 describes the industry segments that comprise this fluorocarbon network. Section 2.3 presents data for these segments in historical context. Finally, section 2.4 presents the footprint analysis for 2016, which is the last year of historical data.

2.2 Industry Segments

2.2.1 Manufacturing Industries

Refrigerants

Fluorocarbon Manufacturing includes all the hydrofluorocarbons (HFCs) and other fluorocarbons used as refrigerants.

The other manufacturing industries represent the markets into which fluorocarbons are sold.

Refrigeration and Air-Conditioning Equipment Manufacturing

Refrigeration and Air-Conditioning Equipment Manufacturing includes residential air conditioners as well as commercial applications like industrial chillers and rooftop units, commercial refrigeration, and refrigerated transport. The full range of air-conditioning applications is included, such as unitary air-conditioning, window units, split systems, heat pumps, and dehumidifiers. Beyond the direct manufacture of equipment in this category, it is important to consider the manufacture of compressors and other components designed for specific fluorocarbon refrigerants. All commercial and residential air-conditioning and refrigeration applications are grouped into a single segment for purposes of the study, except for mobile air-conditioning and home appliances. A very small percentage of commercial units may employ other refrigerants, but these have not been excluded.

Household Appliances

Household Refrigerators and Home Freezers and **Water Heaters** employ fluorocarbons either as a refrigerant or as a component of insulating foam. Although some appliances use alternate refrigerants or foam-blowing agents, there is no available measure of the portion containing no fluorocarbons in either use. Because the alternates are all chosen for their reduced GWP, the entire category is retained for the analysis.

Motor Vehicle Air-Conditioning Equipment Manufacturing

The vast majority of motor vehicles include air-conditioning in the U.S., comprising a significant application for fluorocarbons. The **Motor Vehicle Air-Conditioning Equipment** industry, including compressors and other components, is included in a separately reported segment. The reported estimates may also include a small portion of units employing other refrigerants.

Foams

The foam manufacturing industry uses fluorocarbons as blowing agents for certain types of foams where the fluorocarbons are retained within the foams for their insulating or cushioning value. These represent only a portion of all foams, primarily transportation and construction products made with either **Polyurethane Foam** or **Polystyrene Foam**, and shipping pads made with polyurethane foam.

Other

Fluorocarbons serve as propellants for metered dose inhalers (MDIs) used by the pharmaceutical industry for delivery of respiratory drugs. The **Medical – MDIs** segment as reported here includes only HFCs and not any remaining uses of CFCs or HCFCs.

The greater part of the fluorocarbon involvement in the **Aerosols** industry disappeared when CFCs were banned from this application several decades ago. However, HCFCs were employed for certain applications for a time and some remaining applications, especially hairsprays, colognes, perfumes, and room and personal deodorants use HFCs today.

Fluorocarbons are also used in the production of other materials, either as a raw material consumed to make the new materials or as a process agent that makes production of the new materials possible. Fluoropolymer manufacturing uses fluorocarbons as the raw material (consumed in the process) to manufacture thermoplastic resins, plastics, and elastomers. Fluorocarbons are used as process agents in the manufacture of certain nonwoven materials and manufactured fibers. Because there are relatively few manufacturers involved in these often-proprietary processes, these applications are grouped for reporting purposes as **Fluoropolymers and Process Agents**.

2.2.2 Repair and Maintenance

Most of the manufacturing industries served by fluorocarbons lead to retail products which are used and eventually disposed of without servicing or repair, or where any repairs do not involve the fluorocarbon components. However, the large manufacturing segments producing air-conditioning and refrigeration equipment, and household appliances lead to products that are often serviced repeatedly throughout their lifetimes. An important element is that the repair and maintenance activities generally involve the addition and/or recovery and replacement of refrigerants.

Heating, Air-Conditioning, and Radiator System Repair Services for Cars and Light Trucks are dedicated to servicing air-conditioning units in automobiles.

Commercial Refrigeration Equipment Maintenance and Repair service equipment, including industrial chillers and roof-top units, in commercial environments.

Appliances and Household Equipment Maintenance and Repair help ensure that home appliances (refrigerators, freezers, and water heaters) are maintained and functioning.

2.2.3 Wholesale

The wholesale distribution of air-conditioning and refrigeration equipment is often conducted by businesses covering the full range of heating, ventilation, and air-conditioning, of which air-conditioning is a large part and can be identified and reported separately as Air-Conditioning Wholesalers.

Household Appliances, Electric Housewares, and Consumer Electronics Merchant Wholesalers engage in the distribution of refrigerators, freezers, and water heaters.

Warm Air Heating and Air-Conditioning Equipment and Supplies Merchant Wholesalers sell air-conditioning and heating units for residential, commercial, and industrial customers.

Refrigeration Equipment and Supplies Merchant Wholesalers distribute refrigeration equipment and related parts to commercial industry.

2.2.4 Contractors

Air-Conditioning Installation contractors are responsible for the initial installation of air-conditioning and related equipment and may provide ongoing servicing as part of their contract offering.

2.3 Historical Data

2.3.1 Shipments and Receipts

Shipments and receipts data are available from the *Economic Census* and several annual surveys produced by the Bureau of Census. In table 2.1, we have summarized the shipments for the focus industries, and provided subtotals for manufacturing, wholesale trade, repair and maintenance, and contractors, from 2008 to 2016.[5]

Table 2.1 Value of Shipments/Receipts
Units: Million $

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Fluorocarbon Mfg.	1,989	1,438	1,535	1,638	1,754	1,752	1,740	1,574	1,523
Refrig. & AC Equip.	24,312	21,872	22,760	24,080	25,273	26,055	25,720	26,933	27,033
Home Appliances	6,668	5,398	5,363	5,446	5,705	5,537	5,917	6,027	5,778
Motor Vehicle Air Conditioning	4,918	3,768	4,789	5,257	5,991	6,290	6,891	7,124	7,571
Polystyrene Foam	1,968	1,617	1,740	1,856	2,010	2,096	2,111	2,160	2,205
Polyurethane Foam	2,745	2,255	2,427	2,588	2,803	2,923	2,944	3,012	3,076
Medical - MDIs	4,450	4,004	4,166	4,408	4,626	4,769	4,708	4,930	4,949
Aerosols	1,447	1,302	1,355	1,434	1,505	1,551	1,531	1,604	1,610
Fluoropolymers and Process Agents	2,669	2,401	2,499	2,644	2,775	2,861	2,824	2,957	2,968
Manufacturing Subtotal	**51,167**	**44,055**	**46,635**	**49,350**	**52,442**	**53,835**	**54,386**	**56,321**	**56,712**
Household Appliances Wholesalers	20,285	18,249	18,990	20,091	21,087	21,739	21,460	22,472	22,554
Heating and AC equipment Wholesalers	43,493	39,128	40,716	43,078	45,212	46,611	46,013	48,182	48,359
Refrig. Equip. Wholesalers	14,810	13,324	13,865	14,669	15,396	15,872	15,668	16,407	16,467
Wholesale Subtotal	**78,588**	**70,700**	**73,571**	**77,839**	**81,695**	**84,223**	**83,141**	**87,061**	**87,381**
Auto Heating, AC, Radiator Repair	2,421	2,203	2,483	2,562	2,721	2,810	2,946	3,085	3,171
Commercial Refrig. Equip Repair	1,335	1,130	1,224	1,365	1,457	1,502	1,581	1,601	1,585
Appliances & Household Equip. Repair	574	514	541	567	605	635	662	700	723
Repair and Maintenance Subtotal	**4,330**	**3,847**	**4,249**	**4,494**	**4,782**	**4,947**	**5,189**	**5,386**	**5,480**
Air Conditioning Installation	47,345	42,593	44,673	45,282	49,120	51,330	53,046	54,378	55,586
Contractors Subtotal	**47,345**	**42,593**	**44,673**	**45,282**	**49,120**	**51,330**	**53,046**	**54,378**	**55,586**
Grand Total	**181,429**	**161,195**	**169,127**	**176,965**	**188,039**	**194,334**	**195,762**	**203,145**	**205,158**

Table 2.2 summarizes historical growth rates of the major segments, divided into several distinct periods that illustrate recent macroeconomic cyclical patterns. From 1998 to 2002, this set of industries showed a slight decline (-0.3 percent per year), with the strongest growth being in repair and maintenance (3.4 percent per year). Manufacturing growth was slightly positive, while wholesalers and contractors both declined. This was the period of the "dot-com" recession. During this period, telecommunications and computing services recorded steep declines. However, other investment goods and household durables, such as heating and air-conditioning, also experienced contraction. The period 2002 to 2008 showed fairly healthy growth, averaging 3.3 percent per year, with wholesalers and contractors growing more strongly, at 3.6 percent per year. All major segments experienced a large decline from 2008 to 2009, during the Great Recession. Growth since then has returned to an average of 3.4 percent per year, similar to that of the 2002 to 2008 period. Average growth for the combined set of industry

[5] Appendix A.1 describes the derivation of these data in more detail.

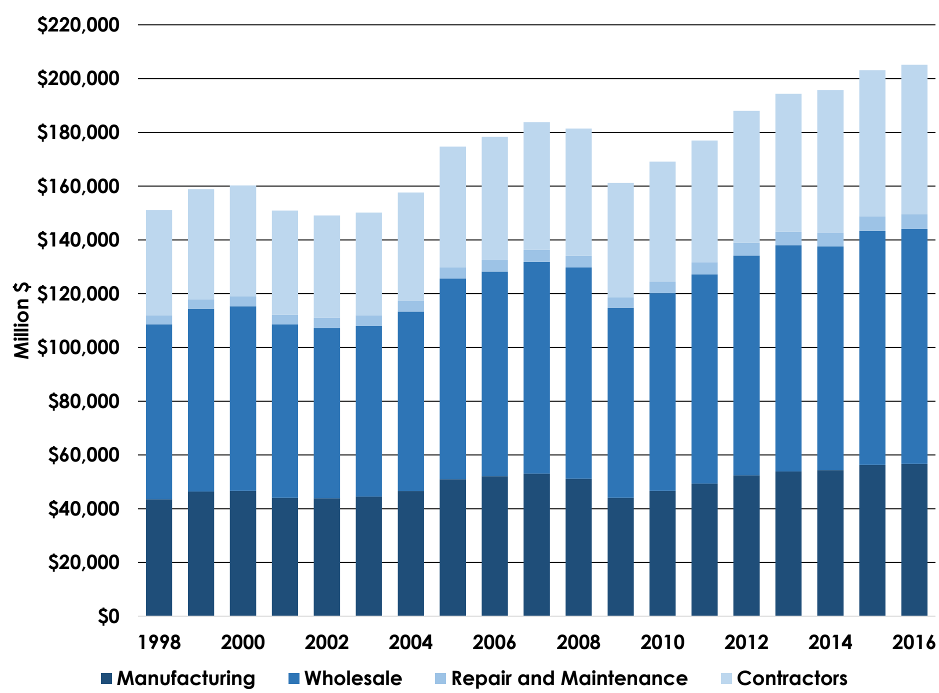
segments from 1998 to 2016 was 1.7 percent per year. The fastest growing segment was repair and maintenance, at 2.8 percent per year.

Table 2.2 Shipments/Receipts Growth
Units: Average Annual Percent Change

	1998-2002	2002-2008	2008-2009	2009-2016	1998-2016
Manufacturing	0.2	2.6	-15.0	3.6	1.5
Wholesale	-0.7	3.6	-10.6	3.0	1.6
Repair and Maintenance	3.4	2.3	-11.8	5.1	2.8
Contractors	-0.7	3.6	-10.6	3.8	1.9
Total	**-0.3**	**3.3**	**-11.8**	**3.4**	**1.7**

Figure 2.1 illustrates the historical data in table 2.1. This graph shows clearly the large declines in shipments in 2008 and 2009, and the 7 years of expansion following 2009.

Figure 2.1 Value of Shipments/Receipts
Units: Million $



2.3.2 Employment

Total employment in the combined set of industry segments declined steadily between 2000 and 2010. The biggest drops in employment occurred in 2001 and 2009, both recession years. Since 2009, steady productivity growth has resulted in employment increasing more slowly than shipments. Employment in wholesale and repair maintenance has been flat. Table 2.3 shows historical data on employment by detailed industry segment. The number of jobs in all years is still lower than that in 2008 for all segments except for contractors. Within manufacturing, the largest employment is found within refrigeration and air-conditioning equipment, at 75,900 jobs in 2016. Employment in motor vehicle air-conditioning (15,800) and home appliances (refrigerators, freezers, and water heaters) (16,700) were also significant in 2016. Total employment in all industry segments was about 589,100 in 2016.

Table 2.3 Employment
Units: Thousand Employees

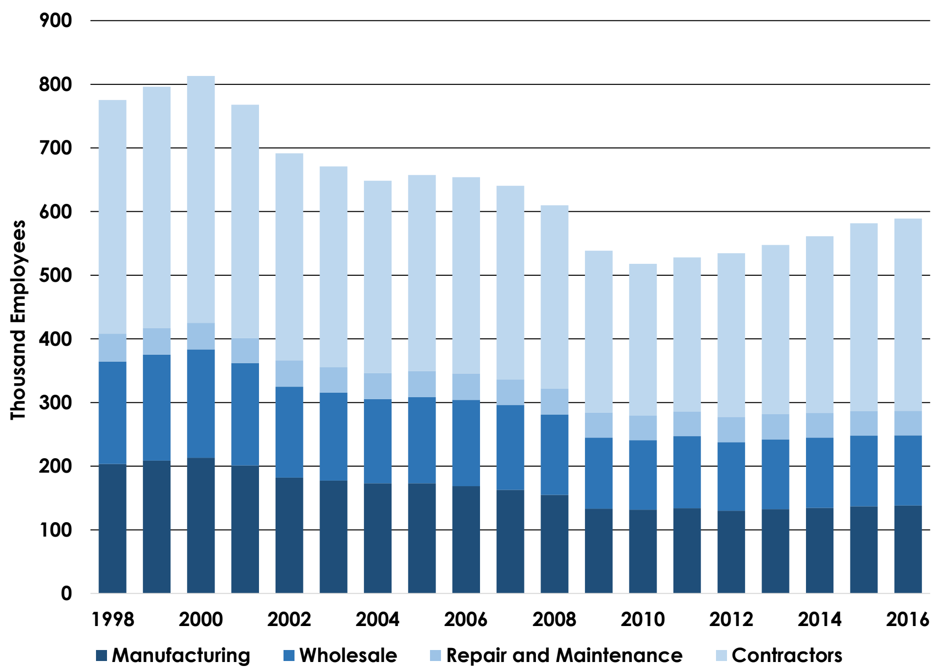
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Fluorocarbon Mfg	2.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.9
Refrig. & AC Equip	86.9	76.8	75.2	77.8	74.2	75.4	76.0	76.4	75.9
Home Appliances	20.3	16.7	17.0	15.5	14.4	15.2	15.6	16.2	16.7
Motor Vehicle Air Conditioning	14.8	11.4	11.4	12.2	13.2	13.7	14.5	15.3	15.8
Polystyrene Foam	6.9	5.8	5.8	5.8	5.9	5.9	5.9	6.1	6.3
Polyurethane Foam	9.7	8.1	8.0	8.1	8.2	8.2	8.2	8.5	8.8
Medical - MDIs	6.3	5.6	5.4	5.6	5.4	5.4	5.5	5.5	5.5
Aerosols	3.9	3.4	3.4	3.5	3.3	3.4	3.4	3.4	3.4
Fluoropolymers and Process Agents	3.5	3.1	3.0	3.1	3.0	3.0	3.1	3.1	3.1
Manufacturing Subtotal	**154.9**	**133.3**	**131.6**	**134.2**	**130.0**	**132.6**	**134.6**	**137.0**	**138.4**
Household Appliances Wholesalers	11.9	10.5	10.3	10.7	10.2	10.3	10.4	10.5	10.4
Heating and AC equipment Wholesalers	78.0	69.0	67.5	69.9	66.6	67.7	68.2	68.6	68.1
Refrig. Equip. Wholesalers	36.2	32.0	31.3	32.4	30.9	31.4	31.7	31.8	31.6
Wholesale Subtotal	**126.1**	**111.5**	**109.1**	**113.0**	**107.7**	**109.4**	**110.3**	**110.9**	**110.2**
Auto Heating, AC, Radiator Repair	27.2	25.5	24.6	25.3	25.0	25.3	24.3	24.7	23.7
Commercial Refrig. Equip Repair	9.0	8.6	8.7	8.0	9.0	8.7	9.1	8.2	9.3
Appliances & Household Equip. Repair	5.1	5.3	5.3	5.1	5.3	5.7	5.6	5.6	5.6
Repair and Maintenance Subtotal	**41.3**	**39.5**	**38.6**	**38.5**	**39.3**	**39.6**	**39.0**	**38.6**	**38.6**
Air Conditioning Installation	287.5	254.2	238.8	242.3	257.5	265.8	277.4	295.1	301.9
Contractors Subtotal	**287.5**	**254.2**	**238.8**	**242.3**	**257.5**	**265.8**	**277.4**	**295.1**	**301.9**
Grand Total	**609.8**	**538.5**	**518.0**	**527.9**	**534.5**	**547.4**	**561.3**	**581.6**	**589.1**

Table 2.4 summarizes historical growth rates of employment in the major industry segments, for the same periods as in table 2.2. From 1998 to 2002, employment in this set of industries declined at an average rate of 2.9 percent per year. The period 2002 to 2008 was characterized by strong labor productivity growth, so total employment declined at 2.1 percent per year on average, while shipments were increasing at 3.3 percent per year. Employment declined slightly more than shipments from 2008 to 2009, falling 12.4 percent. Since 2009, total employment increased every year, albeit by a mild rate of 1.3 percent annually. This growth was made possible by strong expansion of contractor jobs, which increased by 2.5 percent per year between 2009 and 2016. Recent employment gains could not overcome the effects of recession era losses and productivity growth. Consequently, combined employment slipped by an average of 1.5 percent per year between 1998 and 2016. Figure 2.2 shows the same data in stacked bar format.

Table 2.4 Employment Growth
Units: Average Annual Percent Change

	1998-2002	2002-2008	2008-2009	2009-2016	1998-2016
Manufacturing	-2.8	-2.7	-15.0	0.5	-2.1
Wholesale	-3.0	-2.1	-12.3	-0.2	-2.1
Repair and Maintenance	-1.2	-0.1	-4.5	-0.3	-0.7
Contractors	-3.0	-2.1	-12.3	2.5	-1.1
Total	**-2.9**	**-2.1**	**-12.4**	**1.3**	**-1.5**

Figure 2.2 Employment
Units: Thousand Employees



2.4 Indirect and Induced Impacts

2.4.1 Definition of Indirect and Induced Impacts

The impact of fluorocarbon-related manufacturing, wholesaling, repair and maintenance, and contracting extends beyond the direct economic impacts as measured by the products and industries described above. In this analysis, the domestic production of the main industry segments is our starting point, which is called the *direct output*. This activity does not exist in isolation. Instead, it generates demand for goods and services from supplier industries. These supplier industries, in turn, generate demand from their supplier industries. All of the output generated beyond the *direct output* is called the *indirect output.* In addition to the direct and indirect impacts, we calculate *induced output*. This represents the additional demand generated by the disposable income earned in the industry (this may be both wage income and capital income).

To calculate these impacts, we use the Inforum *Iliad* model. *Iliad* maintains detail on 352 industries comprising the U.S. economy. It is based on detailed input-output (IO) tables maintained and updated by Inforum. It shows the interrelationships between industries and GDP in two ways:

1. *Demand Side*. Total output of each industry is sold to other industries or to final demand. Final demand consists of personal consumption, equipment investment, structures investment, intellectual property investment, government purchases, and exports less imports. The demand side of the model is used to determine how changes in final demand ultimately affect the production generated by each industry.
2. *Supply Side*. Total output of each industry is also shown according to the supplying industries, and the amount of value added generated by that industry. Value added consists of labor compensation, capital income, and indirect taxes. The supply side of the model is used to trace back the indirect output, employment, and other measures that contribute to production in a given industry. This is also known as *upstream analysis*.

2.4.2 Results for Manufacturing

The set of manufacturing industries shown in table 2.1 map to portions of several *Iliad* manufacturing industries. Direct output for each manufacturing industry was calculated and provided to the model to calculate employment and other variables, as well as to calculate the indirect and induced output. Total direct output of all manufacturing sectors was $56,712 million in 2016, as shown in the top left corner of table 2.5. Direct employment associated with this output was 138,000 jobs. Value added is about half of total output, or $23,787 million. The labor income portion of that value added was $12,346 million. Purchases from upstream suppliers generated an additional $47,406 million in output, 153,000 jobs, $23,632 million in value added and $12,920 million in labor income.

To calculate induced impacts, we start with the income earned from direct and indirect production. The *Iliad* model then calculates the amount of consumption expenditures that would result from this income, and what types of goods and services are purchased by those expenditures. Induced jobs, value added, and labor compensation then correspond to this additional induced output. The induced results are shown in the third row of table 2.5. The total of direct, indirect, and induced impacts is shown in the last row of table 2.5.

Table 2.5 Direct, Indirect, and Induced Effects for Manufacturing Industries, 2016
Units: Million $

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	56,712	138	23,787	12,346
Indirect	47,406	153	23,632	12,920
Induced	73,711	380	43,449	21,788
Total	177,828	671	90,868	47,054

2.4.3 Results for Downstream Industries

The downstream industries in the fluorocarbon network consist of wholesale distributors, maintenance and repair, and contractors. To calculate the downstream footprint, we use a portion of the Iliad industries corresponding to wholesale distribution, maintenance and repair, and installation of HVAC and related equipment. Total direct output of these industries was $148,446 million in 2016, with total employment of 451,000, total value added of $100,271 million, and total labor income of $26,837 million. Indirect and induced impacts are calculated similarly to the procedure used for manufacturing. Total direct, indirect, and induced footprint is shown in the last line of table 2.6. Total combined downstream output is $443,920 million, and this is associated with 1,874,000 jobs.

Table 2.6 Direct, Indirect, and Induced Effects for Downstream Industries, 2016
Units: Million $

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	148,446	451	100,271	26,837
Indirect	79,073	341	44,592	23,396
Induced	216,400	1,083	128,003	59,811
Total	443,920	1,874	272,865	110,044

2.4.4 Results for Manufacturing and Downstream Combined

Table 2.7 summarizes the results of the previous two tables and shows the combined footprint of manufacturing and downstream industries. Total direct output in 2016 is $205,158 million, and the total employment is 589,000 workers. After including indirect and induced impacts, the total output figure is $621,748 million, with 2,546,000 jobs, $363,732 million in value added, and $157,098 million in payroll.

Table 2.7 Combined Footprint of Manufacturing and Downstream Industries, 2016
Units: Million $

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	205,158	589	124,057	39,183
Indirect	126,479	494	68,224	36,316
Induced	290,111	1,463	171,451	81,599
Total	621,748	2,546	363,732	157,098

3. World Trade Summary

The impacts of Kigali ratification are expected to come in large part from the effects on U.S. exports and imports. As with the markets for many manufacturing industries, the market for HVACR and related equipment is international. Most of the largest producer companies are multinationals. Even when they are headquartered in the U.S., companies typically have manufacturing facilities in many parts of the world.

3.1 Current US Imports and Exports

U.S. exports and imports by NAICS classification are identified in the U.S. Census Bureau's USA Trade database, which is also available classified by Harmonized System (HS) code.[6] These data are used by Inforum, in combination with BEA benchmark and annual input-output tables, to produce the series of current and constant price data used in the Inforum *Iliad* 352-sector model.

Bilateral trade by country is also available from the United Nations' Comtrade database.[7] Comtrade is not available in the NAICS classification. For this project, we have compiled imports and exports by trading partner based on the HS classification.

3.1.1 Fluorocarbons

Total U.S. production of fluorocarbons was just under 400,000 metric tons in 2016. Total production consists of HCFCs, HFCs, HFOs, and HFO blends. Production of HCFCs is being phased out. HFCs, which replace CFCs and HCFCs, do not contain chlorine and/or bromine and do not deplete the ozone layer. However, they have high global warming potential (GWP) and thus are considered greenhouse gases. The extent to which some HFCs, particularly HFC-134a, contribute to global warming has become the subject of significant environmental concern.

Many experts working in the industry predict that adoption of the Kigali Amendment will accelerate innovation and technology development, which should result in an HFC phasedown of about 40 percent by 2024 and double-digit growth of HFOs over the next five years. Some developing countries may leapfrog directly to such HFOs as HFO-1234yf, which is used in mobile air-conditioning. U.S. companies hold significant patents in the

[6] These data can be accessed at https://usatrade.census.gov/.
[7] UN Comtrade can be accessed at https://comtrade.un.org/.

production of HFOs. Adoption of Kigali will not only prevent dumping of old-technology foreign HFC products into the U.S. market, it should also enable the U.S. to expand its market of advanced HFO production considerably. Table 3.1 shows a summary of our preliminary estimates of exports in 2027 with and without Kigali ratification. The biggest change is in the exports of HFOs (+$550 million) although there is also a significant increase in HFO Blends (+$200 million) and HFCs (+$188 million). The total increase in exports is nearly $1 billion[8].

Table 3.1 Estimate of Increased Exports with Kigali Ratification
Units: Million $

Exports	HCFC	HFC	HFO	HFO Blend	Total Exports
2016	29.4	450.0	50.0	0.0	529.4
2027 (without Kigali)	29.4	462.0	300.0	400.0	1,191.4
2027 (with Kigali)	29.4	650.0	850.0	600.0	2,129.4
2027 Difference	0.0	188.0	550.0	200.0	938.0

3.1.2 Air-conditioning and Refrigeration Equipment

Bilateral trade data between the U.S. and its trading partners have been compiled for the following three HS codes for this study. The name in quotes at the end of each line is the title that will be used in the tables and charts that follow:

- 84143: Compressors used in refrigeration equipment ("Compressors")
- 8415: Air conditioners (including motor vehicle AC) ("AC")
- 8418: Refrigerators, freezers, and other refrigerating or freezing equipment ("Refrigeration")

Table 3.2 shows the breakdown of imports of these groups of products, ranked by country of origin, in 2016.

[8] Projections were developed using detailed information from Zhang, et. al (2017), and in consultation with industry experts. However, since the detailed projections are proprietary, only the aggregate figures are given here.

Table 3.2 Top Sources of Imports for HVACR and Related Equipment, 2016
Units: Million $

Compressors			AC			Refrigeration		
Rank	Partner	Imports (Mil $)	Rank	Partner	Imports (Mil $)	Rank	Partner	Imports (Mil $)
	World	**2,123**		**World**	**7,288**		**World**	**8,723**
1	Mexico	595	1	Mexico	3,138	1	Mexico	4,269
2	China	365	2	China	2,465	2	China	2,007
3	Japan	322	3	Canada	412	3	South Korea	1,236
4	South Korea	296	4	Thailand	340	4	Canada	274
5	Thailand	127	5	South Korea	325	5	Italy	180
6	Brazil	92	6	Japan	254	6	Turkey	172
7	Germany	69	7	United Kingdom	42	7	Japan	95
8	Slovakia	52	8	France	32	8	Germany	65
9	Hungary	39	9	Germany	31	9	Thailand	49
10	Singapore	37	10	Italy	30	10	Austria	44

Source: UN Comtrade data for 2016. Note that estimates include figures for home freezers and refrigerators, water heaters and motor vehicle air-conditioners.

The top source of imports for all three product groups is Mexico. Undoubtedly, much of these imports are production by firms also operating in the U.S., and conducting process trade in Mexico. The second largest source of imports for all three products is China, which is the largest exporter, as we will see in the next section. South Korea, Japan, Canada, and Thailand are also important sources of imports.

Figure 3.1 shows the sources of imports of all three sectors combined. Mexico is by far the largest source of imports, at about $8 billion in 2016. The next two largest sources are China ($4.8 billion) and South Korea ($1.9 billion). Canada, Japan, Thailand, and Italy are also important sources. Other countries make up the remaining $1.3 billion of imports. Total imports were just over $18 billion in 2016.

Figure 3.1 Top Source Countries for Total Imports of HVACR and Related Equipment, 2016
Units: Millions of Dollars

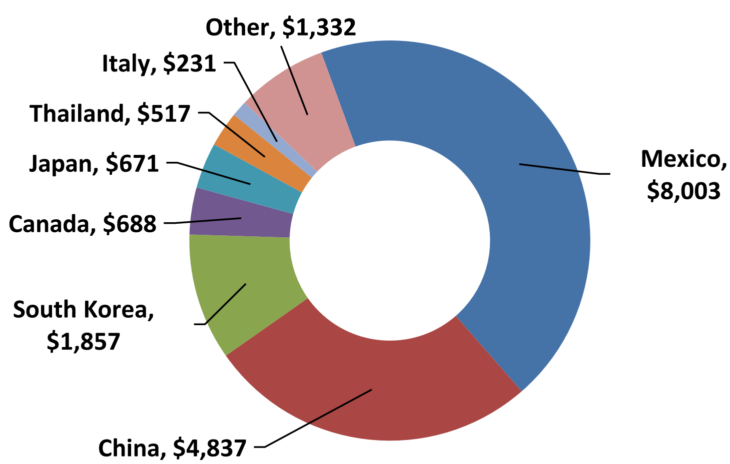


Table 3.3 Top Destinations for U.S. Exports of HVACR and Related Equipment, 2016
Units: Millions of Dollars

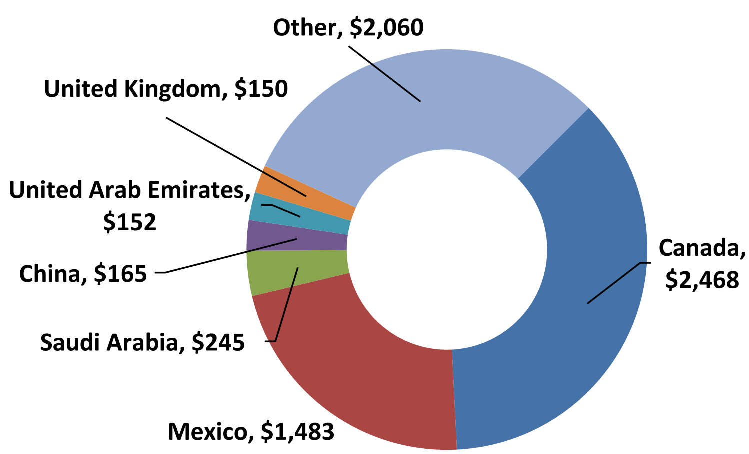
Compressors			AC			Refrigeration		
Rank	Partner	Exports (Mil $)	Rank	Partner	Exports (Mil $)	Rank	Partner	Exports (Mil $)
	World	1,298		World	2,729		World	2,697
1	Mexico	425	1	Canada	1,202	1	Canada	960
2	Canada	306	2	Mexico	554	2	Mexico	504
3	Saudi Arabia	60	3	United Arab Emirates	82	3	Saudi Arabia	118
4	South Korea	59	4	Saudi Arabia	67	4	China	87
5	China	36	5	United Kingdom	62	5	United Kingdom	74
6	United Arab Emirates	36	6	Brazil	42	6	Germany	64
7	France	35	7	China	42	7	Australia	54
8	Brazil	33	8	Panama	38	8	South Korea	49
9	Germany	31	9	Colombia	33	9	Other Asia, nes	44
10	Netherlands	26	10	Rep. of Korea	30	10	Japan	41

Source: UN Comtrade data for 2016. Note that estimates include figures for home freezers and refrigerators, water heaters and motor vehicle air-conditioners.

Table 3.3 is similar to table 3.2, but shows destinations for U.S. exports of HVACR and related equipment. The two largest destinations for all three product segments were Mexico and Canada. Again, these may not represent the ultimate markets for the equipment, but may represent a step in process trade, so we don't have full visibility on the ultimate market for this production. The other importing countries are relatively small. The largest of these are Saudi Arabia, the UK, China, and United Arab Emirates.

Figure 3.2 shows the distribution of exports of the combined market segments, which were about $6.8 billion in 2016.

Figure 3.2 Top Destination Countries for Total U.S. Exports of HVACR and Related Equipment, 2016
Units: Millions of Dollars



3.2 The World Export Market

To better understand what changes may occur to U.S. imports and exports with and without Kigali ratification, it is also helpful to understand the world export market.

3.2.1 Fluorocarbons

As shown in table 3.4, the top fluorocarbon exporting country in 2016 was China, followed by the U.S. and the Netherlands.

Table 3.4 Top Fluorocarbon Exporting Countries, 2016

Units: Millions of Dollars

Rank	Country	Export Value
1	China	668.4
2	USA	298.1
3	Netherlands	154.9
4	Belgium	115.3
5	Japan	111.5
6	France	85.6
7	Germany	58.1
8	India	50.7
9	Malaysia	28.8
10	United Kingdom	24.9
	Total	**1,755.2**

Source: UN Comtrade data for 2016.

This table does not differentiate between HFCs, HCFCs and HFOs[9]. The U.S. and China both have excess capacity and could increase their exports significantly.

3.2.2 Air-conditioning and Refrigeration Equipment

According to UN Comtrade data, the total world export market for HVACR and related equipment was about $94.9 billion in 2016. Currently, China has more than 25 percent of this total market, and the U.S. has about 7.2 percent. Table 3.5 shows the current distribution of exports by exporting country for the three major market segments identifiable in the Comtrade data. The U.S. is the second largest exporter of Compressors and holds fourth place for both Air-conditioning and Refrigeration. China's biggest lead is in the export market for Air-conditioning.

[9] The concordance used to extract these data from UN Comtrade is shown in Table A.6.

Table 3.5 Summary of World Export Market for HVACR and Related Equipment, 2016

Units: Millions of Dollars

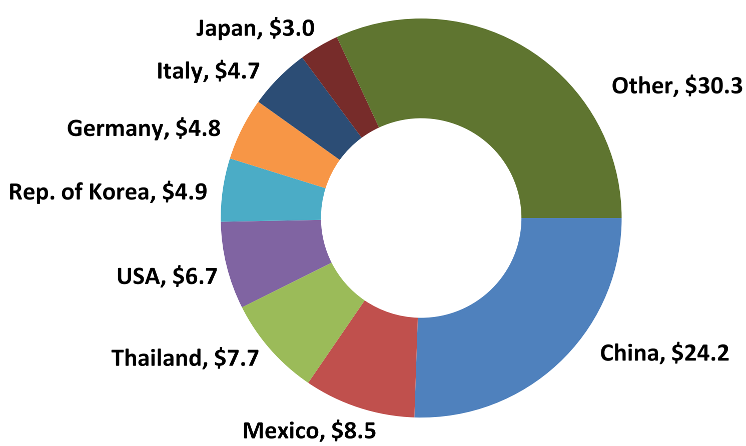
Compressors			AC			Refrigeration		
Rank	Exporting Country	Exports (Mil $)	Rank	Exporting Country	Exports (Mil $)	Rank	Exporting Country	Exports (Mil $)
	World	**13,414**		**World**	**41,423**		**World**	**40,078**
1	China	3,210	1	China	13,121	1	China	7,909
2	USA	1,298	2	Thailand	4,845	2	Mexico	4,694
3	Japan	1,267	3	Mexico	3,126	3	Italy	3,017
4	Thailand	955	4	USA	2,729	4	USA	2,697
5	Germany	946	5	Czechia	1,833	5	South Korea	2,620
6	South Korea	876	6	Germany	1,615	6	Germany	2,254
7	Mexico	713	7	Italy	1,445	7	Thailand	1,872
8	France	562	8	South Korea	1,367	8	Turkey	1,740
9	Brazil	403	9	Malaysia	1,332	9	France	1,392
10	Singapore	383	10	Japan	1,228	10	Poland	1,048

Source: UN Comtrade data for 2016. Note that estimates include figures for home freezers and refrigerators, water heaters and motor vehicle air-conditioners.

Figure 3.3 shows the world export share for the top exports of all three product segments.

Figure 3.3 Top HVACR and Related Equipment Exporting Countries, 2016

Units: Billions of Dollars



3.3 World Market Outlook

We expect the overall world market to grow at about 6 percent annually for the next decade, which implies that the market will nearly double in 10 years.[10] The export market alone will amount to $200 billion.

Growth is expected to be particularly strong in developing regions, such as India, Africa, Other Asia, the Middle East, and Latin America. Market growth in the mature economies, which include North America, OECD countries, and Japan, is expected to be less than 2 percent per year.

4. Scenario Analysis

This scenario analysis looks at two possible paths that the economy may take, either with or without Kigali ratification. We examine the economic implications that may derive from differences in trading patterns, technology, or demand.

In order to evaluate the potential economic impact of the HFC phase-down scheme with and without Kigali Amendment ratification, we used the Inforum *Iliad* model. This model enables the evaluation of impacts at a detailed industry level.[11] Output (production) in each industry is determined by demands from consumers, investment, government, net exports, and other business sectors. The model also forecasts jobs, value added, and labor compensation by sector.

4.1 Framing of the Analysis and Assumptions

To frame the analysis, a scenario was constructed using the *Iliad* model combined with informed opinions from industry experts. This "without Kigali" scenario represents the expected development of the markets assuming the U.S. does not ratify Kigali. An alternative scenario was constructed to represent the expected development of the U.S. economy with Kigali ratification. The horizon of these two scenarios is from 2018 to 2027. The driving factors of this analysis were the impacts of regulatory certainty and a clear transition schedule on U.S. global competitiveness and the resulting effects on imports and exports. For this analysis, we consider only changes in the HVACR equipment market.[12]

Ratifying the Kigali Amendment would bolster regulatory stability and provide clear long-term market signals. This certainty will help domestic firms allocate resources and compete in the global market. Consequently, the "with Kigali" scenario assumes a 2 percent increase in the United States' share of the world HVACR equipment export

[10] It is helpful to remember the "rule of 70" in exponential growth. Divide 70 by the average growth rate, and that will tell you how many years it takes to double.
[11] The *Iliad* model database includes data for 352 industrial sectors, and currently has annual historical data through 2016.
[12] However, as described above, figures are shown for the combined HVACR and related equipment industry segment.

market in 2027. Additionally, it assumes a 10 percent reduction in the United States' HVACR imports by 2027.

Imports are driven by the level of domestic demand, and the share of demand satisfied by imports. Domestic demand of the total of these four segments has grown from $28.3 billion in 1997 to $52.1 billion in 2016, an average growth rate of 3.2 percent.

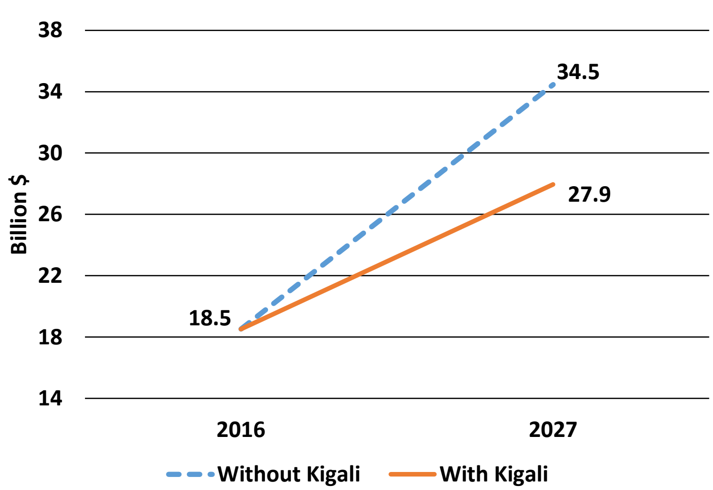
Table 4.1 Domestic Demand and Imports of HVACR and Related Equipment

Units: Millions of Dollars & Percent Share

Year	Domestic Demand	Import Share	Total Imports
1997	28,300	12.0%	3,388
2000	34,232	14.8%	5,071
2005	40,747	22.2%	9,037
2010	39,269	30.0%	11,775
2015	51,265	35.3%	18,120
2016	52,137	35.5%	18,523
2027 (without)	76,195	45.2%	34,456
2027 (with)	76,195	36.7%	27,946

However, the share of demand satisfied by imports has tripled during this period, increasing from 12 percent in 1997 to 35.5 percent in 2016. Our baseline scenario (without Kigali ratification) calls for a continued increase in this import share, reaching 45.2 percent by 2027. Domestic demand is projected to grow to $76.2 billion, so that total imports in this scenario will reach $34.5 billion. Conversations with industry economists and responses to a questionnaire[13] led to the conclusion that U.S. ratification of Kigali could reduce the incursion of imports, perhaps by as much as a 10 percent share of demand. In the "with Kigali ratification" scenario, we let the import share grow only slightly, to 36.7 percent. Imports still increase, but to $27.9 billion instead of $34.5 billion (see figure 4.1).

Figure 4.1 HVACR and Related Equipment Imports: With and Without Kigali Ratification



Exports are driven by the growth of the world market, and the U.S. share of that market. The global HVACR and related equipment market is expected to grow at slightly less

[13] See Appendix A.4.

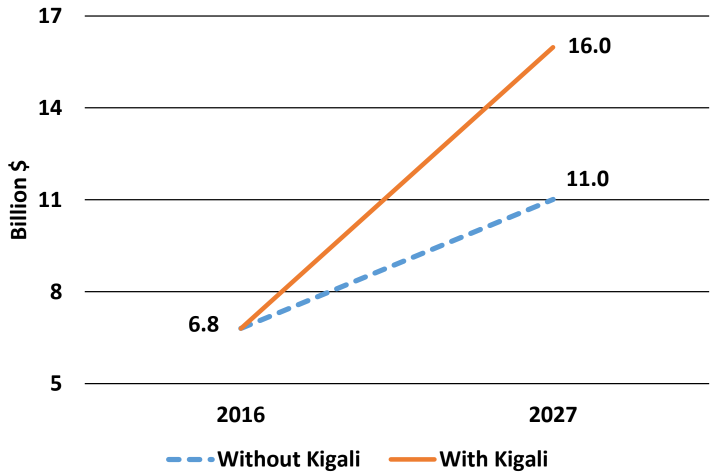
than 6 percent per year over the next decade, primarily in markets such as China, India, Latin America, and Africa. Urbanization and the demand for comfort are growing. Many of these countries are reaching the point where their middle class can afford refrigeration and air-conditioning. Consequently, the demand for HVACR and related products is expected to almost double over the next decade.

Recently, other global exporters have made inroads in the world market share with less efficient, older technologies that would be limited under the Kigali agreement. Without Kigali ratification, we expect this trend to continue. Our estimates indicate that the world market for HVACR and related equipment in 2016 was about $94.9 billion. We project a market total of $177.7 billion by 2027. The U.S. share of this market in 2016 was about 7.2 percent, resulting in exports of about $6.8 billion. Without Kigali ratification, we expect a decline in world market share of about 1 percent, declining to 6.2 percent. This results in a projected figure for U.S. exports of HVACR and related equipment of $11 billion by 2027. With Kigali ratification, we have projected the world market share to increase to 9.0 percent, resulting in U.S. HVACR and related equipment exports of about $16.0 billion, as shown in figure 4.2.

By 2027, the combination of higher exports and lower imports in the Kigali ratification scenario results in an increase of U.S. net exports of HVACR and related equipment of about $11.5 billion, compared to not ratifying.

Based on interviews with industry economists, we have also assumed that U.S. net exports of fluorocarbons will be about $1 billion higher by 2027 in the scenario with Kigali ratification. The total increase in net exports is the sum of HVACR equipment and fluorocarbons, or about $12.5 billion.

Figure 4.2 HVACR and Related Equipment Exports: With and Without Kigali Ratification



4.2 Impact Analysis

Although some of the most important differences between the two scenarios are net exports of the HVACR and related equipment producing industries, we also show total results below for all of the manufacturing segments discussed in section 2.2. These include fluorocarbons, foam, HVACR equipment, vapor-compression home appliances, mobile air-conditioners, medical MDIs, aerosols, and fluoropolymers and process agents. We call this group of industries the "fluorocarbon-related manufacturing industries".

The *Iliad* model was used to calculate direct impacts on output, employment, value added, and payroll, based on the two scenarios. Tables 4.2 to 4.4 show the estimates for 2016, the estimates for 2027 without Kigali, and the estimates for 2027 with Kigali.

From direct output, estimates of indirect (upstream) output were calculated using the input-output solution. This includes purchases from the industries that directly supply goods and services to the fluorocarbon industries, as well as the suppliers upstream from those industries. Employment, value added, and labor compensation associated with this indirect output were also calculated. Indirect output and other variables are shown in the second line of each table below.

Finally, induced output, employment, value added, and labor compensation are calculated by estimating the consumer spending by those employed either directly or indirectly by fluorocarbon-related manufacturing industries. This is shown in line 3 of each table.

Table 4.2 Manufacturing Summary - 2016

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	56,712	138	23,787	12,346
Indirect	47,406	153	23,632	12,920
Induced	73,711	380	43,449	21,788
Total	177,828	671	90,868	47,054

For example, table 4.2 shows that direct output of the fluorocarbon-related manufacturing industries amounted to $56.7 billion in 2016. Total direct employment was 138,000, with value added of $23.8 billion and labor income of $12.3 billion. After including indirect and induced spending, total output is $177.8 billion, with total employment of 671,000 workers and value added of $90.9 billion, and labor income of $47.1 billion.

Table 4.3 Manufacturing Summary – 2027, Without Kigali Ratification

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	**84,001**	**195**	**37,004**	**17,792**
Indirect	**68,631**	**221**	**34,283**	**18,800**
Induced	**106,754**	**550**	**62,927**	**31,555**
Total	**259,387**	**966**	**134,214**	**68,148**

By 2027, without ratification, we estimate the same table for the fluorocarbon-related manufacturing industries as shown in table 4.3. The results with ratification are shown in table 4.4.

Table 4.4 Manufacturing Summary – 2027, With Kigali Ratification

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	**96,475**	**228**	**41,968**	**20,756**
Indirect	**78,445**	**253**	**39,292**	**21,501**
Induced	**123,280**	**635**	**72,667**	**36,440**
Total	**298,200**	**1,117**	**153,927**	**78,697**

The increase in net exports with Kigali ratification leads to an increase in direct output of $12.5 billion by 2027 (Kigali compared to without Kigali), which generates an additional 33,000 jobs. This is associated with an increase of $5.0 billion in value added and $3.0 billion in additional labor income.

Total direct, indirect, and induced impacts due to improvements in manufacturing net exports are: $38.8 billion increase in domestic output, 150,000 increase in jobs, $19.7 billion increase in value added (GDP), and a $10.5 billion increase in labor income. These differences are for 2027.

In addition to the manufacturing impacts, there are important impacts in the downstream industries. These include Wholesale trade, Maintenance and Repair, and Contractor activities. The specific industries of interest and their NAICS codes are shown in Table 4.5.

Table 4.5 Downstream Industries

Wholesalers	
423620	Household appliances, electric housewares, and consumer electronics merchant wholesalers
423730	Warm air heating and air-conditioning equipment and supplies merchant wholesalers
423740	Refrigeration equipment and supplies merchant wholesalers

Repair and Maintenance	
811198	Heating, air conditioning, and radiator system repair services for cars and light trucks
811310	Maintenance and Repair - Commercial refrigeration equipment
811412	Maintenance and Repair - Appliances and household equipment

Contractors	
238220	Air Conditioning Installation

Table 4.6 shows the summary of direct, indirect, and induced impacts from these industries for 2016.

Table 4.6 Downstream Summary – 2016

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	**148,446**	**451**	**100,271**	**26,837**
Indirect	**79,073**	**341**	**44,592**	**23,396**
Induced	**216,400**	**1,083**	**128,003**	**59,811**
Total	**443,920**	**1,874**	**272,865**	**110,044**

Total output of the downstream industries in 2016 is $148.4 billion, generating 451,000 jobs, $100.3 billion of value added (GDP), and $26.8 billion in labor income. Although there are many more jobs created in these industries than in manufacturing, the average salaries and value added per job are lower than in manufacturing. There are more than three times as many jobs in downstream activities, but labor income is only about 25 percent higher.

Table 4.7 shows the projection of the downstream direct, indirect, and induced impacts for 2027.

Table 4.7 Downstream Summary – 2027

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	**216,945**	**659**	**146,539**	**39,220**
Indirect	**115,561**	**498**	**65,168**	**34,191**
Induced	**316,255**	**1,583**	**187,068**	**87,410**
Total	**648,761**	**2,739**	**398,775**	**160,822**

Finally, Tables 4.8, 4.9, and 4.10 show the combined (manufacturing plus downstream) summary for 2016, and for 2027 with and without Kigali ratification.

Table 4.8 Combined Summary – 2016

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	205,158	589	124,057	39,183
Indirect	126,479	494	68,224	36,316
Induced	290,111	1,463	171,451	81,599
Total	621,748	2,546	363,732	157,098

Table 4.9 Combined Summary – 2027, Without Kigali

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	300,947	854	183,543	57,013
Indirect	184,192	719	99,451	52,992
Induced	423,010	2,133	249,994	118,966
Total	908,149	3,706	532,989	228,970

Table 4.10 Combined Summary – 2027, With Kigali

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	313,420	887	188,507	59,977
Indirect	194,006	751	104,460	55,692
Induced	439,535	2,218	259,735	123,850
Total	946,961	3,856	552,702	239,519

5. Summary and Main Findings

In this study we present an economic analysis of the current footprint of the industries that are dependent on the production of fluorocarbons, which is called the fluorocarbon network. We also perform a scenario analysis comparing two states of the world in 2027, with and without the ratification of the Kigali Amendment by the U.S.

The current economic footprint of the focus industries consists of the output, jobs, value added, and payroll of fluorocarbon-related manufacturing industries, wholesale distribution, repair and maintenance, and contractor installation and service of equipment.

The manufacturing industries include fluorocarbons and other refrigerants, refrigeration and air-conditioning equipment, household refrigerators and home freezers, water heaters, mobile air-conditioners, polystyrene and polyurethane foam, medical MDIs, aerosols, and fluoropolymers and process agents. Total direct output of these industries in 2016 is calculated to be $56.7 billion, generating employment of 138,000 jobs (table 4.2). Associated with this direct output is value added of $23.8 billion and $12.3 billion of labor income.

The wholesale, repair and maintenance, and contractor industries owe their existence to the fluorocarbon, refrigerant, and equipment industries. Considered as a whole, they are called the downstream industries. Total direct output of these industries in 2016 came to

$148.4 billion, generating employment of 451,000 jobs (table 4.6). Downstream value added amounts to $100.3 billion, with labor income of $26.8 billion.

The impact of the HFCs, air-conditioning and refrigeration equipment, and related industries certainly extends beyond the direct economic impacts as measured by the products and industries described above. In this analysis, the domestic production of the main industry segments is our starting point, which is called the *direct output*. This activity does not exist in isolation. Instead, it generates demand for supplier industries. These supplier industries in turn generate demand for their supplier industries. All of the output generated beyond the *direct output* is called the *indirect output.* In addition to the direct and indirect impacts, we calculate *induced output*. This represents the additional demand generated by the disposable income earned in the industry (this may be both wage income and capital income).

Combining the manufacturing and downstream industries, and considering direct, indirect, and induced economic activity, we reach the results shown in table 5.1[14].

Table 5.1 Combined Footprint of Manufacturing and Downstream Industries, 2016
Units: Million $

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	205,158	589	124,057	39,183
Indirect	126,479	494	68,224	36,316
Induced	290,111	1,463	171,451	81,599
Total	621,748	2,546	363,732	157,098

Think of the results shown in this table as the *total economic activity* associated with the network of industries related to fluorocarbon and refrigerant production. Total economic activity as measured here translates into $621.7 billion of output, 2.5 million jobs, $363.7 billion of value added, and $157.1 billion of labor income.

The analysis of the economic impact of Kigali ratification was done by specifying two scenarios. The first, "without Kigali" scenario, is consistent with a policy of the U.S. failing to ratify the Kigali Amendment. In this scenario, although U.S. exports continue to increase, the share of U.S. exports in world trade is projected to decline from 7.2 percent in 2016 to 6.2 percent in 2027. On the import side, without Kigali we project a continued encroachment of imports into the domestic market. The import share of domestic demand has already increased from 12 percent in 1997 to 35.5 percent in 2016. In the "without Kigali" scenario, we project a continued increase in import share to 45.2 percent by 2027.

With Kigali ratification, industry experts agree that the continued rise of import share can be slowed or prevented. We have modeled this by letting the import share grow only slightly in this case. Note that imports continue to increase, but not as fast as in the "without Kigali" case. With Kigali ratification, we expect the U.S. export share to increase from 7.2 percent to 9.0 percent, driven by the relative strength of U.S. manufacturing plants in low-GWP fluorocarbons and the HVACR equipment that uses them.

The net result is an additional $5.0 billion of U.S. HVACR equipment exports, and a reduction of $6.5 billion of HVACR equipment imports, for a combined increase of $11.5

[14] Shown earlier as table 2.7.

billion. We also project a net improvement of $1 billion in net fluorocarbon exports, which brings the total effect to $12.5 billion.

An economic footprint analysis is performed on both scenarios for the year 2027. For the current analysis, we assume no changes in the downstream industries, but limit our focus to what happens in manufacturing. Tables 5.2 and 5.3 show the summaries for manufacturing with and without Kigali ratification in 2027.

Table 5.2 Manufacturing Summary – 2027, Without Kigali Ratification

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	84,001	195	37,004	17,792
Indirect	68,631	221	34,283	18,800
Induced	106,754	550	62,927	31,555
Total	259,387	966	134,214	68,148

Table 5.3 Manufacturing Summary – 2027, With Kigali Ratification

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	96,475	228	41,968	20,756
Indirect	78,445	253	39,292	21,501
Induced	123,280	635	72,667	36,440
Total	298,200	1,117	153,927	78,697

With regard to direct effects, Kigali ratification results in an improvement of $12.4 billion in direct output, 33,000 jobs, $5.0 billion in value added, and $3.0 billion in labor income. The change in total economic activity is $38.8 billion in output, 150,000 jobs, $19.7 billion in value added, and $10.6 billion in labor income.

Table 5.4 Manufacturing Summary – 2027, Differences

	Output (Million $)	Employment (thousand persons)	Value Added (Million $)	Labor Income (Million $)
Direct	12,474	33	4,964	2,964
Indirect	9,813	32	5,009	2,701
Induced	16,525	85	9,741	4,885
Total	38,812	150	19,713	10,549

In addition to the impacts described above, ratification of Kigali would also affect R&D and reclaim activities.

Domestic manufacturers are already making investments in next-generation refrigerants and equipment. In 2015, Air-Conditioning, Heating, and Refrigeration Institute's (AHRI) member companies pledged $5 billion through 2025 in R&D and capital investment with the goal of commercializing high efficiency equipment using next-generation refrigerants. If Kigali is ratified, such investment would support 1,400 jobs and $1 billion in capital investment. However, these jobs and investment are in jeopardy if the U.S. government fails to act. Without ratification by the U.S., manufacturing and R&D for new technologies will move to the international markets where local demand for the new technologies justifies the investment.

Ratification of Kigali would also benefit the reclaimed refrigerants industry. Reclaim sales are projected to rise by roughly $0.8 billion per year with Kigali, supporting an additional

4,000 jobs. This activity, while currently small, would become an important part of servicing existing equipment.

Other impacts of Kigali ratification that we have not yet considered are known to be positive, but haven't yet been quantified. They include:

- Investment in U.S. manufacturing capacity would be higher
- Activity of downstream industries would likely be higher

The U.S. HVACR industry historically has been the global leader, building on a strong domestic base and expanding the use of new technology globally. The changes driven by the Montreal Protocol have strengthened and expanded that U.S. leadership. But now, the ratification of Kigali is crucial to continuing that pattern and maintaining U.S. leadership. Without Kigali ratification, growth opportunities will be lost along with the jobs to support that growth, the trade deficit will grow, and the U.S. share of global export markets will decline.

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Appendix A – Data Sources and Methodology

A.1 Data Sources

The Annual Dollar Volume of Goods and Services is determined for each industry by utilizing the data from the 2012 Economic Census sorted by product line, supplemented by industry expert input where necessary.

The payroll and employment figures for each industry are estimated by using the productivity figures derived from 2012 Economic Census data sorted by industry. It is assumed that companies citing that industry as primary are representative of productivity in production of that product line by all companies. That is, the Annual Payroll and Number of Employees are estimated by multiplying the annual dollar volume of shipments or sales of goods and services for a given product line by the corresponding industry productivity figures.

Payroll and employment figures thus assume that productivity measures are similar for all companies manufacturing a given product line, regardless of the company's reported primary industry. They also assume in some cases that productivity measured across a broad product line can be applied to all subcategories within that product line. Although these are both reasonable assumptions, they do imply that employment and payroll are somewhat more uncertain than sales of goods and services.

Table A-1 shows the segment summary of the industries in our focus group, which are divided into 1) Manufacturing; 2) Wholesalers; 3) Repair and Maintenance; and 4) Contractors.

Manufacturing data are derived from several tables of the 2012 *Census of Manufacturing*. Selected shipments data were used from the table EC1231SP1 - *Product Summary: Products or Services Statistics: 2012*[15]. This table has the most detailed breakdown available by Census NAICS Product code. However, in some cases, the products that we need to focus on for this study were at a finer level of detail than what is shown in that table. In these cases, the Census data were supplemented by informed estimates from industry experts or company representatives. This is the case for the following segments:

1. Other Refrigerants
2. Medical – MDIs
3. Aerosols
4. Fluoropolymers and Process Agents

Table A-2 shows selected rows of the *Product Summary* table that comprise the totals in table A-1.

The Product Summary does not include information on payroll or employment. To estimate these figures, we used the table EC1231SG1 – *Manufacturing Industry Summary Statistics,* which includes sales, payroll, employment, and several other pieces of

[15] Available from https://www2.census.gov/econ2012/EC/sector31/EC1231SP1.zip.

information by 6-digit NAICS code[16]. From these data we constructed ratios of employment and payroll to shipments which were applied to the sales estimates, to obtain the figures in the payroll and employment columns of table A-1.

Table A-1 Segment Summary, Based on the 2012 Economic Census

Parent NAICS Code	Segment	Value of Shipments / Receipts ($Million)	Estimated Annual Payroll (Census, $Million)	Estimated Paid Employees (Census, Thousands)
Manufacturing				
3251	Fluorocarbons and Other Refrigerants	1,754.1	163.3	2.3
333415	Refrigeration and Air Conditioning Equipment	25,272.9	3,200.5	71.0
3352	Home Appliances	5,705.3	692.9	13.8
336390	Motor Vehicle Air Conditioning	5,991.0	574.0	12.6
326140	Polystyrene Foam	2,009.7	221.0	5.6
326150	Polyurethane Foam	2,803.0	354.7	7.8
325412	Medical - MDIs	4,626.3	387.0	5.1
325998	Aerosols	1,504.7	164.6	3.2
	Fluoropolymers and Process Agents	2,774.8	173.4	2.9
	Manufacturing Subtotal	**52,441.8**	**5,931.5**	**124.3**
Wholesalers				
423620	Household appliances, electric housewares, and consumer electronics merchant wholesalers	21,086.7	658.8	10.2
423730	Warm air heating and air-conditioning equipment and supplies merchant wholesalers	45,212.4	4,214.0	66.6
423740	Refrigeration equipment and supplies merchant wholesalers	15,395.7	3,371.6	30.9
	Wholesale Subtotal	**81,694.9**	**8,244.4**	**107.7**
Repair and Maintenance				
811198	Heating, air conditioning, and radiator system repair services for cars and light trucks	2,720.9	757.9	25.0
811310	M&R - Commercial refrigeration equipment	1,456.7	440.7	9.0
811412	M&R: Appliances and Household Equipment	604.8	167.9	5.3
	Repair and Maintenance Subtotal	**4,782.4**	**1,366.5**	**39.3**
Contractors				
238220	Air Conditioning Installation	49,119.7	12,732.4	257.5
	TOTAL	**188,038.8**	**28,274.8**	**528.8**

[16] At https://www2.census.gov/econ2012/EC/sector31/EC1231SG1.zip.

Table A-2 Manufacturing Product Lines and Estimated Shipments

Segment	NAICS Product Line	Description	2012 Values	Total
Fluorocarbons and Other Refrigerants				
	325120G	Fluorocarbon gases	1,169,404	
	325199R	Other synthetic organic chemicals	212,909	(part, estimated)
	325199T	Miscellaneous end-use chemicals and chemical products, excluding urea	371,793	(part, estimated)
				1,754,106
Refrigeration and Air-Conditioning Equipment				
	3334152	Heat transfer equipment (excluding electrically operated dehumidifiers), mechanically refrigerated, self-contained, excluding motor vehicle mechanical air-conditioning systems	7,135,378	
	3334152193	Heat transfer factory-fabricated water cooling towers	166,918	Excluded
	3334152195	Other heat transfer equipment, including room air-induction units, mechanical refrigeration systems used on all types of vehicles, and absorption refrigeration and dehydration systems	1,228,204	Excluded
	3334153	Commercial refrigerators and related equipment	3,446,526	
	3334155	Refrigeration condensing units, all refrigerants, excluding ammonia (complete)	728,949	
	3334156	Room air conditioners and dehumidifiers, excluding portable dehumidifiers	395,814	
	3334159	All other miscellaneous refrigeration and air-conditioning equipment	962,825	
	3334159121	Evaporative air coolers	127,538	Excluded
	333415A	Compressors and compressor units, all refrigerants, excluding automotive	2,565,208	
	333415D	Parts and accessories for air-conditioning and heat transfer equipment	1,633,970	
	333415D181	Parts for warm air furnaces, including duct furnaces (excluding complete humidif	203,740	Excluded
	333415E	Unitary air conditioners, excluding air source heat pumps	6,192,293	
	333415F	Air-source heat pumps, excluding room air conditioners	1,797,099	
	333415G	Ground and ground water source heat pumps (single and split systems)	205,695	
	333415W	Air-conditioning and warm air heating equipment and commercial and industrial	1,935,570	
				25,272,927
Home Appliances				
	335222	Household refrigerator and home freezer manufacturing	3,497,263	
	3352281	Household water heaters, electric, for permanent installation	957,459	
	3352283	Household water heaters, excluding electric	1,250,608	
				5,705,330

Table A-2 Manufacturing Product Lines and Estimated Shipments (Continued)

Segment	NAICS Product Line	Description	2012 Values	Total
Motor Vehicle Air-Conditioning				
	3363902	Motor vehicle air-conditioning systems	4,626,572	
	3363903	Automotive air-conditioning compressors (open-type, with or without motor)	1,028,384	
	3363909514	Motor vehicle air-conditioning hose assemblies, new	336,074	
				5,991,030
Polystyrene Foam				
	3261401	Transportation polystyrene foam products (including seating, dash, and other interior-exterior components)	597,078	
	3261403	Building and construction polystyrene foam products	1,412,624	
				2,009,702
Polyurethane Foam				
	3261501	Transportation polyurethane foam products	1,398,278	
	3261502116	Polyurethane foam protective shipping pads and shaped cushioning (peanuts, disks, etc.)	190,597	
	3261503	Building and construction polyurethane foam products	1,214,110	
				2,802,985
Medical - MDIs				
	325412A1	Pharmaceutical preparations, acting on the respiratory system, for human use	4,626,273	(part, estimated)
				4,626,273
Aerosols				
	325998J1H1	Filling pressurized aerosol containers with materials owned by others (excluding interplant transfers)	640,138	
	325998J1V1	Chemical preparations, other	864,557	(part, estimated)
				1,504,695
Fluoropolymers and Process Agents				
	3252111160	Other thermoplastic resins and plastics materials	2,424,717	(part, estimated)
	32521203	Butyl, polychloroprene, and stereo polyisoprene elastomers, and nitrile rubber, including latex	265,261	(part, estimated)
	325220A115	Other manufactured noncellulosic fibers, yarn (including strip), monofilament and group (multi) filament, made by filament yarn producers	84,810	(part, estimated)
				2,774,788

Estimates of relevant wholesale activity were derived using the 2012 *Census of Wholesale Trade*. The table EC1242SLLS1 - *Wholesale Trade: Subject Series - Product Lines: Product Lines Statistics by Industry for the U.S. and States: 2012*[17] shows sales by product line (type of good) by different kinds of wholesale businesses. The sales estimates were totals of relevant product lines, as shown in table A-3.

The report EC1242I1 - *Wholesale Trade: Industry Series: Preliminary Summary Statistics for the U.S.: 2012*, contains information on sales, payroll, employment, and many other characteristics of wholesale businesses by NAICS code. Payroll and employment to sales ratios were calculated to apply to the sales estimates in table A-1 to estimate these variables.

[17] At https://www2.census.gov/econ2012/EC/sector42/EC1242SLLS1.zip.

Table A-3 Wholesale Product Lines and Sales for HVACR

(primary) NAICS	NAICS Title	Product Line	Product Line Title	Value of Sales	Totals
423620	Household appliances, electric housewares, and consumer electronics merchant wholesalers	11515	Household refrigerators and freezers	21086.7	21086.7
423730	Warm air heating and air-conditioning equipment and supplies merchant wholesalers	11912	Central air-conditioners	27027.8	
		11914	Heat pumps	6167.0	
		11917	Compressors for air-conditioners	5766.8	
		11918	Condensing units for air-conditioners	6250.9	45212.4
423740	Refrigeration equipment and supplies merchant wholesalers	12011	Commercial refrigerators	3102.7	
		12012	Unit coolers for commercial refrigerators	2327.0	
		12013	Condensing units for commercial refrigerators	550.9	
		12014	Refrigerants	2519.9	
		12015	Other commercial refrigeration equipment and supplies	6895.1	15395.7

Table A-4 Repair and Maintenance

NAICS	NAICS Title	Product Line	Product Line Title	Value of Receipts
8111	All other automotive repair and maintenance	31785	Heating, air conditioning, and radiator system repair services for cars and light trucks	**2,720,922**
811310	Commercial and industrial machinery and equipment (except automotive and electronic) repair and maintenance	32031	M&R - Commercial refrigeration equipment	**1,456,676**
811412	Appliance Repair and Maintenance	32052	M&R: Major Household Type Appliances	1,675,285
				604,778

A.2 Methodology for the Economic Impact Analysis

The tool used for the economic impact analysis is the Inforum *Iliad* model, which is a detailed model of the U.S. economy. For each of 352 industries, it shows the demand and supply structure for each industry. The demand structure includes the sales to other industries (intermediate), and sales to final demand. Final demand includes personal consumption (household) expenditures, equipment investment, construction investment (residential and nonresidential), federal and state and local government spending, and exports less imports. The supply structure of each industry includes the other industries it buys from, the labor cost, indirect taxes, and capital income.

The input-output (IO) relationships are arrayed as a matrix, with each industry showing up both as a column and a row of the matrix. Each row of the matrix shows the distribution of sales of that industry's product or service. Each column of the matrix shows the purchases made by that industry.

The *Iliad* model is built on a detailed industry database, which draws from the U.S. Benchmark Input-Output Accounts, the U.S. Annual Input-Output Accounts, gross output by industry, and Census merchandise trade statistics. Both domestic and import prices have been compiled for each sector, so results can be expressed either in nominal (current prices) or real (constant prices) form.

The economic impact analysis consists of several parts:

1. *Upstream analysis* – This traces the impact of a given producing industry on supplier industries, including the suppliers to those suppliers. For each industry, calculations are made on output, jobs, earnings, and value added impacts.
2. *Downstream analysis* – This traces the impact of purchases of products through wholesale and retail trade distribution channels. The input-output table is used to estimate the distribution and total level of wholesale and retail trade activity generated through the distribution of a given product.
3. *Induced analysis* – This additional level of impact comes about through the earnings generated in the upstream or downstream industries. It represents the impact of consumer spending from the capital and labor earnings in these industries.

The initial analysis is done for 2016, and all results are in 2016 dollars. The impact analysis begins with the output of each industry segment. In the first iteration, all supplier industries' output is calculated, using the input-output coefficients from the column of the matrix. Note that not all of the output of the focus industry goes to domestic suppliers. Some is supplied by imports, which are calculated in each iteration according to the average import share of that industry. Some of the output is paid out in value added. Both imports and value added can be thought of as leakages that reduce the total output required from domestic suppliers. In each subsequent iteration, the suppliers to the previous round of suppliers are calculated. Because of the leakages just described, the amount necessary to supply each further round becomes smaller and smaller. At some point, the additional supplier output is very small, and the process converges.

Associated with each round of direct and supplier (indirect) output are the employment, earnings, and value added necessary to supply that output. When the solution has completed, the model shows the total direct and indirect effects, as well as detailed impacts by supplying industry.

A.3 The UN Comtrade Database

UN Comtrade[18] is the pseudonym for United Nations International Trade Statistics Database. Over 170 reporter countries/areas provide the United Nations Statistics Division (UNSD) with their annual international trade statistics data detailed by commodities/service categories and partner countries. These data are subsequently transformed into the United Nations Statistics Division standard format with consistent coding and valuation using the processing system.

The UN COMTRADE is the largest depository of international trade data. It contains well over 3 billion data records since 1962 and is available publicly on the internet. In addition, it offers public and premium data API for easier integration/download.

All commodity values are converted from national currency into US dollars using exchange rates supplied by the reporter countries, or derived from monthly market rates and volume of trade. Quantities, when provided with the reporter country data and when possible, are converted into metric units. Commodities are reported in the current classification and revision (HS 2012 in most cases as of 2016). For this study, we used the HS 2012 classification

The concordance of HS 2012 to NAICS is not one-to-one, so some judgement needs to be applied to choose the appropriate HS codes. Tables A.5 and A.6 indicate the sets of HS codes we have used in this study to determine international trade in the relevant fluorocarbon, HVACR, and related product categories.

Table A.5 HS Codes Used to Represent Trade in HVACR and Related Equipment

HS Code	Title
841430	Compressors of a kind used in refrigerating equipment
841510	Air conditioning machines; comprising a motor-driven fan and elements for changing the temperature and humidity, window or wall types, self-contained or split-system
841520	Air conditioning machines; comprising a motor driven fan and elements for changing the temperature and humidity, of a kind used for persons, in motor vehicles
841581	Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps)
841582	Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit
841583	Air conditioning machines; containing a motor driven fan, other than window or wall types, not incorporating a refrigerating unit
841590	Air conditioning machines; with motor driven fan and elements for temperature control, parts thereof
841810	Refrigerators and freezers; combined refrigerator-freezers, fitted with separate external doors, electric or other
841821	Refrigerators; for household use, compression-type, electric or other
841829	Refrigerators; household, electric or not, other than compression-type
841830	Freezers; of the chest type, not exceeding 800l capacity
841840	Freezers; of the upright type, not exceeding 900l capacity
841861	Heat pumps; other than air conditioning machines of heading no. 8415
841869	Refrigerating or freezing equipment; n.e.c. in heading no. 8418
841891	Refrigerating or freezing equipment; parts, furniture designed to receive refrigerating or freezing equipment
841899	Refrigerating or freezing equipment; parts thereof, other than furniture

[18] These data can be freely accessed at http://comtrade.un.org.

Table A.6 HS Codes Used to Represent Trade in Fluorocarbons

HS Code	Title
290371	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; chlorodifluoromethane
290372	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; dichlorotrifluoroethane
290373	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; dichlorofluoroethanes
290374	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; chlorodifluoroethanes
290375	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; dichloropentafluoropropanes
290376	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; bromochlorodifluoromethane, bromotrifluoromethane, and dibromotetrafluoroethanes
290377	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; n.e.c. in headings 290371 to 290376, perhalogenated only with fluorine and chlorine
290379	Halogenated derivatives of acyclic hydrocarbons containing two or more different halogens; n.e.c. in item no. 2903.7
382471	Mixtures containing halogenated derivatives of methane, ethane or propane; containing chlorofluorocarbons (CFCs), whether or not containing hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs) or hydrofluorocarbons (HFCs)
382474	Mixtures containing halogenated derivatives of methane, ethane or propane; containing hydrochlorofluorocarbons (HCFCs), whether or not containing perfluorocarbons (PFCs) or hydrofluorocarbons (HFCs), but not containing chlorofluorocarbons (CFCs)
382478	Mixtures containing halogenated derivatives of methane, ethane or propane; containing perfluorocarbons (PFCs) or hydrofluorocarbons (HFCs), but not containing chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs)
390490	Vinyl chloride, other halogenated olefin polymers; n.e.c. in heading no. 3904

A.4 Questionnaire for Industry Experts

We developed assumptions for the model scenarios by canvassing industry experts on a set of questions relating to trade and competitiveness.

These questions were as follows:

1. The U.S. Bureau of Census trade data indicate a trade deficit of a little over $10 billion in 2016 in air-conditioning and refrigeration equipment, starting from almost balance in 2000. If the US does not ratify Kigali, do you expect the trade deficit in equipment to continue to get worse?

a. Knowing that it was $5 billion in 2010, what figure would you expect for 2025?

a) parity
b) deficit of $5 billion
c) deficit of $10 billion
d) deficit of $20 billion

b. If the US does ratify Kigali, do you expect the US to become more competitive?

<Yes/No>

c. If so, by how much would you expect the trade balance to improve from the situation without ratification by 2025?

a) $5 billion
b) $10 billion
c) $20 billion
d) 40 billion

2. UN World trade data indicate that the current export market for air-conditioning, refrigeration, freezers, compressors and motor vehicle air-conditioners totaled about $95

billion in 2016. How rapidly do you see the world export market growing per year on average to 2025?

a) 2 percent
b) 3 percent
c) 4 percent
d) 6 percent

3. The same UN world trade data show the US exports of these in 2016 totaling $6.7 billion, or about 7.1 percent of the world market.

a. Without Kigali ratification, do you expect this share to:

a) decline (and by how much?) by 2025
b) stay the same
c) increase (and by how much?)

b. With Kigali ratification, how much do you expect the share of world market to increase by 2025:

a) not at all
b) 1 percent
c) 5 percent
d) 10 percent
e) other amount

4. Due to special customer relationships between US fluorochemical firms and US equipment producers, do you see the US equipment producers enjoying a special competitive edge due to advanced US research in fluorochemicals? <yes/no>. Will the importance of these relationships increase with Kigali ratification?

A.5

Kigali Specified Controlled Substances

Table A.7 provides a list of the substances specifically mentioned in the Annex to the Montreal Protocol in relation to the Kigali amendment. The table provides the common substance name and the 100-year global warming potential (GWP).[19]

Table A.7 Annex F to the Montreal Protocol

HFCs (Group I)		HCFCs	
Substance	**GWP value (100 year)**	**Substance**	**GWP value (100 year)**
HFC-134	1100	HCFC-21	151
HFC-134a	1430	HCFC-22	1810
HFC-143	353	HCFC-123	77
HFC-245fa	1030	HCFC-124	609
HFC-365mfc	794	HCFC-141b	725
HFC-227ea	3220	HCFC-142b	2310
HFC-236cb	1340	HCFC-225ca	122
HFC-236ea	1370	HCFC-225cb	595
HFC-236fa	9810		
HFC-245ca	693	**CFCs**	
HFC-43-10mee	1640	**Substance**	**GWP value**
HFC-32	675	CFC-11	4750
HFC-125	3500	CFC-12	10 900
HFC-143a	4470	CFC-113	6130
HFC-41	92	CFC-114	10 000
HFC-152	53	CFC-115	7370
HFC-152a	124		
HFCs (Group II)			
HFC-23	14 800		

[19] Source: Polonara et al. (2017).

A.6 Principal Investigators

Joseph M. Steed was architect and lead implementer of DuPont's corporate response to stratospheric ozone depletion concerns during the 1980s, including the ultimate science-based decision to lead the global industry in committing to complete phase-out of CFC production in advance of regulatory requirements. He is an expert in developing broad industry and government support for economically driven international and domestic regulations that achieve a smooth transition for customers.

He has over 20 years of experience as a leader of strategic change in diverse industries and organizations. As CEO of startup International Titanium Powder, LLC, Dr. Steed built on both technical and business background to develop business and financial plans and successfully initiate the transition from development toward commercial operation. As Manager of e-Ventures at DuPont, Dr. Steed served as a catalyst to drive profitable adoption by business leaders of internet transaction tools.

Lent by DuPont to the chemical industry-financed marketplace startup Elemica, Inc., Dr. Steed led marketing strategy, segmentation, customer relationship management (CRM) strategy, and branding for a successful startup that has now outlasted the majority of its imitators. Dr. Steed led Global Strategic Planning for a $2 billion DuPont business, implementing a strategic redirection toward higher value offerings, with a modern ERP infrastructure to drive cost efficiency and customer service. In technology, Dr. Steed led process R&D for a major business resulting in implementation of proprietary and highly profitable cost reductions, waste reduction programs, and novel feedstocks. As Corporate R&D Planning Manager, Dr. Steed drove corporate growth through a funding mechanism for entrepreneurial developments and effective networking of new business development leaders across the corporation.

He also served as a general manager at the technology development company EarthShell Corporation. His recent consulting includes work with the private equity firm Texas Pacific Group, providing chemical industry expertise to assist in their evaluation of a $1B+ buyout. He also served as a principal in a project for AHRI to design a mechanism for stimulating the rate of recycle of HFCs and HCFCs in the United States. Dr. Steed has a Ph.D. in Chemical Physics from Harvard and Sc.B. and Sc.M. degrees from Brown, along with executive training from Columbia's Graduate School of Business. He has published numerous peer-reviewed technical articles and book chapters, including both atmospheric modeling and estimates of global CFC emissions.

Douglas S. Meade is the executive director of Inforum (**In**terindustry **For**ecasting at the **U**niversity of **M**aryland). Dr. Meade has over 30 years of experience in private sector and government in the areas of econometric modeling, economic analysis, and the development of economic data. He was the principal investigator for a previous study done for AHRI, analyzing the national and state level contribution of the HVAC industries within the U.S. economy. Dr. Meade also has extensive experience in international modeling, having helped develop the Inforum bilateral trade model, as well as developing and performing studies with models of Japan, Vietnam, Ukraine, Tanzania, North Korea, and Myanmar.

Prior to his current period at Inforum, he was Deputy Directory of the Industry Division at the Bureau of Economic Analysis, where he was responsible for the development of the 2002 benchmark input-output table. Other previous experience includes work with Data Resources, Inc., an econometric consulting firm which is now part of IHS Global, and with the Census Bureau, serving a research function in the development of manufacturing statistics. He received his B.S. in Economics from George Mason University in 1980, and his Ph.D. in Economics from the University of Maryland in 1990.

Troy A. Wittek graduated with a Criminal Justice degree from the University of Maryland in 2007. He completed a master's degree in Applied Information Technology from Towson University in 2012. He joined Inforum in 2006 and became a full-time Research Assistant in 2009. Troy's responsibilities include collecting and analyzing statistical data for use in policy analysis, business planning, and academic research. He has helped to write and edit reports for a variety of audiences in the academic, government, and private sectors. Troy is one of the main researchers responsible for maintaining the Inforum *Lift* and *Iliad* models of the U.S. economy. He works with the Department of Defense to project defense purchases and skilled labor requirements by industry and by region using Inforum economic models. Other projects include providing forecasts for domestic industries and analyzing the impact of major soft drink bottler operations in Asia. Additional responsibilities include literature review, software testing, and website development.

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Interindustry Forecasting at the University of Maryland

Consumer Cost Impacts of a U.S. HFC Phasedown

Report Prepared for the
Air-Conditioning, Heating, & Refrigeration Institute
and the
Alliance for Responsible Atmospheric Policy

December, 2019

1.1.1 Authors' Note:

The following report, originally published in November, 2018 was prepared to explore the economic impacts of an HFC phasedown in the United States. The nominal case for a phasedown was chosen to be the schedule and requirements of the Kigali Amendment to the Montreal Protocol, with which the study interviewees were familiar. The "ratification of Kigali" case is equivalent to a phasedown of HFCs using Kigali's timing, regardless of how implemented. The methodology and conclusions of the study are independent of any other considerations related to actual ratification of the amendment by the United States.

Douglas S. Meade, Ph.D.
Joseph M. Steed, Ph.D.

Final Report

Consumer Cost Impacts of a U.S. HFC Phasedown

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Abbreviations

AHAM	Association of Home Appliance Manufacturers
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ARAP	The Alliance for Responsible Atmospheric Policy
CARB	California Air Resources Board
CFC	Chlorofluorocarbon
EPA	Environmental Protection Agency
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HVACR	Heating, Ventilation, Air-Conditioning, and Refrigeration
INFORUM	Interindustry Forecasting at the University of Maryland
SNAP	Significant New Alternatives Policy (EPA)
UNEP	United Nations Environment Program

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Executive Summary

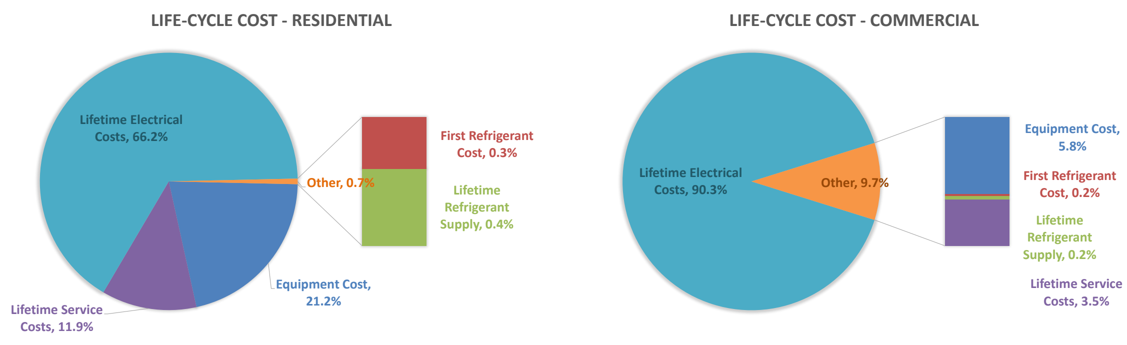
Industries producing and using fluorocarbons play a significant role in the U.S. economy. The broad industry using fluorocarbons as a refrigerant includes the Heating, Ventilation, Air-Conditioning, and Refrigeration (HVACR) industry, along with the related industries: household appliances and motor vehicle air-conditioning. HVACR equipment includes commercial and residential HVACR and commercial refrigeration and is the largest manufacturing industry using fluorocarbons. Insulating foams, medical metered-dose inhalers, aerosols, and several other applications, along with the production of the fluorocarbons themselves, comprise the rest of the broad fluorocarbon-based U.S. industry. Together these industries and their contractor, service, and distribution networks provide 589,000 direct jobs in the U.S. The HVACR and fluorocarbon technologies used globally today are signature American technologies.

U.S. industry supports ratification of the Kigali Amendment to the Montreal Protocol, followed by domestic implementation. The Kigali Amendment provides a global platform for gradual introduction and commercialization of next generation technologies in the U.S. and in the rapidly expanding global market. Prior transitions under the Montreal Protocol enabled these important U.S. industries to maintain their technology leadership. The new Kigali Amendment, which creates a clear path toward global adoption of the next generation technologies, will have a similar effect.

Previous economic analysis indicates that U.S. implementation of the Kigali Amendment is good for American jobs. It will both strengthen America's exports and weaken the market for imported products. Finally, it will enable U.S. technology to continue its world leadership role. The demonstrated benefits to industry are driven by additional equipment exports and domestic replacement of equipment imports, not higher prices for American consumers.

This report presents analysis of the impacts on consumers. It looks in detail at the costs faced by consumers of new equipment in two of the largest manufacturing segments in the industry, residential and commercial air conditioning. For a nominal purchase ten years from now, the various contributions to the consumers' total costs of ownership are examined See Figure ES.1. Energy consumption is the dominant contribution, 66% of lifetime cost for residential air conditioning and 90% for commercial. Refrigerant costs over the lifetime are only 0.7% of lifetime costs for residential and 0.4% for commercial.

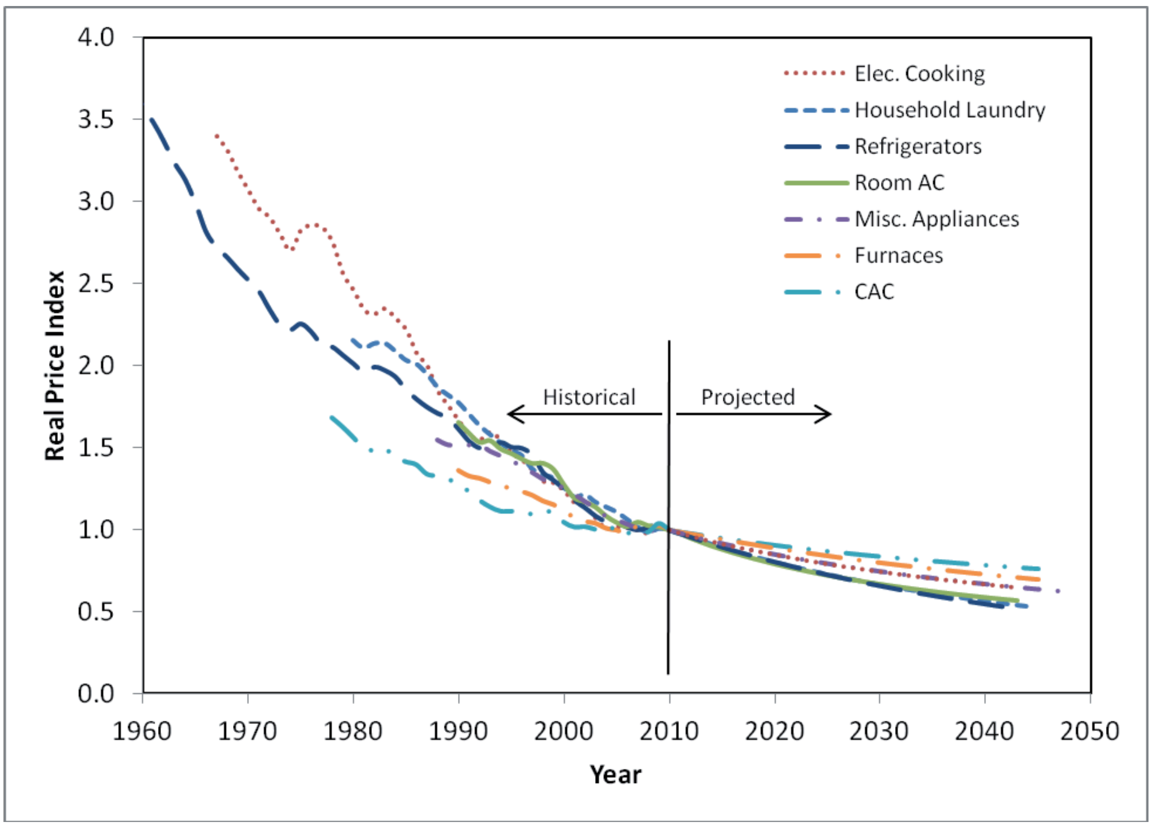
Figure ES.1: Lifetime Cost Breakdown: 2.5-Ton Residential & 15 Ton Commercial Units, 2019



With reasonable expectations about the development of the market, in scenarios assuming U.S. ratification of Kigali compared to assuming no adoption in the U.S., total lifetime ownership costs are very similar, with consumer savings in the 'with Kigali' case. Although there is no reason to expect that refrigerant prices will behave differently during the Kigali transition than during the two previous transitions away from ozone-depleting substances, even assuming a five-times higher price for replacement refrigerants would not significantly change the impact on consumers.

The consumer savings identified in this report cover only two of the largest industry segments. There are over 60 use segments that could be analyzed using more detailed models, such as EPA's Vintaging Model, as a basis. There are likely benefits elsewhere in HVACR as well as in other industries. A qualitative review of several smaller manufacturing segments supports the expectation of at least small consumer savings in several applications. For several segments there is also an underlying trend of reduced real consumer prices over time through previous transitions. Figure ES.2 shows real price indices for refrigerators, room AC, and residential central AC (CAC) along with other appliance categories.

Figure ES.2: Historical & Projected Real Price Indices for U.S. Major Appliance Categories



Ratification and implementation of the Kigali Amendment in the U.S. allows American industries to continue their history of global technology leadership, encouraging domestic production investments, without an increased cost to the consumer. Furthermore, this study shows that some of the largest industrial users of fluorocarbons, particularly residential and commercial air conditioning, will see savings from timely implementation.

Background on the Kigali Amendment

The Kigali Amendment to the Montreal Protocol was agreed upon at a meeting of more than 170 countries in October 2016. It has since been ratified by a sufficient number of countries to enter into effect globally on January 1, 2019, but it has not yet been ratified by the U.S. The fifty-eight countries that have ratified to date include all other major developed country economies. The agreement establishes timetables for all developed and developing countries to freeze and then to reduce their production and use of HFCs, chemicals that are used widely by the U.S. and global industries. HFCs will be phased down over time for most uses, and they will be replaced with new and existing chemicals and products that are more sustainable, while maintaining high energy efficiency. However, countries will also continue to look to the U.S. for policy and technology leadership in the transition.

Under the Montreal Protocol, the global fluorocarbon-using industries have undergone two prior transitions. In each case, U.S. industries were able to use their technological strengths to play a major role in defining the new generation technologies. New technology and manufacturing investments were made in the U.S., and U.S. manufacturers led the way as the world moved toward these new technologies. The transitions have been defined in such a way that older equipment can continue to be serviced with existing refrigerants and need not be replaced before the end of its useful life, minimizing consumer impact. Kigali adopts the same phased approach with long-term goals.

The Montreal Protocol is recognized as perhaps the most successful global agreement of any kind. It has also been good for the U.S. economy, providing certainty to businesses optimizing global investments and benefits to consumers. The Kigali Amendment will continue this economically beneficial effect.

Key Findings

Next Generation Products

- The suppliers of refrigerants and other materials are preparing to supply the materials needed for the Kigali transition in the U.S. Some full-scale manufacturing facilities are in operation in the U.S., and the industry is prepared to expand to serve growth, both domestically and internationally.
- The average market prices of refrigerants and other new materials are not expected to change significantly in real dollars during Kigali implementation, if Kigali is ratified in a timely manner.
- Timely U.S. ratification of the Kigali Amendment provides the smoothest, least costly transition, especially because it would then happen in concert with the rest of the developed countries and rapidly growing markets in developing countries.

Industry Response to Kigali

- Manufacturers in most applications have options to move methodically to Kigali-compliant products, with a range of alternatives to HFCs, including some which are less costly. Many have already begun the transition, but some changes require modified standards and codes to address flammability.

- Especially in the HVACR segment, U.S. businesses expect to participate in global post-Kigali markets irrespective of U.S. action on Kigali.
- Consistent with Department of Energy mandates, air conditioning equipment designed for sale in the U.S. in 2029, regardless of refrigerant choice, will be more energy efficient than today's equipment. However, consistent with other modeling studies of the transition, the average equipment sold in the 'with Kigali' scenario is assumed to be 1.3% more energy efficient on average than the equipment in the 'without Kigali' scenario.
- Because efficiency standards can place upward pressure on equipment prices, manufacturers must constantly innovate in technology, sourcing, and other areas to minimize those impacts. By coordinating design cycles for refrigerant replacement and efficiency standards, industry can minimize impacts overall.
- Although Kigali-compliant equipment will be manufactured in both scenarios, U.S. manufacturers will locate operations in the near term to support growth of the most promising markets. With Kigali, new facilities are likely to be concentrated in the U.S. Without Kigali, however, the U.S. market for next generation products is likely to grow more slowly, and offshore locations will be favored, also adding freight costs to products shipped back to the U.S. for sale.
- Without Kigali ratification, the U.S. market could become more fractured if states or localities enact non-uniform regulations with varying requirements. The resulting regulatory uncertainty would hinder the development of economies of scale, complicate development cycles, and possibly impact costs. Kigali ratification in the U.S. would eliminate the need for state action and would provide more certainty for planning, avoiding these problems.

HVACR Consumer Cost Elements

- With or without Kigali, consumers in all sectors can continue to use existing equipment throughout its useful life. If implementation of the Kigali amendment is managed properly, consumer access to refrigerant for servicing existing equipment could maintained in a cost-effective manner. Demand would be met by a combination of virgin and reclaimed refrigerants as occurred during previous transitions. Assuming effective refrigerant management approaches, there is no reason to expect a significant cost impact due to Kigali.
- The potential for consumer impact is greatest when equipment reaches the end of its useful life and it is time to purchase new equipment. By continually innovating and balancing cost considerations during design, the initial cost (in constant dollars) of HVACR equipment, refrigerators, room air conditioners and other HFC applications can be minimized substantially, while energy efficiency increases.
- Many industry participants anticipate that equipment prices will remain constant in real terms. Ongoing design cycles are built into product pricing, and there is no information to indicate that designing for Kigali will be more costly than previous design cycles and previous transitions. However, to address unforeseen issues in redesign for Kigali-compliant refrigerants, the analysis instead uses a conservative estimate that the average equipment with Kigali is 10% more expensive than equipment sold in the 'without Kigali' scenario.
- Energy efficiency in HVACR, driven by stepwise government requirements, is expected to improve by the equivalent of about 1.5% per year over the next decade regardless of Kigali implementation.

- Considering the range of refrigerants expected to be in use, the average refrigerant charge size is assumed to be 6.7% smaller for the low-GWP refrigerants and equipment used in compliance with Kigali than for the range of refrigerants and equipment in use without Kigali.
- The industry has an ongoing trend toward reduced refrigerant leak rate in residential and commercial air conditioning and refrigeration products. Leaks and recharging over the lifetime of air conditioning equipment without Kigali are estimated for this study to be equivalent to a leak rate of 10% per year. There is additional incentive to lower significantly the leak rate of flammable and low flammability low-GWP refrigerants, with the improvements applied to all equipment. The average leak rate is assumed here to be approximately 5% with Kigali, reducing consumer recharging costs.
- Maintenance and service fees are expected to be similar with and without Kigali, but average annual costs for the analysis are reduced by 13% for the 'with Kigali' case, reflecting less frequent servicing to recharge lower-leak-rate equipment.
- Refrigerant prices in the air conditioning industry without Kigali are expected to remain constant and are estimated, considering a weighted average of refrigerants in use, to be about $7/lb. Implementation of Kigali would change the mix of refrigerants over time, with initial higher prices for low-volume products but later declines with further growth, combined with growing use where feasible of refrigerants costing much less than HFCs. The average price with Kigali is expected to stabilize over the next decade to at most a slight increase over today's average prices, in real dollars.
- Implementation of similar rules, but rapidly and without Kigali's attention to coordinated phasing in of changes, can create market chaos as seen to some extent under European Union F-gas rules, raising prices, obsoleting existing equipment, and not allowing time for the innovation that has kept costs down in previous transitions.

<u>Air Conditioning Total Cost of Ownership</u>

- For both residential and commercial air conditioning, the total cost of ownership is dominated by energy consumption, approximately 66% of the cumulative total for residential, and almost 90% for commercial.
- Equipment cost is over 20% of the total for residential air conditioning, but under 7% for commercial.
- Maintenance costs are about 12% of the total ownership cost for residential and less than 4% for commercial air conditioning
- The cost of refrigerant, over the lifetime of the equipment, is a very minor component, less than 0.75% of total cost of ownership for a residential unit and less than 0.5% for a commercial unit.
- Life time cost of ownership are shown in the Figures ES.3 and ES.4 for residential and commercial air conditioning with and without Kigali implementation in the U.S. In both cases, energy savings dominate all other costs for a reduced cost of ownership with Kigali.

Figure ES.3: Residential Air Conditioning Total Cost of Ownership for 2029

	Total	Annual Average
Without Kigali	**$17,966**	$1,197.74
With Kigali	**$17,869**	$1,191.29

Figure ES.4: Commercial Air Conditioning Total Cost of Ownership for 2029

	Total	Annual Average
Without Kigali	$393,035	$26,202.34
With Kigali	$388,340	$25,889.34

- Both costs of ownership are relatively insensitive to refrigerant price. Although all assessments of price fail to suggest the average price might be higher, the cost of ownership calculations were repeated assuming average refrigerant prices were five times higher with Kigali. For residential air conditioning the small benefit became an equally small cost. For commercial, the 'with Kigali' scenario still showed a consumer benefit.

Costs in Other Applications

- Applications within the HVACR industry all share the characteristics described for residential and commercial air conditioning. Refrigerant costs are a minor component of total ownership cost over the lifetime of the equipment. For some applications, low-cost refrigerants play an increasing role in Kigali compliance, but must be balanced against other design factors that can add to design costs. Reduced charge size and increased efficiency of next generation refrigerants can help minimize the increase in commodity metals costs otherwise required to achieve efficiency targets. There is little or no reason to expect an increased long-term cost to consumers.
- Home refrigerators are in the process of being converted to low-cost refrigerants today, again for a net improvement in costs. Even before conversion, the refrigerant content represents less than $2 of the total cost of the appliance.
- The foam insulation in refrigerators is also being converted to next-generation blowing agents while maintaining or improving insulating capability, with little overall cost impact.
- Window air conditioners and motor vehicle air conditioners also share the same characteristics and are expected to continue their long-term downward trend in constant dollar pricing.
- The energy savings provided by foam insulation far outweighs its cost, which is only a fraction of the total cost of insulating buildings and refrigerators.
- The reduced leak rate and charge size of next generation equipment in the 'with Kigali' case will reduce the frequency of refrigerant replacement, reducing both the cost of refrigerant needed and the number of service calls required.
- For all applications, next-generation materials are expected to deliver equivalent or better performance at equal or lower total cost of ownership.

1 Introduction

The Montreal Protocol is an international treaty designed to protect the ozone layer. Taking effect in 1989, the agreement required the phase-out of chlorofluorocarbons (CFCs) and, eventually, hydrochlorofluorocarbons (HCFCs). Hydrofluorocarbons (HFCs) were originally introduced in order to achieve a rapid response as a replacement for ozone-depleting substances. In subsequent years, however, the science and technology communities shared concerns regarding the potential impacts of HFCs on the atmosphere and expressed the desire to replace them with next generation technologies.

On October 15, 2016, representatives from more than 170 countries met in Kigali, Rwanda, to develop the Kigali Amendment to the Montreal Protocol. The aim of the Amendment is to reduce worldwide use of HFCs. Under the agreement, developed countries would begin reducing their use of HFCs by 2019, while developing countries would start their reductions by 2024. The goal is to reduce use of HFCs by 85 percent by 2047 and replace them with low-GWP technologies, including hydrofluoroolefins (HFOs), which have far less impact on the atmosphere.

This Amendment is subject to Senate ratification in the U.S. but will formally take effect globally on January 1, 2019 whether or not the U.S. ratifies. Fifty-eight countries have now ratified the Kigali Amendment, including all major developed country economies other than the U.S. A list of ratifying countries is included in Appendix A.1. Specified controlled substances under Kigali are listed in Appendix A.2.

The previous industry-wide transition from CFCs to HFCs resulted in a 90 percent reduction of global warming potential (GWP). Replacing HFCs with next generation technologies such as HFOs, HFC blends, and other choices is expected to reduce global warming potential by an additional 90 percent.[1] Although the environmental goals of the Kigali Amendment are clear, policymakers in the U.S. would like to understand better the economic consequences of Kigali ratification, both the health of the industries employing HFCs in their current products and the costs or benefits to U.S. consumers.

Historical experience through the previous transitions under the Montreal Protocol proceeded smoothly with costs to customers benefitting in many segments from reduced initial equipment price or energy efficiency over the life of the equipment.[2]

1.1 Study Objectives

A previous study[3] by this report's authors examined the current economic contribution of the fluorocarbon, HVACR, and related industries to the U.S. economy and projected how these industries may change over a 10-year or longer period, with and without Kigali ratification. The benefits to American industry in terms of job creation and balance of trade clearly favor ratification of the Kigali amendment.

The current study extends that work to examine the implications for U.S. consumer costs, with two main objectives:

[1] UNEP (2017).
[2] The Alliance for Responsible Atmospheric Policy (2018).
[3] INFORUM and JMS Consulting (2018).

1. Examine in detail the lifetime operating costs for two of the largest HFC-using applications, residential and commercial air conditioning. Specifically, understand the impact on consumers of changes in equipment and refrigerants expected in the two cases: a) with U.S. ratification of Kigali and b) without U.S. ratification of Kigali.
2. Assess, at a high level, the likely consumer impacts of expected changes in other HFC-using industry segments.

The approach is to consider how consumer choices are affected by industry's responses to Kigali and the corresponding impact on consumer costs.

1.2 Background

The current study examines expected changes in consumer costs resulting from Kigali ratification. The focus is on two of the largest air conditioning segments with the greatest direct connection to the consumer, which are also among the largest uses of HFCs. The full range of industry segments and sub-segments includes over 60 segments, each with unique opportunities for additional consumer savings. In addition to the authors' own experience in the industry and in economic analysis, information was gathered from the industry via questionnaire and subsequent interviews. Some of the factors used in the analysis are based on very detailed analyses done by the California Air Resources Board[4].

JMS Consulting has extensive experience in working with the chemicals and HVACR industries. A study completed in 2013[5] provided an earlier analysis of the economic impact of the network of industries related to fluorocarbon production.

Inforum specializes in input-output and industry modeling at the national and regional levels, and also has extensive experience in international trade analysis. Inforum maintains a large database of bilateral imports and exports by Harmonized System (HS) 4-digit products, which is used for the Inforum bilateral trade model of the largest world economies. Inforum recently worked with the Center for Manufacturing Research of the National Association of Manufacturers to complete an industry analysis at the national and regional level for the Air-Conditioning, Heating, & Refrigeration Institute (AHRI).[6]

1.3 Consumer Choices; Consumer Impacts

Consumer choices and the cost impacts of those choices both influence industry actions and are dependent on the business-driven decisions made by industry. In section 2, the expected actions by industry, globally, are first compared for the 'with Kigali' and 'without Kigali' scenarios and are then used to define the market choices available to consumers.

Section 3 then examines the market from a consumer's viewpoint to compare the situations faced by a nominal consumer in 2029, with and without Kigali. It examines the lifetime costs of ownership for both residential and commercial air conditioning. It then considers other potential impacts in the remaining smaller markets.

[4] California Air Resources Board (2017).
[5] Steed (2013).
[6] Center for Manufacturing Research and Inforum (2017).

2 Market Implications of Kigali Ratification

To understand the impact of Kigali ratification on U.S. consumer costs, it's essential to understand what choices the consumer will have based on actions being taken now and over the next few years by U.S. industry. Those actions are likely to vary based on the U.S. government's decision on Kigali, as demonstrated in our earlier work. With an understanding of how the offerings available in the U.S. market would shift, the consumers' decisions within that market can be examined.

2.1 Overview

Earlier work outlined the likely benefits to U.S. industry as a result of Kigali ratification. The total industry is a significant contributor to the economy, employing 589,000 in the U.S. The benefits are driven by the HVACR equipment industry with a contribution from fluorocarbon manufacturing. Direct effects include an improvement of $12.4 billion in direct output in the U.S., 33,000 additional U.S. manufacturing jobs, $5.0 billion in value added, and $3.0 billion in labor income. Importantly, those benefits to U.S. industry come not from the pockets of U.S. consumers, but from a slowed rate of increase in equipment imports to the U.S. and an increased rate of exports of U.S.-manufactured equipment – improved market shares home and abroad rather than increased local prices.

The primary driver for the changed U.S. trade balance is the direction of the U.S. HVACR market. In the absence of Kigali ratification, there is little reason to expect strong near-term market demand for Kigali-compliant products in the U.S. In fact, significant regulatory uncertainty will drive industries to delay U.S. investment in new products and processes until there is more clarity about which products will be in demand. Most of the U.S. companies involved are multinational, and will also be attentive to global markets, the most important of which are sending clear market signals to manufacturers through their adoption of Kigali controls. The companies will certainly continue to invest in development and manufacture of Kigali-compliant products, but the facilities supplying the products will be strongly advantaged by being located near the sources of early, strong, and more certain demand. The U.S. companies may benefit regardless, but the additional U.S. jobs and improved trade balances are not likely without Kigali ratification.

If, however, Kigali requirements are implemented in the U.S., a large, fairly certain market will exist nearer the headquarters development facilities for most of those companies. Design and commercialization of new products can be simplified. Production in excess of local demand can and will be exported to other markets. Regulatory certainty and customers committed to the transition are expected to enable U.S. businesses to lead their efforts from their home bases and strengthen their participation in world markets, employing more workers in the U.S. to serve growing export markets and providing better products to the U.S. market, reducing imports of older technologies.

2.2 Alternatives to HFCs

Domestic implementation of the Montreal Protocol has worked to minimize consumer cost impacts by ensuring multiple options for technology transition and identification of reasonable timetables for transition. Industry has worked to achieve cost-effective transitions through coordination of design cycle changes with implementation of additional product development and manufacturing efficiencies. And opportunities for multiple options have driven healthy competition at all levels of the industry. Hence, the

Montreal Protocol has exhibited a track record of technology development and improved performance, which also achieves overall environmental objectives.

2.2.1 Product Supply and Pricing

In the case of the transition to be driven internationally by the Kigali Amendment, most of the replacement products are existing products. For example, HFC-32, hydrocarbons, and carbon dioxide are commercial products priced at relatively low levels. Some of the newer, but also already commercial, alternatives are blends incorporating these existing refrigerants with a quantity of one of several hydrofluoroolefins (HFOs). HFOs are also used alone in some applications. Additional options will continue to be developed, but the refrigerant and other supplier industries are prepared to supply the needed materials for the Kigali transition in the U.S. Some full-scale chemical manufacturing facilities are also in operation in the U.S., and the industry is prepared to expand to serve growth, both domestically and internationally.

Pricing of alternative products to meet Montreal Protocol requirements has been raised as an issue at each of the previous transitions. But in each case, the issue failed to emerge as a significant impact on consumer costs. An understanding of the normal product life cycle for new products explains why.

New product development is a costly endeavor and the development of refrigerants is no exception. In the early part of a product's lifecycle, it can cost as much as hundreds of dollars per pound to prepare a small quantity of a new product for laboratory testing. When larger quantities are produced, the costs are reduced. For example, production cost for such a product in a pilot plant might be less than one hundred dollars per pound and from a small commercial facility might be tens of dollars per pound. Manufacturing cost reductions continue throughout the product's growth period as facilities become larger and more efficient to realize economies of scale, investments are recovered, and the producers pursue optimizations like yield improvements and other process refinements.

The industry's experience with HFC-134a is instructive. When this refrigerant was first introduced to replace CFC-12 in automobiles, it was estimated that its long-term cost would be as much as ten times the material it was replacing. In fact, today's bulk prices are competitive in real dollars with refrigerants from the early 1990s. The early commercial pricing for HFC-134a was somewhat higher but was driven down very quickly by competition and manufacturing experience.

A few of the new generation refrigerants are still early enough in their life cycles that today's prices are well above their expected long-term levels. As before, there are unsupported predictions that long-term bulk prices will be as high as today's quoted retail prices for small quantities. Yet detailed analysis predicts otherwise. For instance, as worldwide demand for HFO-1234yf increases and global capacity is added to meet this demand, the cost of manufacture will continue to decline. Since HFO-1234yf was introduced, the auto industry has already seen its price decline significantly from growing economies of scale and increased competition. Long-term cost of HFO-1234yf is expected to equilibrate[7] at levels in line with the assumptions of the present study.

As countries around the world prepare to implement Kigali, lower costs will come about in concert with the effectiveness of the transition. In addition, there are only a few end

[7] Center for Climate and Energy Solutions (2017).

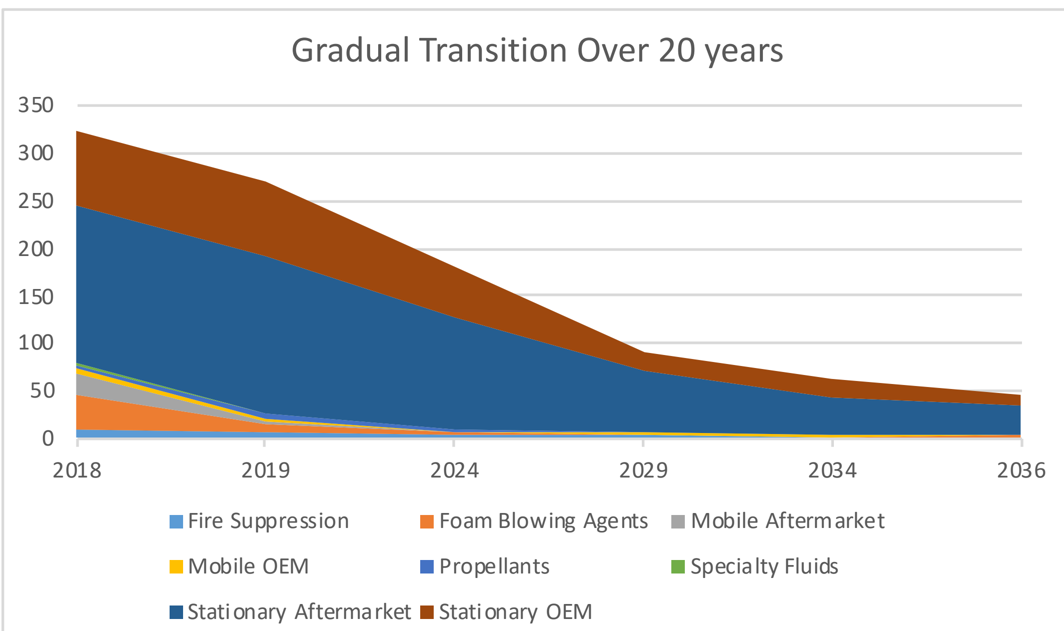
use applications where HFOs are used alone. If present in a low-GWP blend, the HFO component is at a relatively low percentage versus other lower cost refrigerants. Thus, even if HFO prices are high early in the life cycle, they will have minimal impact on the price of low-GWP refrigerant blends.

The average price of refrigerants over time will reflect the mix of materials being used at the time and their weighted costs. For the Kigali Amendment transition, prices will be a blend of remaining use of existing materials, transitions to lower cost refrigerants, and transitions to blends and other new refrigerants. Expected transitions over time have been studied for each use by industry, EPA, CARB, and others. The average refrigerant and other new materials market prices are not expected to change significantly in real dollars during Kigali implementation, if Kigali is ratified in a timely manner. The following section includes an explanation of how delays can require rapid, expensive changes instead of a smooth transition.

2.2.2 Changes in Demand Related to Kigali Ratification

Industry participants and regulators study the prospective adoption rates for various next generation materials and technologies, both to plan facilities to make materials and products available to support growth and to ensure that environmental goals can be met in a timely manner. In some cases, likely changes are studied for each application in the market. One such forecast for the U.S. market was translated into a total contribution to global warming, calculated as volume multiplied by global warming potential (GWP) for each material and grouped by industry segment for a total contribution from each segment, measured in millions of CO_2-equivalent metric tons.[8] The results shared with the authors contain no individual product forecasts, but only how the segments overall are expected to reduce their contributions to global warming.

Figure 2.1: GWP-Weighted Product Consumption by Industry Segment -- Gradual



[8] Private communication from an industry participant.

Figure 2.1 shows the GWP-weighted consumption of all existing and new products for each of the major segments in the case of gradual adoption of new products and technologies consistent with the scheduled Kigali requirements. This is how segments are likely to change with timely ratification of Kigali in the U.S.

Without ratification of Kigali, any changes in the U.S. are expected to be much slower to develop, if at all in some cases. The incentive to act is minimal, and the forecasted GWP-weighted product consumption is shown in Figure 2.2. There is essentially no reduction in GWP-weighted product consumption over the period, as any transitions taking place are offset by industry growth.

Figure 2.2: GWP-Weighted Product Consumption by Industry Segment – No Transition

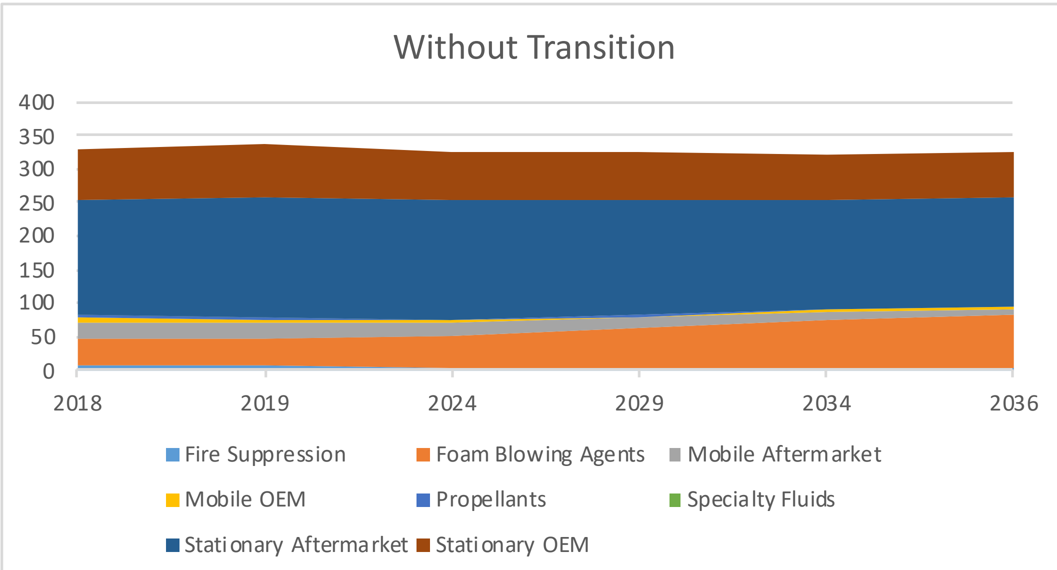
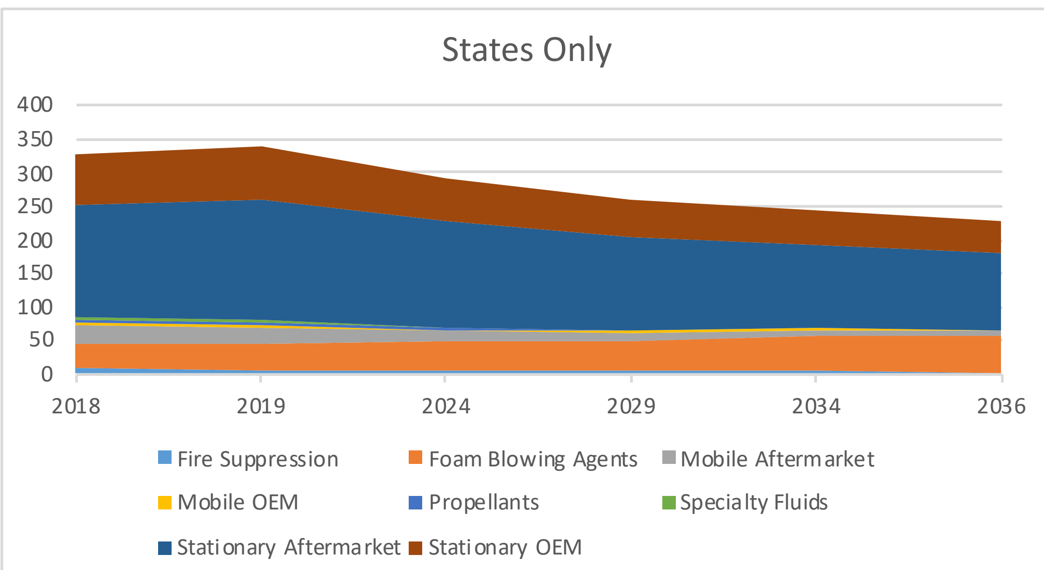


Figure 2.3: GWP-Weighted Product Consumption by Industry Segment – States Only

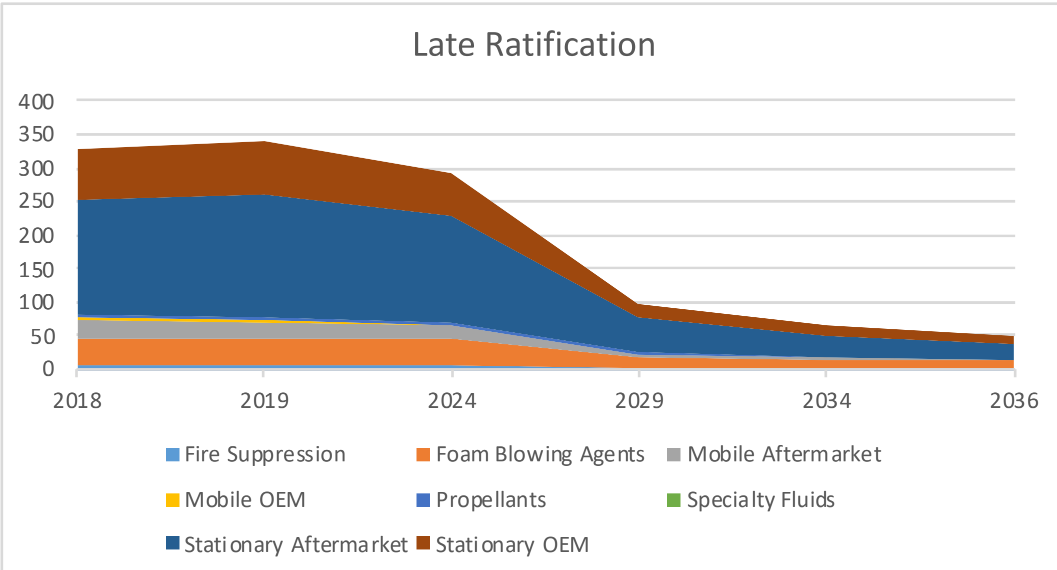


As discussed elsewhere in the report, in the absence of Kigali ratification, a number of individual states likely would choose to regulate. That possibility is shown in Figure 2.3.

There is less environmental benefit, and piecemeal actions could be expected to add to industry costs. It is unclear the extent to which these industry costs would be translated into consumer costs.

A final forecast considered the case where Kigali is ratified in the U.S., but only after a delay of five years. Little action is expected in the uncertain environment before the ratification, followed by a rapid, more expensive transition to meet the Kigali requirements in later years. This is shown in Figure 2.4. Previous experience has demonstrated the benefits of the methodical transition provided by the Montreal Protocol's gradual reduction schedules as compared with significant short-term curtailments is reflected in the figure.

Figure 2.4: GWP-Weighted Product Consumption by Industry Segment – Late Ratification



These forecasts are indicative of the kinds of changes that will take place as the Kigali Amendment goes into force globally in 2019, depending on the kind of action taken in the U.S. Timely U.S. ratification of the Kigali Amendment provides the smoothest, least costly transition, especially because it happens in concert with the rest of the developed countries.

2.3 Industry Actions

The costs that fall to consumers are obviously determined by a combination of what products are available on the market and what choices the customers make among those products. Industry, however, must make some of its choices in advance of actual consumer demand. Development cycles, other regulatory requirements, and facility construction or modifications all create time constraints. To understand impact on consumers, one needs a view of the future market choices.

2.3.1 Available Alternatives

In addition to the refrigerants that are dominant in today's market, a number of new choices have become available, including hydrofluoroolefins (HFOs) and hydrocarbons. Some, notably hydrocarbons, are less expensive even than today's refrigerants. But they bring flammability concerns, requiring additional equipment engineering to prevent leaks, to provide additional fireproofing, and so on. Some applications, like household refrigerators, require only small volumes of refrigerant, are largely leak-free already, and are moving to newer refrigerants.

Where larger refrigerant volumes are involved, some of the new refrigerants have very low flammability that requires less significant design changes. One of the concerns has been the high prices of such products when demand is still low, products are early in their life cycle, and production costs remain high. In this case, the history of previous transitions is relevant. During both of the previous Montreal Protocol transitions, away from CFCs and away from HCFCs, the HFCs that replaced them were initially expensive, but competition, manufacturing scale, and the typical learning curve for new products has brought prices back to more traditional levels.

Another important consideration is the energy efficiency of the cooling system. Refrigerants vary in their own contributions to efficiency, with some improving energy efficiency as much as 10%. System design can achieve additional efficiency in other ways as well, with possible tradeoffs in design and development cost. Ongoing requirements for efficiency improvements in overall systems create a pressure to find the most favorable options for achieving the required efficiencies.

Of course, manufacturers also consider expected long-term refrigerant pricing in making their selections, but next generation refrigerant prices are expected to decline, with increased market growth and competition, toward cost parity. Manufacturers also look to experience from previous transitions for guidance. When R134a, an HFC, was first introduced in the 1990s, there were predictions of long-term pricing between $4.50 and $12/lb. for bulk purchases ($7.70 to $20/lb. in current dollars). Recent distributor prices are in the neighborhood of $3/lb.[9], demonstrating the expected decline over time as volumes and competition have increased and manufacturing processes have been refined.

The history of pricing has been highly dependent on the gradual chemical phasedowns and logical user transitions under the Montreal Protocol. Experience with the European Union F-gas rules reaffirms the need for both. Europe has experienced extraordinary cost increases because they failed to coordinate the chemical phasedown with the equipment and other end-user transitions; they accelerate the Kigali phasedown ahead of the ability to achieve the transition; and they significantly impacted the existing equipment base by limiting availability of current HFC supply for this importance service need. This is precisely opposite what U.S. industry is urging for implementation in the U.S.

Equipment manufacturers' decisions on what equipment to design and produce take all of these factors into account. They also note that the volume of refrigerant constitutes a relatively small part of the cost of a new air conditioning unit. Further, with the ongoing effort to contain leaks, the need for replacement refrigerant during the equipment's operating lifetime is also reduced, minimizing the impact on service costs.

2.3.2 Equipment Design

Air conditioning manufacturers operate with a design cycle that ensures new equipment meeting all anticipated regulatory requirements will be available as needed for commercial introduction. Refrigerant suppliers work with them to ensure that the chosen

[9] Private communication from a supplier.

refrigerants will also be available. Early in the design cycle, the expected regulatory environment must be anticipated, to ensure that efficiency and other regulatory requirements will be met. Having the clarity of Kigali timelines will enable design cycles to be completed meeting both sets of requirements.

Design cycles are full of tradeoffs: a low-cost refrigerant might require more expensive components in some parts of cooling equipment. A more expensive refrigerant might offer equipment savings or energy efficiency elsewhere. Manufacturers seek to manage these tradeoffs while meeting all the external requirements, and the balance can be different in different segments and applications.

One of the biggest challenges during a period of transition is understanding what the requirements will be. The Montreal Protocol, and more recently the Kigali Amendment, acknowledged this challenge by imposing gradual changes to allow the transition to be smooth, minimizing impacts on both manufacturers and consumers. By having date-certain and well-defined requirements, industry has clear design targets and can maintain an efficient design cycle.

Similarly, energy efficiency requirements are mandated to change over time, with the timing well understood. U.S. Department of Energy (DOE) efficiency rulemakings are anticipated in both 2023 and 2029. DOE cites advantages to manufacturers overall as a result of the standards and the way they are designed.[10] The periodic increases in DOE energy conservation standards are, however, a significant cost burden for manufacturers and these costs are ultimately passed on to consumers. Efficiency improvements generally require a larger heat transfer surface, meaning additional materials such as steel, aluminum and copper. To lessen the cost impacts of these efficiency increases, industry innovates to commercialize improved compressor technology and heat transfer surfaces, sources commodities and components from lower cost suppliers and incorporates new technologies to drive manufacturing efficiencies. Additionally, some alternate refrigerants are more efficient, allowing manufacturers to add less material content, again reducing the impact of these transitions.

Coordinating a refrigerant transition with energy conservation standards will significantly reduce the anticipated cost impacts associated with major design cycles, enabling industry to move quickly and efficiently to new equipment designs appropriate to the market. Without Kigali, separate uncoordinated design cycles will have a negative impact on consumer cost. The phasedown steps negotiated in Kigali create an opportunity to align the 2029 transition in residential and commercial split air conditioning systems while meeting the 2029 DOE-mandated efficiency improvement. The timing also allows for equipment safety standards and building codes to be updated and adopted by jurisdictions. For modeling purposes, meeting the DOE requirements is equivalent to about 1.5% per year improvement.

Regulatory uncertainty is a constant challenge. Some designs must be developed in case they are needed but may never be used if the regulatory environment does not develop as anticipated. Without federal action, some states or localities in the U.S. are implementing regulations on their own, as happened in the Montreal Protocol transition away from CFCs. Manufacturers are faced with the decision of single designs sufficient to meet all such requirements or multiple designs tailored to each regulatory environment. OEM sources[11] note that the costs of design cycles for the redesign of a product line (by

[10] See Department of Energy (2017).
[11] Private communication from a U.S OEM.

major manufacturers) traditionally run in the $20-$50 million range depending on the time required and the complexity of the transition.

The cost of major product line transitions can be significantly reduced when both energy conservation standards and refrigerant transitions are combined and guided by certainty and predictability, allowing manufacturers to find efficiencies and synergies when executing their multi-generation product plans. Lack of coordination adds to design costs and ultimately to consumer costs. Multiple low volume lines also provide only very limited economies of scale, and the equipment from the lower volume lines will be more expensive. Alternatively, if regulations are non-uniform, an attempt to meet multiple conflicting requirements in a single design leads to higher cost of manufacture and can be made obsolete in a state with the passage of newer regulations, possibly impacting consumer prices.

As part of their design work, manufacturers are constantly working on developments to reduce their own costs in other ways to increase profits without increasing prices, or to counterbalance expensive improvements with savings elsewhere.

A final ongoing design effort across the industry seeks to reduce leak rates. For all equipment, this can reduce ongoing cost of ownership in addition to the environmental benefits. For refrigerants with any flammability risk, even low flammability, it's essential. Reduced leaking saves refrigerant costs and maintains sufficient charge to keep the equipment's performance near its optimum for longer. According to the EPA EnergyStar program, properly charged equipment operates 5%-20% more efficiently than improperly charged equipment.[12]

2.3.3 World Trade and Manufacturing Site Decisions

An important consideration for equipment manufacturers, most of which have multi-national operations, is the location of new manufacturing facilities. The markets for their products are international and their competition is global. Typically, companies will make choices that allow most of their production to flow to local markets, with an intent to export additional production. This can be especially important with new product introductions, where the earliest production facilities are often located where the market for the product is expected to be fastest growing.

For prior transitions under the Montreal Protocol, the U.S. was a consistent leader in implementing the required changes. Most U.S. companies designed and introduced new products in their home markets and used that base, as well as additional offshore facilities over time, to build their strength in world markets. Today, with much of the world having already committed to Kigali and the U.S.'s commitment far from certain, there is a great deal of pressure on U.S. companies to locate new facilities offshore, where their markets will be more certain. That decision would make the new delivered equipment prices higher in the U.S. after adding the cost of shipping back to the U.S. Similarly, the U.S. home market is constantly being challenged by imports of older equipment as the global market for equipment using current refrigerants shrinks with the implementation of Kigali. The large U.S. market offers the best prospect for sales of the outdated equipment. Conversely, with Kigali ratification, the U.S. would offer the most attractive market for sales of next generation technology and equipment.

[12] See Environmental Protection Agency (2009).

2.3.4 Anticipated Industry Responses

U.S. industry has necessarily begun its planning for product developments over the next several years. Some new equipment is being developed with new refrigerant choices, work is underway to meet energy efficiency requirements, and site selection decisions are already being considered for equipment using new refrigerants.

Without U.S. Kigali ratification, production will likely continue for equipment using HFC refrigerants, modified as necessary to meet energy efficiency requirements. More of it will likely be supplied by imports from other countries. New offerings will be available, but at a higher price because of smaller volumes and market prices influenced by the demand for such products in countries meeting Kigali's requirements. Similarly, alternative refrigerants will likely retain at least some of their low-volume higher pricing for the foreseeable future. Investments by U.S. companies in manufacturing facilities for new equipment using new refrigerants are more likely to be located offshore or, if required for meeting state regulations, to be smaller in scale.

In the event the Kigali Amendment is ratified, the incentive for U.S. domestic manufacturing becomes much greater. Both new refrigerants and the equipment to use them will be fully available to U.S. consumers at the most competitive prices in the world, and the volumes will grow sufficiently to quickly moderate the early, developmental scale pricing.

2.4 Market Implications

From the consumer's viewpoint, the decisions involved in compliance with Kigali are much simpler. Current air conditioning equipment owners want to maintain their existing equipment, with refrigerant recharging as necessary, throughout its useful life. The want to buy a new system only when their own needs dictate, independent of Kigali timing. A decision to purchase new or replacement air conditioning equipment is made from within the market offering at the time of purchase. A decision on new equipment in a given year is best looked at by considering the average market expected during that year. One can then consider the ownership experience throughout the equipment's useful life.

2.4.1 Support of Existing Equipment

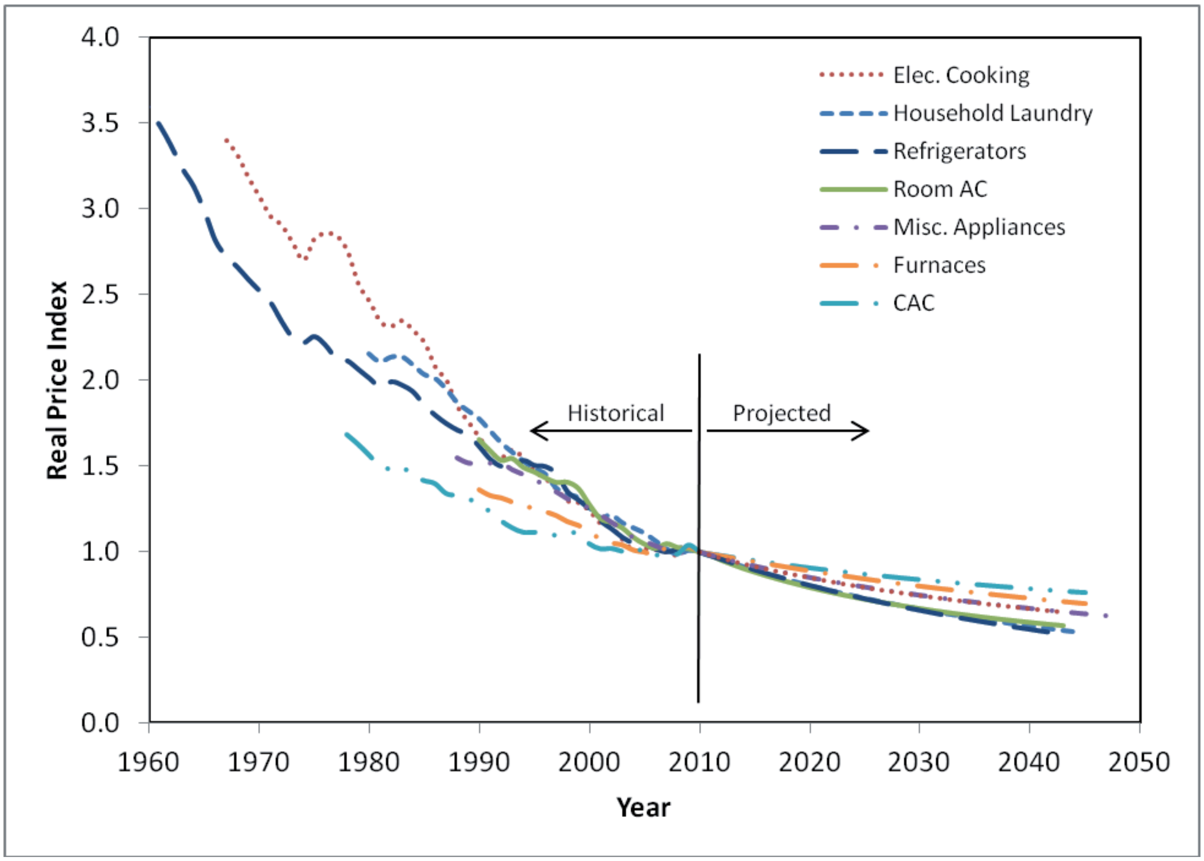
Owners of existing equipment will experience little or no impact from Kigali. Under the Montreal Protocol, regulated refrigerants remained available throughout the lifetimes of the equipment using them, and are still available today, long after production of the refrigerant was stopped. Some operating commercial equipment is more than thirty years old. The reclaim market has served as a buffer to provide products at reasonable prices, to meet the market demand. A similar situation will exist for HFCs post-Kigali, regardless of whether the U.S. participates. What that means is that there is no Kigali-driven mandate for an early purchase of new equipment, other than a consumer's own choice.

2.4.2 New Equipment Cost

When a consumer decides to purchase new air conditioning equipment, the choice will be made from equipment on offer at the time. Some purchasers will favor lower initial purchase costs; others will look for new features. Some, particularly commercial purchasers, will be guided by ongoing operating costs or expected total cost of ownership. Starting with what is on offer, they will shape the market by purchasing more of what they want and less of what they don't want. Historically, manufacturers consider an average of the prices paid for a given capacity air conditioning unit as one useful market measure. From the consumer's viewpoint, this is a one-time decision: What will I pay now for a unit to cool my house or building?

Markets, not just costs, drive pricing in competitive industries. Suppliers will try to pass along their cost increases, but that works only so long as customers continue to buy. Recent residential air conditioning equipment pricing has somewhat stabilized in constant dollars.[13] Historic data suggests that, despite the numerous transitions under the Montreal Protocol and domestic energy efficiency programs, real dollar pricing in central air conditioning (CAC), as well as room (window) air conditioning and refrigerators, declined between 1980 and 2010, as shown in Figure 2.5.[14]

Figure 2.5: Historical and Projected Real Price Indices for U.S. Major Appliance Categories



It is reasonable to assume that consumers will continue to face an array of different choices meeting whatever regulatory requirements are in place at the time, but without a significant change in average market pricing.[15] It is possible that a slight increase in the average might occur with Kigali, but that is not the historical experience.

[13] Goetzler, et al. (2016).
[14] See Desroches, et al. (2018). Historical trends based on the PPI published by the U.S. Bureau of Labor Statistics. Projected trends are experience curve fits to the historical data.
[15] See Navigant (2018)

2.4.3 Operating Expenses

A final important consideration for consumers can be their ongoing operating costs for a piece of air conditioning equipment. The primary contributors are operating costs, in the form of electricity, and maintenance, including the cost of refrigerant for recharging as needed.

The size of a unit and of course its energy efficiency determine its electricity requirement. For a given size, then, it is reasonable to look at the average energy efficiency expected to be offered by the manufacturers. This is driven largely by regulatory requirements. Over the long term, those efficiencies will increase. Equipment bought in the future will consume less electricity over its lifetime than equipment bought today. However, the inherent efficiency advantages of the low-GWP alternatives for residential and light commercial applications that would transition in 2029 offer an advantage of improved cycle efficiency. In line with modeling by CARB, this benefit has been valued in the present study as an efficiency increase of about 1.3% in the compliant products using low-GWP refrigerants in 2029 with Kigali ratification. relative to products sold in 2029 without Kigali.[16] An alternative would be to reflect the benefit as reduced cost of commodity metals required to achieve the mandated efficiency. In fact, this is considered the more likely scenario for all but the most efficient equipment lines. The benefit from reduced initial consumer cost would be comparable to the alternative efficiency benefit.

Average costs for a maintenance or service visit will not differ markedly for consumers facing 'with Kigali' or 'without Kigali' market scenarios. However, the increasing effort necessary to reduce leak rates with new refrigerants because of even minor flammability concerns is expected to have a significant impact on the market. Leaks tend to happen when a system is compromised for some reason rather than slow leaks over time. Current equipment can be considered to have about a 10% per year leak rate on average, meaning one to two full refrigerant recharges over a fifteen-year lifetime.[17] Kigali-compliant equipment is expected to reduce that to 5% per year, or roughly one full replacement over a lifetime.

The impact of Kigali on maintenance costs, then, consists of a reduction in replacement refrigerant volume and a reduction in the average cost of maintenance and service due to fewer visits. For the attentive consumer, these costs will factor into their purchase decisions, but again, their choices will be limited by the products available at the time. A non-Kigali scenario is not likely to offer the lifetime savings.

[16] California Air Resources Board (2017).

[17] Both the current estimated leak rate and the improvements associated with Kigali compliance for flammable and low-flammability refrigerants are estimates from industry sources familiar with design targets.

3 Consumer Impacts of Kigali Ratification

Consumer impacts under Kigali benefit from the phased-in controls. Existing refrigerants remain available for servicing existing equipment. New equipment purchases are not accelerated other than by customer choice. The same is true in most applications.

The cost issue for consumers is therefore focused on their new equipment purchases and what they will experience. We have selected two of the largest applications in the HVACR industry and largest users of HFCs for a detailed analysis of the cost of ownership over the lifetime of the equipment. These applications are residential and commercial air conditioning. The former is well-represented by an average sized unit of 2.5 tons capacity. The latter, typically rooftop units on commercial buildings, is well represented by a nominal 15-ton unit. We began by assessing the costs of a purchase in 2019, using it as the basis for projections for costs with and without Kigali implementation in 2029.

We also conducted a brief assessment of several other HFC-using applications considering the impacts of Kigali. Many share characteristics with the air conditioning applications, however these assessments are primarily qualitative.

3.1 Methodology: Calculation of Life Cycle Cost

Life cycle cost analysis[18] can be used to compare the average cost of ownership and use for alternative equipment with similar operating characteristics. For this analysis, we have collected from several of the individual producers of air-conditioning equipment, or projected based on their input, information[19] on the following operating characteristics:

1. Initial cost of the equipment, including the initial charge of refrigerants.
2. Average service life.
3. Resale value at the end of life, if any, or disposal cost.
4. Annual fuel and/or electricity expense.
5. Average annual service cost, including parts and refrigerant replacement.

For each type of equipment considered, we first evaluate current (2019) cost parameters. We then project likely future (2029) cost for the two cases – with and without Kigali ratification. All projections are based on the data collection and interviews. Conservative assumptions made for each air conditioning application are described.

To estimate the life-cycle cost (LCC) from these parameters, we will use the following formula:

$$LCC = I - Res + E + OM\&R + O$$

LCC = Total LCC in present-value (PV) dollars of each given alternative

I = Initial investment cost

Res = PV residual value (resale value, salvage value) less disposal costs

[18] See Fuller and Petersen (1995) for a standard government reference on life-cycle costing.
[19] California Air Resources Board (2017).

E = PV of energy costs

OM&R = PV of non-fuel operating, maintenance and repair costs, including refrigerant replacement

O = PV of other costs

When calculating present value, we have considered both the undiscounted sum of costs and the costs discounted at 7 percent, over the average expected lifetime of the equipment.

3.2 Residential Air Conditioning

3.2.1 Current Cost Variables

Figure 3.1 presents important variables to be considered in calculating the full life-cycle cost of a nominal residential AC (2.5-ton) unit. Average refrigerant cost, average charge size, installed cost, annual service and maintenance cost and average electricity consumption are based on the collective input of the industry, plus analysis by CARB in the case of refrigerant cost and electricity consumption. Average electricity cost uses the DOE/EIA Projected Electricity Prices from the Annual Energy Outlook 2018, expressed in 2019 dollars. Annual refrigerant cost is calculated as the replacement cost for an average leak or loss rate of 10% of the charge size per year, although the replacement would likely not occur in those increments.

Figure 3.1: Life Cycle Cost Variables for a 2.5-Ton Residential Unit, 2019

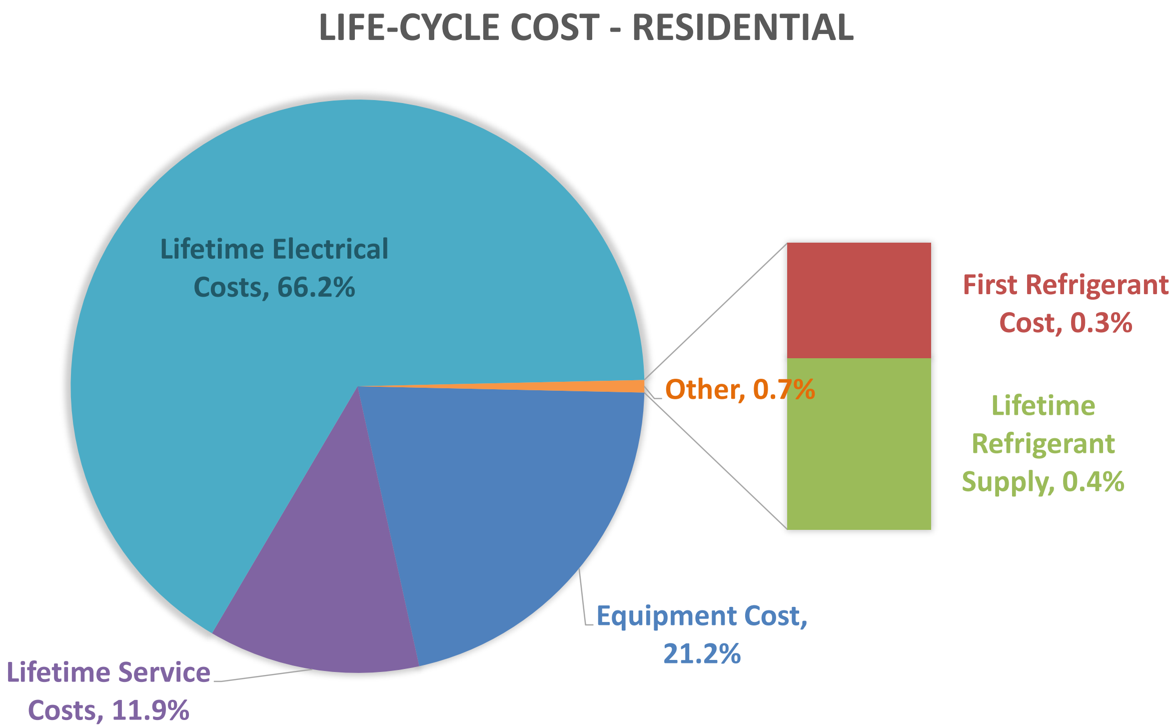
Installed Cost	Initial Refrigerant Cost	Expected Life (Years)	Annual Operations Cost	Annual Electricity Cost	Electricity Consumption	Avg Electricity Cost ($/Kwh)	Annual Refrigerant Cost	Average Charge Size (lbs/unit)	Regrigerant Cost ($/lb)	Annual Service & Maintenance Cost
$4,000	$53	15	$838	$832.39	6,125	$0.136	$5.250	7.5	$7.00	$150

We start with the initial cost and initial refrigerant cost. For the life of the equipment (15 years), we cumulate the annual operations cost and annual service and maintenance cost. Operations cost is further divided into annual electricity cost and annual refrigerant cost. All dollar figures are in 2019 constant prices. In this modeling, we assume, for simplicity that the parameters don't change over the lifetime of the equipment.

Undiscounted total initial and annual cost using the formula in section 3.1 comes to $18,867.06. Average annual cost is $1,257.80. The calculation can also be done with discounting, at a 7 percent rate. Discounting puts more weight on the initial installation cost, and less weight on cost savings that may occur in future years. The total discounted cost is $12,637.35. Average discounted cost per year is $842.49.

Figure 3.2 shows the breakdown in costs for the life cycle of a residential air conditioner. The dominant component in total costs for purchase of a home air conditioner, even in the discounted case is energy consumption at over 66%, followed by initial investment at 21% and annual service and maintenance at 12%. The contribution of initial refrigerant and replacement charges to cost is approximately 0.7% of the total.

Figure 3.2: Life Cycle Cost Breakdown for a 2.5-Ton Residential Unit, 2019



3.2.2 Projected Cost Variables: 2029

Surveys of industry experts and CARB projections formed the basis for the following conservative assumptions about how costs will change between now and 2029. All costs are expressed in 2019 dollars.

- In the absence of Kigali, we expect no difference in the cost of an average unit. For the Kigali case, we assume conservatively that low-GWP equipment in 2029 would be roughly 10 percent more expensive. We were cautioned that historical prices in constant dollars have come down over time, that most of the changes required would likely be offset by other manufacturing cost reductions, and that ongoing design cycle costs are already priced into equipment. For the analysis, we chose conservatively to allow for potential increase.
- By 2029 low-GWP refrigerant blends and high-GWP refrigerant blends would have approached the same cost ($7/lb.). This assumption is based on extensive CARB analysis of likely shifts in refrigerant choice combined with analysis of pricing patterns over time for previous generations of refrigerants. We will explore the sensitivity to this assumption as part of the analysis.
- Efficiency opportunities with the low-GWP equipment can be used by manufacturers to minimize cost while achieving energy targets. However, in line with previous modeling, the benefit will be modeled as an increase in energy efficiency of 1.3 percent relative to high-GWP equipment.
- The average refrigerant charge size in the low-GWP equipment is approximately 6.7% smaller than for today's equipment, based on trends noted by manufacturers from their own design work.

- The low-GWP residential and commercial air conditioning equipment is assumed in the model to have a significantly lower leak rate, 5 percent instead of 10 percent per year average. Industry constantly works to minimize leaks, and some types of equipment are already even tighter than this. However, the acceptance of flammability in refrigerants will accelerate this effort, justifying the assumed improvement.

3.2.3 Life Cycle Costs: 2029

Using the projections from engineers and economists from 6 of the top U.S. producers of air-conditioning equipment, we calculated the lifetime costs of ownership and use. Figure 3.3 shows the results of projecting life-cycle costs, both with Kigali ratification and without. Again, all values are in 2019 dollars.

Figure 3.3: Life Cycle Cost Variables for a 2.5-Ton Residential Unit, 2029 Projections

	Installed Cost	Initial Refrigerant Cost	Expected Life (Years)	Annual Operations Cost	Annual Electricity Cost	Electricity Consumption	Avg Residential Electricity Cost (2019$/Kwh)	Annual Refrigerant Cost	Average Charge Size (lbs/unit)	Regrigerant Cost (2019$/lb)	Annual Service & Maintenance Cost
Without Kigali	$4,000	$53	15	$778	$772.32	5,272	$0.1465	$5.25	7.5	$7.00	$150
With Kigali	$4,400	$49	15	$765	$762.24	5,203	$0.1465	$2.45	7.0	$7.00	$130

The results of these assumptions using a static calculation (no discounting) is shown in Figure 3.4. The results with discounting are in Figure 3.5. Note that in either case, the life cycle costs are not much different. Both comparisons represent a tradeoff between higher initial cost with the low-GWP equipment and refrigerants and lower annual operations and maintenance costs. With the simple static computation, the low-GWP equipment life cycle cost with Kigali is slightly lower. In the discounted case shown in Figure 3.5, the cost savings in the future are given less weight and are not quite sufficient to offset the higher initial cost.

Figure 3.4: Comparison Using Static Calculation (undiscounted) for 2029

	Total	Annual Average
Without Kigali	**$17,966**	$1,197.74
With Kigali	**$17,869**	$1,191.29

Figure 3.5: Comparison Using Discounting for 2029

	Total	Annual Average
Without Kigali	**$12,165**	$810.97
With Kigali	**$12,273**	$818.23

One cost element in particular has been the subject of much speculation. Although our analysis and the input that was collected both support our refrigerant price assumptions, we have explored the sensitivity of the results to a much higher price. The same calculation was performed with a refrigerant cost of $35/lb. instead of $7, a factor of five difference. For the high refrigerant cost, the total cost in the undiscounted calculation increases by $343 from $17,869 to $18,212, or an annual average of $1,214.15, an increase of 1.9%, and only 1.4% per year more than the 'without Kigali' cost. The discounted total for the 'with Kigali' case increases $282 from $12,273 to $12,555, or an annual average of $837.01, an increase of 2.3%.

The consumer cost impacts over a full life cycle in the 'with Kigali' scenario in comparison to the market expected without Kigali range from a small benefit in an undiscounted calculation to a small added cost in a discounted calculation, less than one percent in both cases. Even if refrigerant prices have been underestimated by a factor of 5, life cycle costs do not markedly increase. To the extent the initial equipment pricing, as very reasonably predicted by some respondents, avoids the 10% increase used here, that would reduce the 'with Kigali' costs by $400 in both the undiscounted and discounted cases, more than offsetting any increase in the refrigerant price.

3.3 Commercial Air Conditioning

3.3.1 Current Cost Variables

Figure 3.6 presents important variables to be considered in calculating the full life-cycle cost of a nominal commercial AC (15-ton) unit. Average refrigerant cost, average charge size, installed cost, annual service and maintenance cost and average electricity consumption are based on the collective input of the industry, plus analysis by CARB in the case of refrigerant cost and electricity consumption. Average electricity cost uses the DOE/EIA Projected Electricity Prices from the Annual Energy Outlook 2018, expressed in 2019 dollars. Annual refrigerant cost is calculated as the replacement cost for an average leak or loss rate of 10% of the charge size per year, although the replacement would likely not occur in those increments.

Figure 3.6: Life Cycle Cost Variables for a 15-Ton Commercial Unit, 2019

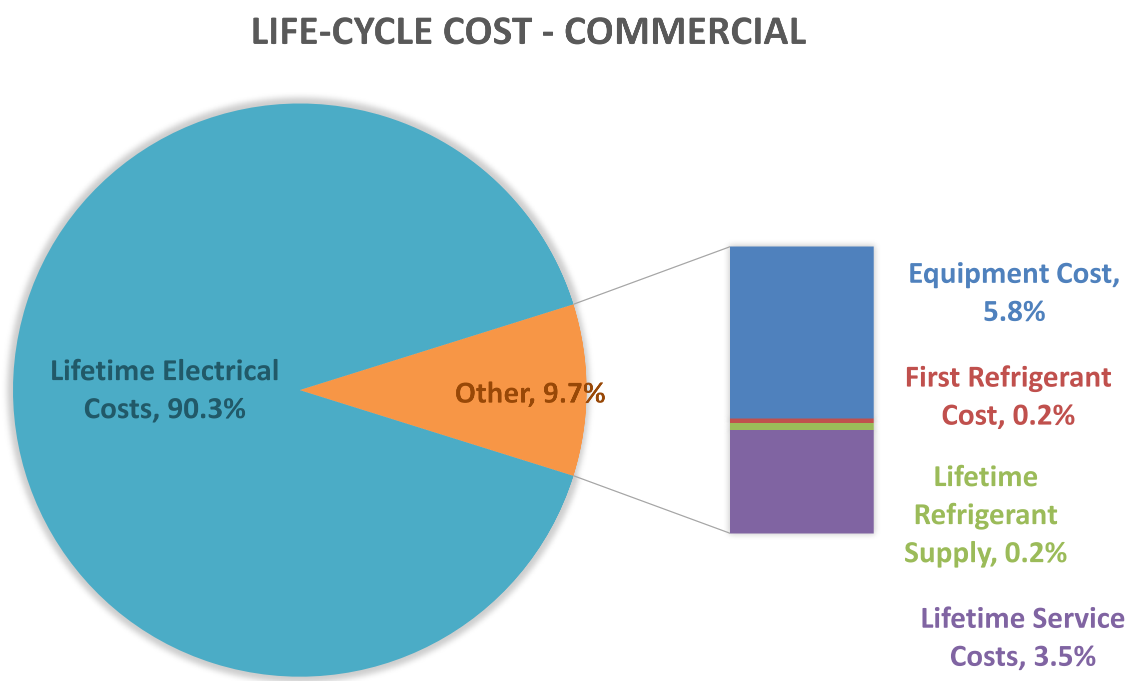
Installed Cost	Initial Refrigerant Cost	Expected Life (Years)	Annual Operations Cost	Annual Electricity Cost	Electricity Consumption	Avg Electricity Cost ($/Kwh)	Annual Refrigerant Cost	Average Charge Size (lbs/unit)	Regrigerant Cost ($/lb)	Annual Service & Maintenance Cost
$25,000	$700	15	$26,060	$25,990.00	230,000	$0.113	$70.00	100.0	$7.00	$1,000

We start with the initial cost and initial refrigerant cost. For the life of the equipment (15 years), we cumulate the annual operations cost and annual service and maintenance cost. Operations cost is further divided into annual electricity cost and annual refrigerant cost. All dollar figures are in 2019 constant prices. In this modeling, we assume, for simplicity that the parameters don't change over the lifetime of the equipment.

Undiscounted total initial and annual cost using the formula in section 3.1 comes to $430,600.00. Average annual cost is $ $28,773.33. The calculation can also be done with discounting, at a 7 percent rate. Discounting puts more weight on the initial installation cost, and less weight on cost savings that may occur in future years. The total discounted cost is $ $261,652.36. Average discounted cost per year is $17,443.49.

Figure 3.7 shows the breakdown in costs for the life cycle of a residential air conditioner. The dominant component in total lifetime costs for purchase of a commercial air conditioner, even in the discounted case, is energy consumption at over 90%. Even the annual energy cost is greater than the initial equipment investment, which is less than 6% of lifetime costs. After those two elements follows annual service and maintenance at less than 4%. The contribution of initial refrigerant and replacement charges to cost is approximately 0.4% of the total.

Figure 3.7: Life Cycle Cost Breakdown for a 15-Ton Commercial Unit, 2019



3.3.2 Projected Cost Variables: 2029

Surveys of industry experts and CARB projections formed the basis for the following assumptions about how costs will change between now and 2029. All costs are expressed in 2019 dollars.

- In the absence of Kigali, we expect no difference in the cost of an average unit. For the Kigali case, we assume conservatively that low-GWP equipment in 2029 would be roughly 10 percent more expensive. We were cautioned that historical prices in constant dollars have come down over time, that most of the changes required would likely be offset by other manufacturing cost reductions, and that ongoing design cycle costs are already priced into equipment. We chose for the analysis to allow for possible increases.
- By 2029 low-GWP refrigerants and high-GWP refrigerants would have approached the same cost ($7/lb.). This assumption is based on extensive CARB analysis of likely shifts in refrigerant choice combined with analysis of pricing patterns over time for previous generations of refrigerants. We will explore the sensitivity to this assumption as part of the analysis.

- Additional engineering improvements in the low-GWP equipment achieve an increase in electricity efficiency of 1.3 percent relative to high-GWP equipment. However, both types of equipment are more efficient than the 2019 vintage.
- The average refrigerant charge size in the low-GWP equipment is approximately 6.7% smaller than for today's equipment, based on trends noted by manufacturers from their own design work.
- The low-GWP equipment has a significantly lower leak rate, 5 percent instead of 10 percent per year average. This is consistent with design intent to minimize leaks over time in this equipment.

3.3.3 Life Cycle Costs: 2029

Using the projections from engineers and economists from 6 of the top U.S. producers of air-conditioning equipment, we calculated the lifetime costs of ownership and use. Figure 3.8 shows the results of projecting life-cycle costs, both with Kigali ratification and without. Again, all values are in 2019 dollars.

Figure 3.8: Life Cycle Cost Variables for a 15-Ton Commercial Unit, 2029 Projections

	Installed Cost	Initial Refrigerant Cost	Expected Life (Years)	Annual Operations Cost	Annual Electricity Cost	Electricity Consumption	Avg Commercial Electricity Cost (2019$/Kwh)	Annual Refrigerant Cost	Average Charge Size (lbs/unit)	Regrigerant Cost (2019$/lb)	Annual Service & Maintenance Cost
Without Kigali	$25,000	$700	15	$23,489	$23,419.00	197,963	$0.1183	$70.00	100.0	$7.00	$1,000
With Kigali	$27,500	$653	15	$23,146	$23,113.12	195,377	$0.1183	$32.67	93.3	$7.00	$867

The results of these assumptions using a static calculation (no discounting) is shown in Figure 3.9. The results with discounting are in Figure 3.10. Note that in either case, the life cycle costs are not much different. Both comparisons represent a tradeoff of higher initial cost with the low-GWP equipment and refrigerants with lower annual operations and maintenance cost. The discounting places a lower weight on the cost savings in the future, when making the comparison. With both the simple static computation and the discounted calculation, the low-GWP equipment in the 'with Kigali' case has slightly lower total cost of ownership.

Figure 3.9: Comparison Using Static Calculation (undiscounted) for 2029

	Total	Annual Average
Without Kigali	$393,035	$26,202.34
With Kigali	$388,340	$25,889.34

Figure 3.10: Comparison Using Discounting for 2029

	Total	Annual Average
Without Kigali	$239,868	$15,991.19
With Kigali	$238,153	$15,876.90

One cost element in particular has been the subject of much speculation. Although our analysis and the input provided support our refrigerant price assumptions, we have explored the sensitivity of the results to a much higher price. The same calculation was performed with a refrigerant cost of $35/lb. instead of $7, a factor of five difference. For the high refrigerant cost, the total cost in the undiscounted calculation increases by $4,574 from $388,340 to $392.914, or an annual average of $26,194.23, still 0.03% less than the 'without Kigali' cost. The discounted total for the 'with Kigali' case increases by $3757 from $238,153 to $241,910, or an annual average of $16,127.30, less than 0.9% higher than the 'without Kigali' cost.

The consumer cost impacts over a full life cycle in the 'with Kigali' scenario in comparison to the market expected without Kigali show lower total cost with Kigali, whether discounted or not. Even if refrigerant prices have been underestimated by a factor of 5, the undiscounted life cycle cost remains lower with Kigali. But the discounted total shows a small increase with less weight given to future benefits. To the extent the initial equipment pricing, as very reasonably predicted by some respondents, avoids the 10% increase assumed here, that would reduce the 'with Kigali' costs by $2500 in both the undiscounted and discounted cases, more than offsetting any increase in the assumed refrigerant price.

3.4 Other Consumer Markets

In addition to the detailed consumer cost estimates for the two large air conditioning sectors, we have gathered information regarding the potential impact on other segments. In many cases, parallels can be drawn to the air conditioning application. In others, manufacturers are moving to non-fluorocarbon refrigerants. These are addressed next.

3.4.1 Other Commercial Air Conditioning and Refrigeration

Most refrigeration applications share some similarities with the residential and commercial air conditioning segments. Efficiency targets and refrigerant transitions present similar challenges, although the technology solutions may differ.

Manufacturers of large commercial chillers[20] have already commercialized equipment using next generation refrigerants. In fact, some large capacity chillers that use low-pressure, low-GWP refrigerants have increased efficiency over the HCFC and HFC refrigerants they replace. Some customers are purchasing this equipment purely for the decreased energy costs over its life cycle. With certainty as to the regulatory future, other consumers will choose to convert existing equipment if that investment will pay back in future energy savings. The primary impact of Kigali ratification for this industry will be certainty, enabling them to focus their product lines on the new refrigerants. Energy cost savings can offer a very large incentive to invest in new technology in this segment because of its dominant contribution to total costs of ownership.

3.4.2 Automotive Air Conditioning

Like the stationary air conditioning systems discussed in detail above, the automotive air conditioning industry continues to drive for lower refrigerant charges, greater efficiency, and reduced average leak rates. Approximately 60% of the industry has already

[20] GIZ (2015).

transitioned to low-GWP HFO refrigerants.[21] Because these are small systems, the added cost for a manufacturer to convert to a new refrigerant, including both refrigerant costs and equipment differences is estimated by industry experts to be less than 0.1% of the vehicle price.

In terms of lifetime costs, servicing of automotive systems must be considered. Again, over the long term, refrigerant costs are expected to be similar, with or without Kigali, and are mitigated in any case by the reduced charge. Historically, the transition to R134a was predicted in 1994 to lead to recharging costs in 1996 and beyond of as much as $200 ($318 in current dollars).[22] Yet recent quoted repair shop charges range between $123 and $156[23], less than half the predictions. There is little reason to expect the current transition to be different as new refrigerants gain economies of scale and increased competition.

3.4.3 Home Refrigerators

In 2016, the Association of Home Appliance Manufacturers (AHAM) announced that members will voluntarily transition to new generation refrigerants by 2024[24]. The transition is underway. Prior to the change, the R134a refrigerant in a single refrigerator would cost $1.00 to $1.50.[25] Most units are moving to isobutane, at a cost of $0.05 per refrigerator.[26] The reduced cost helps offset the capital required to retool for the new flammable or mildly flammable refrigerant, including fireproofing manufacturing facilities and making a system with extremely low leak rates even tighter.

The same replacement process is also underway for the insulating foams in the walls of refrigerators. A number of alternative blowing agents are already available with manufacturers making different choices based on their design needs.

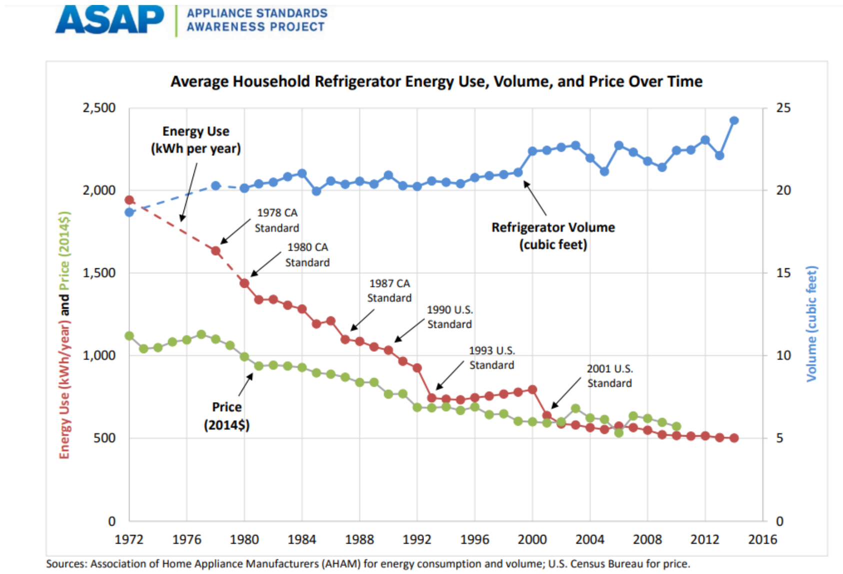
Underlying these changes is the long-term pricing trend. Figure 3.11, from the Appliance Standard Awareness Project, shows the long-term trends in price, energy consumption and effective volume for refrigerators in the U.S. market. Since the early 1970s, even as they have gotten larger, these appliances have dramatically cut their energy consumption and their prices have declined by half. And in an earlier report they note,[27] "Between 1987 and 2010, real prices [of refrigerators] decreased by about 35% while average energy use decreased by more than 50%." The time period begins before the Montreal Protocol went into effect and includes the Protocol's previous transitions. Consumers have seen not more cost but rather benefits. With the industry's aggressive movement to next generation refrigerants, that trend should continue.

The primary importance of U.S. Kigali compliance in the home refrigerator sector is the clarity it provides on timing, allowing a coordinated design cycle, including refrigerant changes and new foams along with energy efficiency requirements. AHAM has estimated that inability to coordinate design cycle requirements could lead to tens of

[21] Chemours (2018).
[22] Lieberman (1994).
[23] Johnson (2017).
[24] Association of Home Appliance Manufacturers (AHAM) (2016).
[25] Assumes 0.3 lb. of refrigerant (ICF International Report on the Assessment of Refrigerator/Freezer Foam End-of-Life Management Options) and bulk pricing of HFC 134a.
[26] Assumes cost of isobutane is $0.29 per pound and reduced charge size (communications with manufacturers).
[27] Appliance Standards Awareness Project (n.d.).

million dollars of added design costs for the industry and additional consumer expense, as would a patchwork of regulations at the state level.

Figure 3.11: Refrigerator Energy Use, Volume, and Price History[28]



3.4.4 Window Air Conditioning Units

Like refrigerators and other household appliances, the cost of a window air conditioner has continually declined over time in real dollars. According to Mark Perry[29], the price of an 8000 BTU room air conditioner in 1973 was $216.75. In 2015, Kenmore's 8000 BTU unit was priced at $219.99. This is essentially flat in current dollars, but at average U.S. wages in 1973, it took over 50 hours of work to purchase a unit. In 2015, it took only 10.4 hours of average wages for the same purpose, and the unit consumed significantly less energy. This continuing trend includes all previous refrigerant transitions. The quantity of refrigerant in these units is small and it is rarely replaced, so the service contribution is minimal.

3.4.5 Foam Insulation

The experience with prior transitions away from CFCs and HCFCs led producers in several foam applications to explore the use of alternative blowing agents in addition to using HFCs. Today, for many foam types, OEMs and consumers can choose from several solutions that are commercialized in the U.S. and globally.

In general, foam insulation provides savings to consumers that far outweigh the cost of the materials. Prices vary among the different foam choices, but the total cost of the foam remains a very small fraction of cost of buildings, refrigerators, or most of foam's other applications. On a lifetime cost basis, considering energy savings, even the more expensive options can deliver savings supporting additional initial investment, although competition can drive builders to less efficient solutions. The consumer can benefit from lower initial cost or benefit even more from higher energy efficiency.

[28] Appliance Standards Awareness Project (2016).
[29] Perry (2018).

3.4.6 Refrigeration and Air Conditioning Equipment Service

Equipment service was considered in the life cycle cost calculations for residential and commercial air conditioning. Predicted high costs for auto air conditioning service, as discussed above, never materialized. Similarly, service costs have remained and are predicted to remain reasonably stable in other sectors as well.[30] Reduced leak rate and charge size have contributed.[31] With Kigali, additional leak reduction and smaller charge sized using next generation refrigerants lowers the frequency of refrigerant replacement, reducing both the cost of refrigerant needed and the number of service calls required.

3.5 Conclusions

With timely U.S. ratification of Kigali, residential air conditioning consumers in 2029 are expected to see little to no change in the lifetime costs of purchasing and operating their units. At expected refrigerant prices, they will see a small net savings. At five times that refrigerant price they would see an equally small net cost. On a discounted basis, they would see a cost of less than 1%. These results also assume conservatively that new equipment price is increased by 10% for compliance with Kigali, although such an increase is not justified by historical equipment pricing trends.

Commercial air conditioning consumers in 2029 can expect a similar cost outlook with Kigali ratification. At expected refrigerant prices, lifetime costs, discounted or undiscounted are expected to be reduced by less than one percent. Even with a refrigerant price five times higher than expected, undiscounted total life cycle costs would retain a small net benefit. On a discounted basis, the five times higher refrigerant price would slightly increase costs.

In all of the smaller applications assessed, the cost impact of Kigali ratification on consumers is minimal, and in many cases, consumers will see a net benefit, either from a transition to a less costly material such as a hydrocarbon or from improved energy efficiency, reduced charge size, and reduced leak rates. Consumers in some segments also benefit from the increased competition where manufacturers have already begun to convert some of their products.

[30] See Navigant (2018)
[31] OEM discussions.

4 Summary

The Kigali Amendment to the Montreal Protocol would reduce global use of HFCs by 85% by 2047, replacing them with next-generation hydrofluoroolefins and other products. This Amendment is subject to Senate ratification in the U.S. but will formally take effect globally on January 1, 2019 whether or not the U.S. ratifies. An important consideration in the ratification decision is the impact of the Amendment's requirements on the U.S. economy, both the health of the industries employing HFCs in their current products and the costs or benefits to U.S. consumers.

U.S. industry expects to be more competitive in global markets with Kigali implementation in the U.S. There is strong support for Kigali among the businesses in this industry. A prior study showed that, for the largest sector, HVACR, adoption of the Kigali requirements would increase domestic suppliers' share of the U.S. market over time compared to a future without Kigali. It also showed a pattern of increases in exports over time. Together, these two sources of additional demand supported increased domestic production, jobs, and wages. These jobs and other benefits derived from increased production, not increased prices for products and services in the U.S.

To better understand the effects on consumers, we have analyzed first the considerations faced by manufacturers, either to comply with Kigali's requirements or to operate in a situation where Kigali is implemented elsewhere but not in the U.S. Those decisions will define the market for U.S. consumers. To examine consumer impacts, we then considered the purchasing options for consumers in the two scenarios.

For a detailed study of two of the largest markets, residential and commercial air conditioning, we examined purchases, in 2029, of nominal 2.5-ton and 15-ton air conditioners, using average market cost parameters for each scenario, with and without Kigali ratification. We also examined the characteristics of other market segments to estimate qualitatively the impacts on consumer costs.

Ratification and implementation of the Kigali Amendment in the U.S. allows U.S. industries to address the domestic market in concert with the rest of the world, leading with domestic production rather than focusing their efforts on international investments. This can be accomplished without an increase in costs to the U.S. consumer, and in some cases can generate savings. Although there is no reason to expect that refrigerant prices will behave differently during the Kigali transition than during the two previous transitions away from ozone-depleting substances, even a price higher by a factor of five would not significantly change these conclusions.

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Appendix

A.1 Kigali Amendment Ratifying Countries

Table A.1 provides a list of the countries that have ratified (or otherwise approved) the Kigali Amendment, along with their dates of ratification

Table A.1 List of Kigali Amendment Ratifying Countries

Country	Date	Country	Date
Austria	9/27/18	Lao People's Democratic Republic	11/16/17
Australia	10/27/17	Luxembourg	11/16/17
Barbados	4/19/18	Malawi	11/21/17
Belgium	6/4/18	Maldives	11/13/17
Benin	3/19/18	Mali	3/31/17
Bulgaria	5/1/18	Marshall Isalnds	3/31/17
Burkina Faso	5/1/18	Mexico	9/25/18
Canada	11/3/17	Micronesia (Federated States of)	5/12/17
Chile	9/19/17	Netherlands	2/8/18
Comoros	11/16/17	Niger	8/29/18
Costa Rica	5/23/18	Niue	4/24/18
Ca te d'Ivoire	11/29/17	Norway	9/6/17
Czech Republic	9/27/18	Palau	8/29/17
Democratic People's of Korea	9/21/17	Panama	9/28/18
Ecuador	1/22/18	Portugal	7/17/18
Estonia	9/27/18	Rwanda	5/25/17
European Union	9/26/18	Samoa	3/23/18
Finland	11/14/17	Senegal	8/31/18
France	3/29/18	Slovakia	11/16/17
Gabon	2/28/18	Sri Lanka	9/28/18
Germany	11/16/17	Sweden	11/17/17
Greece	10/5/18	Togo	3/8/18
Grenada	5/29/18	Tonga	9/17/18
Guinea-Bissau	10/22/18	Trinidad and Tabago	11/17/17
Hungary	9/14/18	Tuvalu	9/21/17
Ireland	3/12/18	United Kingdom of Great Britian	11/14/17
Kiribati	10/26/18	Uganda	6/21/18
Latvia	8/17/18	Uruguay	9/12/18
Lithuania	7/24/18	Vanatu	4/20/18

A.2 Kigali Specified Controlled Substances

Table A.2 provides a list of the substances specifically mentioned in the Annex to the Montreal Protocol in relation to the Kigali amendment. The table provides the common substance name and the 100-year global warming potential (GWP).[32]

Table A.2 Annex F to the Montreal Protocol

HFCs (Group I)		HCFCs	
Substance	**GWP value (100 year)**	**Substance**	**GWP value (100 year)**
HFC-134	1100	HCFC-21	151
HFC-134a	1430	HCFC-22	1810
HFC-143	353	HCFC-123	77
HFC-245fa	1030	HCFC-124	609
HFC-365mfc	794	HCFC-141b	725
HFC-227ea	3220	HCFC-142b	2310
HFC-236cb	1340	HCFC-225ca	122
HFC-236ea	1370	HCFC-225cb	595
HFC-236fa	9810		
HFC-245ca	693	**CFCs**	
HFC-43-10mee	1640	**Substance**	**GWP value**
HFC-32	675	CFC-11	4750
HFC-125	3500	CFC-12	10 900
HFC-143a	4470	CFC-113	6130
HFC-41	92	CFC-114	10 000
HFC-152	53	CFC-115	7370
HFC-152a	124		
HFCs (Group II)			
HFC-23	14 800		

[32] Source: Polonara et al. (2017).

A.3 Principal Investigators

Joseph M. Steed was architect and lead implementer of DuPont's corporate response to stratospheric ozone depletion concerns during the 1980s, including the ultimate science-based decision to lead the global industry in committing to complete phase-out of CFC production in advance of regulatory requirements. He is an expert in developing broad industry and government support for economically driven international and domestic regulations that achieve a smooth transition for customers.

He has over 20 years of experience as a leader of strategic change in diverse industries and organizations. As CEO of startup International Titanium Powder, LLC, Dr. Steed built on both technical and business background to develop business and financial plans and successfully initiate the transition from development toward commercial operation. As Manager of e-Ventures at DuPont, Dr. Steed served as a catalyst to drive profitable adoption by business leaders of internet transaction tools.

Lent by DuPont to the chemical industry-financed marketplace startup Elemica, Inc., Dr. Steed led marketing strategy, segmentation, customer relationship management (CRM) strategy, and branding for a successful startup that has now outlasted the majority of its imitators. Dr. Steed led Global Strategic Planning for a $2 billion DuPont business, implementing a strategic redirection toward higher value offerings, with a modern ERP infrastructure to drive cost efficiency and customer service. In technology, Dr. Steed led process R&D for a major business resulting in implementation of proprietary and highly profitable cost reductions, waste reduction programs, and novel feedstocks. As Corporate R&D Planning Manager, Dr. Steed drove corporate growth through a funding mechanism for entrepreneurial developments and effective networking of new business development leaders across the corporation.

He also served as a general manager at the technology development company EarthShell Corporation. His recent consulting includes work with the private equity firm Texas Pacific Group, providing chemical industry expertise to assist in their evaluation of a $1B+ buyout. He also served as a principal in a project for AHRI to design a mechanism for stimulating the rate of recycle of HFCs and HCFCs in the United States. Dr. Steed has a Ph.D. in Chemical Physics from Harvard and Sc.B. and Sc.M. degrees from Brown, along with executive training from Columbia's Graduate School of Business. He has published numerous peer-reviewed technical articles and book chapters, including both atmospheric modeling and estimates of global CFC emissions.

Douglas S. Meade is the executive director of Inforum (**In**terindustry **For**ecasting at the **U**niversity of **M**aryland). Dr. Meade has over 30 years of experience in private sector and government in the areas of econometric modeling, economic analysis, and the development of economic data. He was the principal investigator for a previous study done for AHRI, analyzing the national and state level contribution of the HVAC industries within the U.S. economy. Dr. Meade also has extensive experience in international modeling, having helped develop the Inforum bilateral trade model, as well as developing and performing studies with models of Japan, Vietnam, Ukraine, Tanzania, North Korea, and Myanmar.

Prior to his current period at Inforum, he was Deputy Directory of the Industry Division at the Bureau of Economic Analysis, where he was responsible for the development of the 2002 benchmark input-output table. Other previous experience includes work with Data Resources, Inc., an econometric consulting firm which is now part of IHS Global, and with the Census Bureau, serving a research function in the development of manufacturing statistics. He received his B.S. in Economics from George Mason University in 1980, and his Ph.D. in Economics from the University of Maryland in 1990.

Troy A. Wittek graduated with a Criminal Justice degree from the University of Maryland in 2007. He completed a master's degree in Applied Information Technology from Towson University in 2012. He joined Inforum in 2006 and became a full-time Research Assistant in 2009. Troy's responsibilities include collecting and analyzing statistical data for use in policy analysis, business planning, and academic research. He has helped to write and edit reports for a variety of audiences in the academic, government, and private sectors. Troy is one of the main researchers responsible for maintaining the Inforum *Lift* and *Iliad* models of the U.S. economy. He works with the Department of Defense to project defense purchases and skilled labor requirements by industry and by region using Inforum economic models. Other projects include providing forecasts for domestic industries and analyzing the impact of major soft drink bottler operations in Asia. Additional responsibilities include literature review, software testing, and website development.

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Economic & Consumer Impacts of HFC Phasedown

December 12, 2019

HFC Phasedown Background

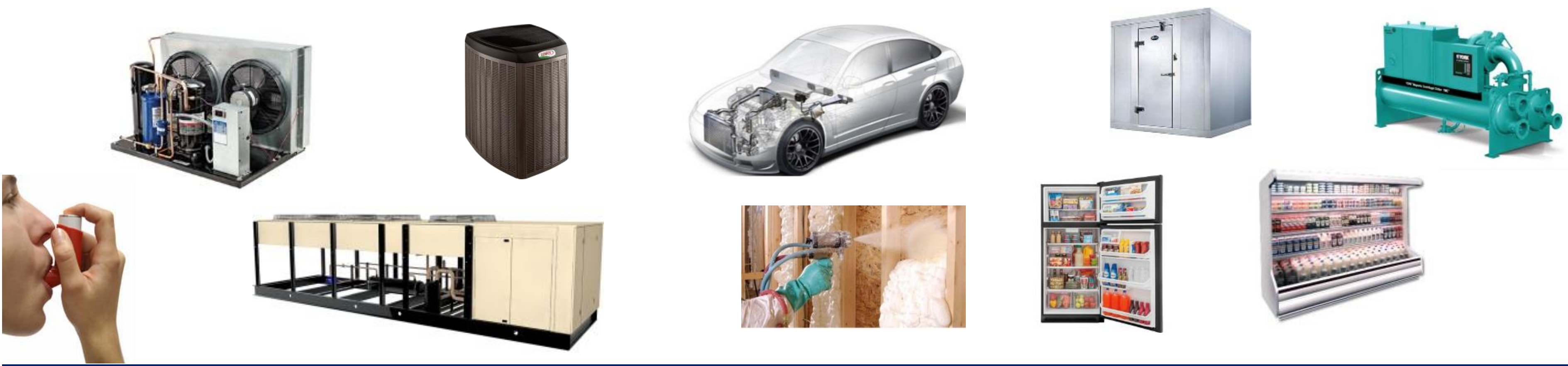
- With regulatory certainty, the technology transition to low-GWP next-generation technology is underway in all major developed countries and is gathering momentum in most major developing countries including India, China, Korea, and Indonesia.
- The transition path in the U.S. is uncertain with no federal action to date However, a dozen states have started a patchwork of legislation or regulation creating an unpredictable state-based HFC phasedown.
- Investment decisions are being made now on implementation of these next-generation technologies, but under the current circumstances the U.S. market will be fractured and less efficiently served, increasing consumer costs and diminishing U.S. global technology leadership.
- A predictable federal U.S. HFC phasedown positions industry to maintain global technology leadership, create additional manufacturing jobs, and cost-effectively produce these new technologies that benefit consumers.
- The Kigali Amendment to the Montreal Protocol has been ratified by 91 countries and went into effect on Jan 19. 2019, initiating a broad-based orderly phasedown of HFCs.

Economic Analysis

- Inforum and JMS Consulting previously:
  - Assessed fluorocarbon industry size
  - Conducted scenario analysis, focusing on HVACR, the largest segment
  - Examined consumer costs in residential/commercial air conditioning, the largest uses
- Scenarios compared ratification and implementation of global HFC phasedown requirements in the U.S. versus a “business as usual” case with no mandated U.S. phasedown. The “consistent with global HFC phasedown” case assumes U.S. action, with or without formal ratification by the Senate.
- Analysis incorporated public data, estimates from Inforum models, and industry interviews, using conservative assumptions.
- U.S. HFC phasedown implementation adds American jobs, increases exports, decreases imports, and supports American technology leadership.
- Delays in implementation or ongoing uncertainty due to state actions will inhibit or eliminate the opportunity to achieve the forecast gains
- Life-cycle cost analysis of air conditioning applications shows the transition during HFC phasedown is expected to further reduce consumer costs.

U.S. Industry Segments (Fluorocarbons)

- Fluorocarbon-using products impact how we live on a daily basis.
- Fluorocarbons are used in commercial HVAC, residential HVAC, commercial refrigeration, household appliances, and motor vehicle air conditioning
- Insulating foams, medical metered-dose inhalers, aerosols, and several other applications make up the remainder of the manufacturing sector



American-made products that preserve the health, safety and comfort of our daily lives

U.S. Industry Objective

- U.S. industry strongly supports domestic phasedown of HFCs consistent with the Montreal Protocol.
- Heating Ventilation Air Conditioning and Refrigeration (HVACR) and Fluorocarbon technologies are signature American technologies.
- The phasedown being implemented globally under the Montreal Protocol provides a platform for gradual introduction and commercialization of next generation technologies.
- An HFC phasedown in the U.S. opens the door for domestic production to serve the rapidly expanding global market without harming U.S. consumers.
- Implementation of the HFC phasedown is good for American jobs, the balance of trade, and continued American technology leadership.
- The transition during HFC phasedown is expected to reduce consumer costs in the air conditioning industry.

We urge Congress to implement a U.S. HFC phasedown.

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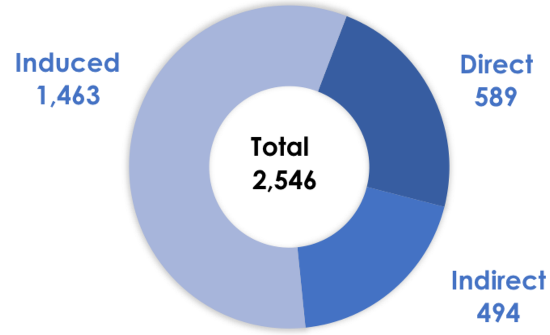
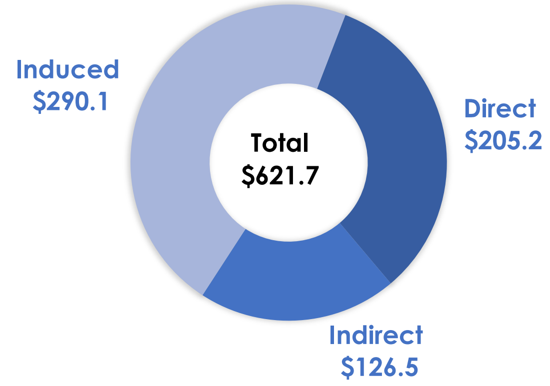
U.S. Manufacturing Impact
Fluorocarbons in the American Economy

- **Jobs**
  - **589K** direct employment
  - **$39B** in payroll
  - **$205B** in sales
  - **2.5M** total employment impact
- **Output**
  - **$621B** in economic output, including manufacturing, distribution, service & installation (includes supply chain and induced demand)
- **Manufacturing**
  - **$178B** contribution
  - **671K** jobs, dominated by HVACR equipment
  - Downstream contracting, wholesale, and service make up the rest

TOTAL EMPLOYMENT, 2016
(THOUSAND PERSONS)



TOTAL OUTPUT, 2016
(BILLION $)

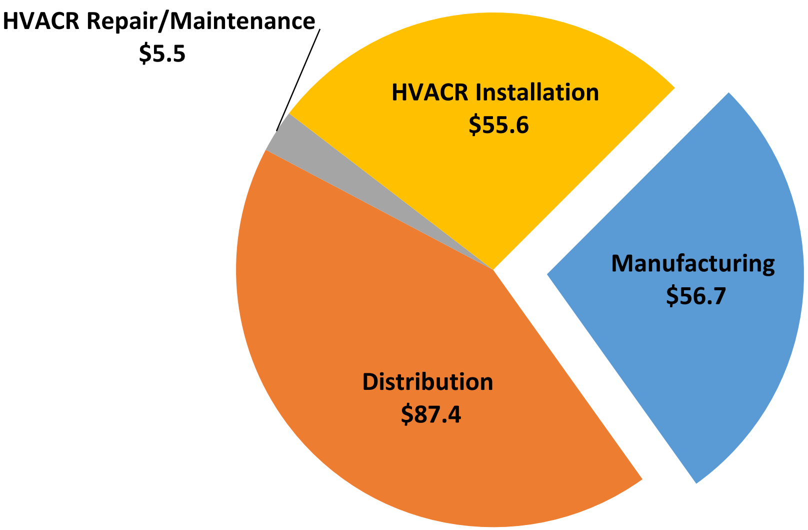


This industry is a significant contributor to American jobs, trade & economic output

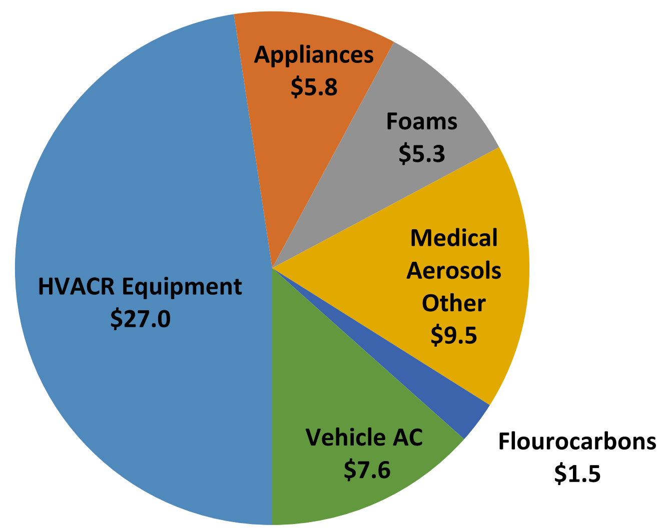
U.S. Industry Segments
Manufacturing and Downstream Output

- Current manufacturing output is $56.7B
- Downstream output in the wholesale, contracting, and repair and maintenance sectors is almost 3X that of manufacturing

Manufacturing + Downstream (Billions $)



Manufacturing Shipments (Billions $)



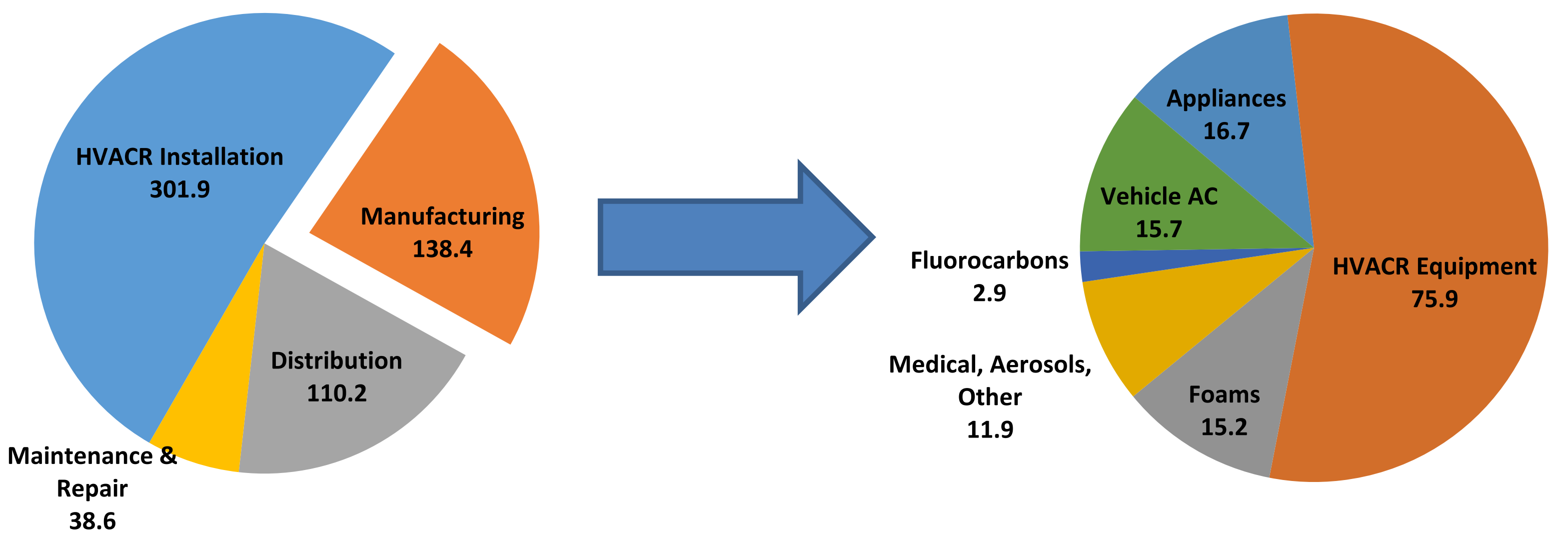
Downstream output is almost 3X the size of the manufacturing output

U.S. Industry Segments Employment

- Current manufacturing impact is 138.4K jobs

Direct Industry Employment - 2016 (Thousands)

Manufacturing Employment 2016 (Thousands)



Downstream employment is over 3X the size of the manufacturing employment

U.S. Industry Growth Prospects

- Over the next 10 years…
  - International HVACR market expected to more than double
  - The cumulative global market will be over $1 trillion
  - Developed countries are already transitioning to new technologies
  - Developing countries will transition away from ozone-depleting substances and this transition is at its apex between now and 2047
  - Foams, medical applications and aerosols also have large global growth opportunities
- American Innovation
  - Commercialization of next generation technology is essential at this point in the Montreal Protocol transition
  - The U.S. HVACR industry has traditionally led these transitions and it is vital they lead this transition
  - Typical design cycle for the industry is 5-10 years, decisions being made now

American industry <u>must</u> lead the transition to new technologies to be competitive

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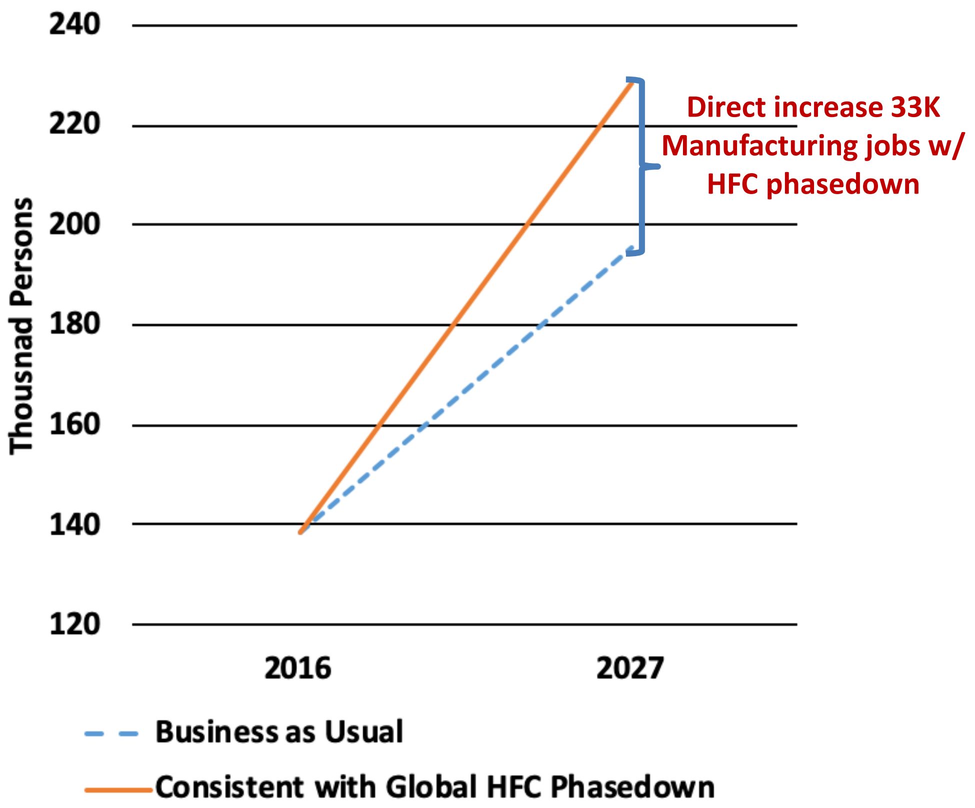
HFC Phasedown Impact 2027

Scenarios Compared:

"Consistent with Global HFC Phasedown" – U.S. implements HFC phasedown on Montreal Protocol schedule

"Business as Usual" – No U.S. phasedown

- **Manufacturing Jobs**
  - Current manufacturing impact is **138.4K** jobs
  - HFC phasedown increases direct manufacturing jobs by **33K**
  - Manufacturing growth translates into an incremental **150K** jobs economy-wide
- **Direct Economic Output**
  - HFC phasedown improves direct manufacturing output by **$12.5B**
  - Total increased output of **$38.8B** versus no-phasedown scenario
- **Trade Balance**
  - Positive impact on balance of trade
  - Manufacturing impacted directly



U.S. HFC phasedown essential to jobs growth, industry growth, trade balance

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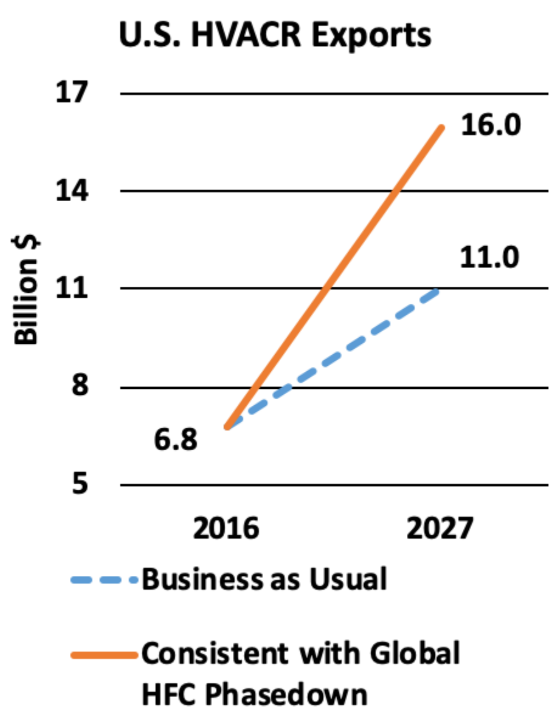
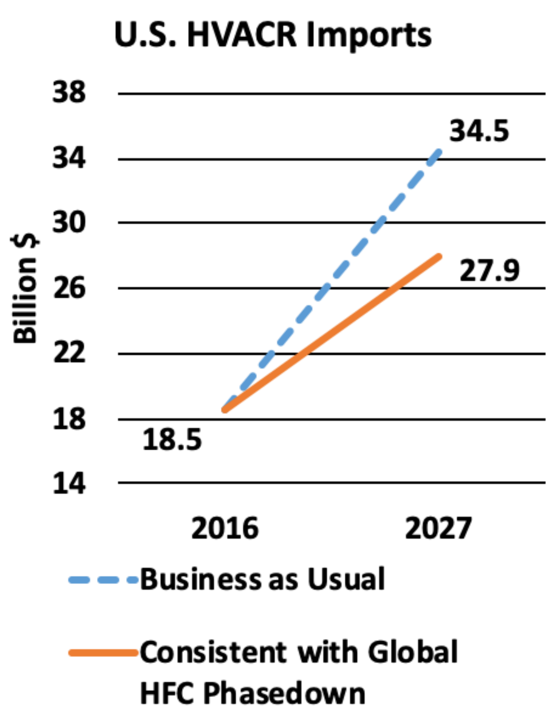
HFC Phasedown Impact
Global Trade

- **Global Trade Impacts**
  - U.S. HFC phasedown will increase U.S. supply to global HVACR markets by $5.0B
  - Phasedown will inhibit growth of old technology HVACR imports by $6.5B
  - Fluorocarbon manufacture adds $1 billion in net trade benefit

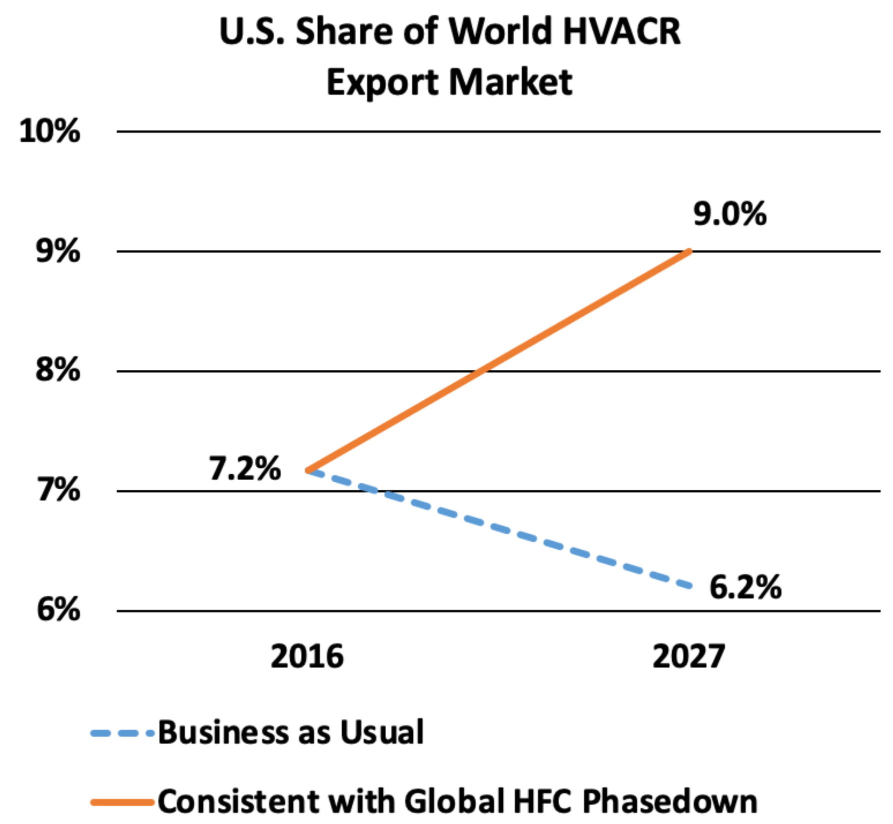




U.S. HFC Phasedown will grow U.S. exports and improve balance of trade

HFC Phasedown Impact
HVACR Global Export Market

- The HVACR global export market will grow by 6% per year to meet needs of China, India, Latin America, and Africa
- With HFC phasedown, U.S. exports will outperform, increasing U.S. share of global market from 7.2% to 9.0%
- Without HFC phasedown, exports will underperform



U.S. is a net importer, but gains share of global market with a U.S. HFC phasedown

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HFC Phasedown Impact
Refrigerant Production & Reclaim

- Fluorocarbon manufacturing would benefit from increased exports if HFC phasedown is enacted and suffer from imports of older refrigerants if not
- $1B net benefit included in analysis
- Reclaimed HFCs with a U.S. HFC phasedown are estimated to increase reclaim sales by $0.8 billion and add almost 4,000 jobs. (not included in totals)

HVACR Technology & Investment

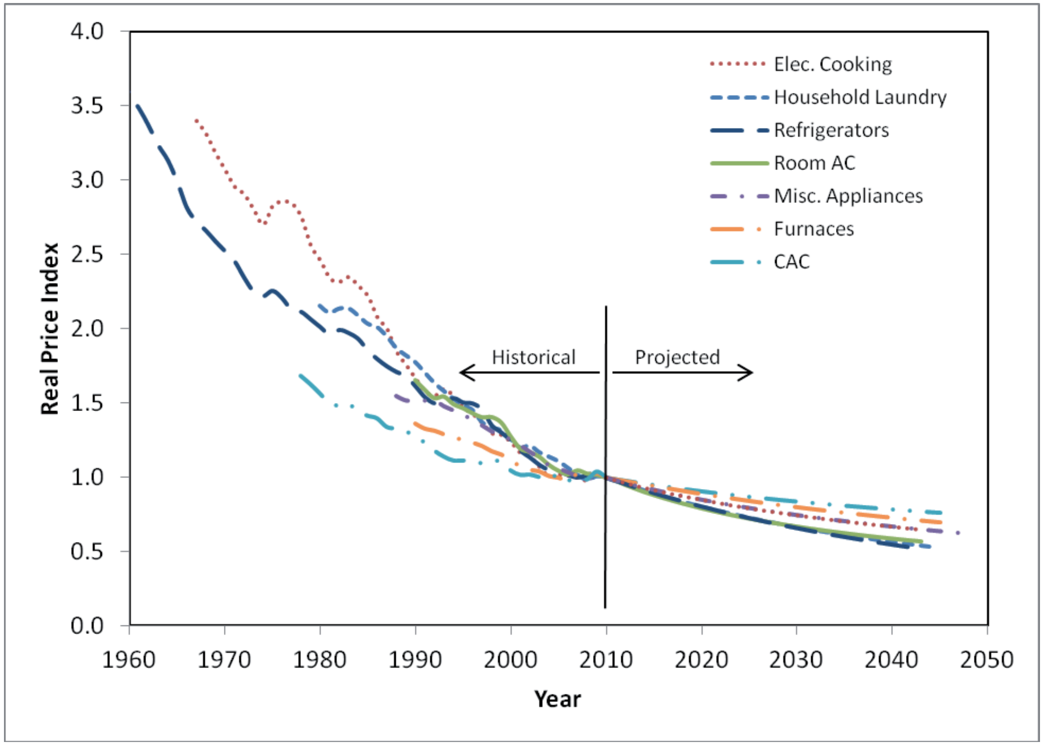
- The American HVACR industry led global innovation, which is driven by domestic demand
- Investments in next generation refrigerants and equipment technologies are already underway
  - In 2015, AHRI members representing 90% of U.S. HVACR manufacturing committed $5B through 2025 in R&D and capital investment to commercialize high efficiency equipment using next generation refrigerants
  - American investments in R&D and capacity for HFC phasedown-related growth will generate 1,400 additional jobs and $1B in capital investment if a U.S. HFC phasedown is implemented
  - Without U.S. HFC phasedown, manufacturing and R&D for new technologies will move to international markets to meet local demand for new technologies

U.S. HFC phasedown essential to maintain and expand American leadership

Key Consumer Costs Continue to Decline

- The 30-year history of the Montreal Protocol shows the industry has used innovations, new technologies, and more sustainable compounds to drive continued reduction of consumer costs.
- Industry innovation, gradual transition schedules, and avoiding impacts on existing equipment owners allowed the industry to accommodate major transition costs over time, minimizing impact on consumer prices.
- U.S. appliance prices have declined over time and are expected to continue to do so.
- Room air conditioners, refrigerators, and central air conditioners have all seen real price declines through two technology transitions under the Montreal Protocol.

Historical & Projected Real Price Indices for U.S. Major Appliance Categories



See Desroches, et al. (2018). Historical trends based on the PPI published by the U.S. Bureau of Labor Statistics. Projected trends are experience curve fits to the historical data.

Innovation and planning minimized costs of conversion under the Montreal Protocol.

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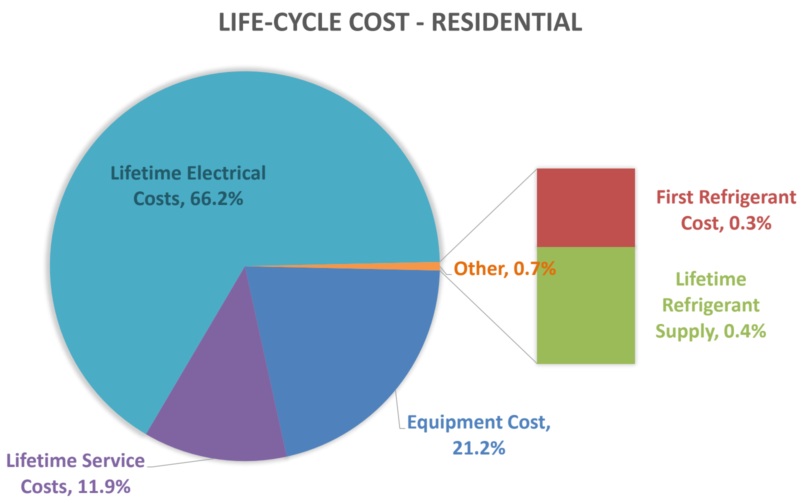
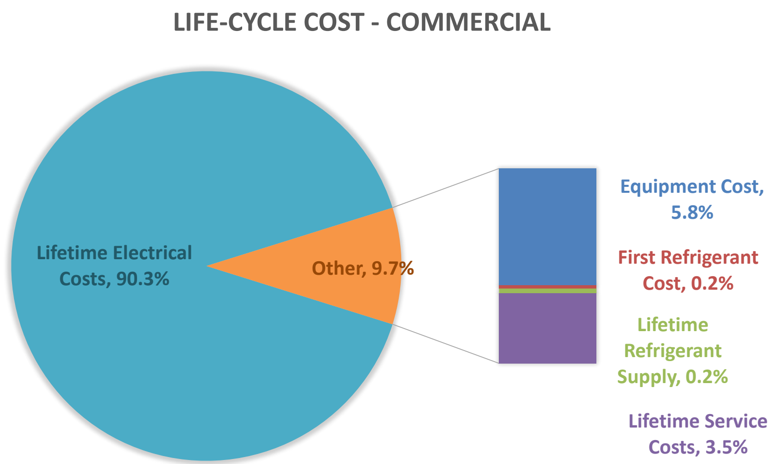
Life-Cycle Costs of Air Conditioning





- Electricity dominates lifetime costs for both residential and commercial air conditioning.
- Refrigerant Supply is less than 1% of lifetime costs.
- Cost projections of each element were made for a new equipment purchase in 2029, with and without U.S. HFC phasedown.

Energy cost dominates even equipment cost, and refrigerant is a minor contributor.

U.S. Consumers Benefit from HFC Phasedown

- Total costs were estimated over 15-year lifetime for average 2.5 ton residential and 15 ton commercial U.S. air conditioning units.
- Equipment with HFC phasedown ("Consistent with HFC Global Phasedown") is conservatively assumed to be 10% more costly, but on average slightly more efficient, with lower leak rates and smaller charge sizes.
- The average price among all refrigerants is expected to equilibrate and continue to average ~$7/lb.
- Driven by energy, total costs decline slightly with HFC phasedown. There are no significant consumer cost impacts even if refrigerant prices were 5x higher.

Total Cost of Ownership for 2029 Purchase

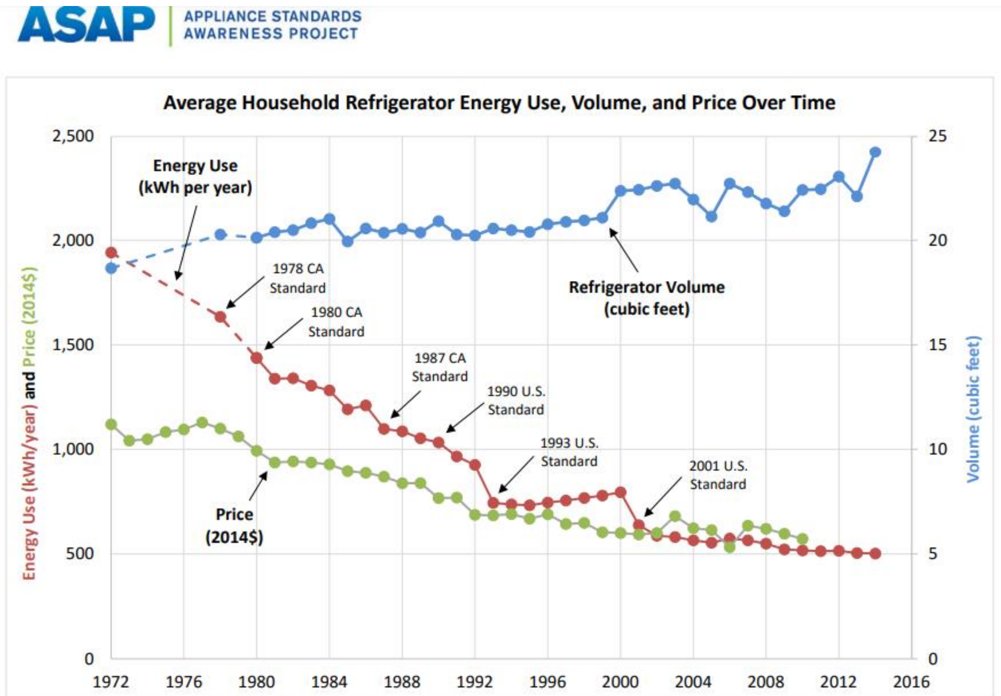
RESIDENTIAL AIR CONDITIONING	Business as Usual	Consistent with Global HFC Phasedown
Equipment Cost	$4,000	$4,400
First Refrigerant Cost	$53	$49
Lifetime Refrigerant Supply	$79	$37
Lifetime Service Costs	$2,250	$1,950
Lifetime Electrical Costs	$11,585	$11,434
TOTAL OWNERSHIP COSTS	$17,966	$17,869
ANNUAL AVERAGE COSTS	$1,197.74	$1,191.29

COMMERCIAL AIR CONDITIONING	Business as Usual	Consistent with Global HFC Phasedown
Equipment Cost	$25,000	$27,500
First Refrigerant Cost	$700	$653
Lifetime Refrigerant Supply	$1,050	$490
Lifetime Service Costs	$15,000	$13,000
Lifetime Electrical Costs	$351,285	$346,697
TOTAL OWNERSHIP COSTS	$393,035	$388,340
ANNUAL AVERAGE COSTS	$26,202.34	$25,889.34

HFC phasedown will not increase consumers' cost of air conditioning.

Refrigerators Add Value at Lower Cost

- Refrigerators today are larger, lower-priced, and more energy-efficient than ever.
- The trend has been persistent despite 30 years of transitions under the Montreal Protocol.
- Similarly, other applications have already begun to transition to new compounds and can benefit further from the clarity of the HFC phasedown schedule.



Sources: Association of Home Appliance Manufacturers (AHAM) for energy consumption and volume; U.S. Census Bureau for price.

No reason to expect consumer impacts of HFC phasedown to differ from earlier transitions.

Summary of HFC Phasedown Impacts

- U.S. Industry needs certainty about transition timing to win globally
  - The global HVACR market will double in ten years
  - U.S. industry must be cost competitive to expand global market share
  - Phasedown timing certainty reduces transition costs
- U.S. Economic Benefits
  - Increase American manufacturing jobs
  - Grow U.S. share of the global market
  - Improve the U.S. balance of trade
  - Phasedown timing certainty delivers economic benefits
- American Consumer Impact
  - AC continues to be more efficient
  - AC continues to be more affordable for American consumers
  - Phasedown timing certainty reduces the cost to consumers

U.S. HFC phasedown benefits industry, the economy, and consumers

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Statement of Cindy Newberg

Director of the Stratospheric Protection Division

U.S. Environmental Protection Agency

Legislative Hearing on

The American Innovation and Manufacturing Leadership Act of 2020

Subcommittee on Environment and Climate Change

House Energy and Commerce Committee

January 14, 2020

Good Morning Chairman Tonko, Ranking Member Shimkus, and members of the subcommittee. My name is Cindy Newberg, and I am the Director of the Stratospheric Protection Division in the Office of Atmospheric Programs in the Office of Air and Radiation at the U.S. Environmental Protection Agency (EPA). The Stratospheric Protection Division oversees implementation of the *Montreal Protocol on Substances that Deplete the Ozone Layer* and Title VI of the Clean Air Act, which have the shared goal of restoring the ozone layer.

I appreciate the opportunity to testify today regarding the Committee's American Innovation and Manufacturing Leadership Act of 2020. Although the Agency does not have a formal position on the bill, my testimony today will focus on how the EPA implements current stratospheric protection programs, as well as the technical aspects of the Committee's bill to address hydrofluorocarbons (HFCs), which are substitutes for certain ozone-depleting substances.

To provide a brief background, I have been with EPA for more than 27 years and served on delegations for the Montreal Protocol representing the United States and EPA's interests under the last three administrations. The Montreal Protocol is a global agreement to protect the Earth's ozone layer by phasing out production and consumption of the chemicals that deplete it. The Protocol was signed by the United States in 1987 and ratified by the United States Senate in 1988. Today, all countries that are members of the United Nations are parties to the Protocol. By restoring the ozone layer, we reduce risks of skin cancer and cataracts. For Americans, full implementation of the Montreal Protocol is expected to result in the avoidance of more than 280 million cases of skin cancer, approximately 1.6 million skin cancer deaths, and more than 45 million cases of cataracts in the United States alone.

Ozone depleting substances have been used in many household, industrial, and military applications. The phaseout of the U.S. production and consumption of ozone-depleting substances is managed by issuing tradeable allowances through rulemaking. In addition, Title VI of the Clean Air Act includes complementary measures to smooth transition to alternatives for ozone-depleting substances including provisions to support the recovery and reuse of existing chemicals and identification of alternatives for all relevant applications. To facilitate smooth transition to a range of alternatives, EPA has implemented domestic regulations and partnership programs that have enabled the United States to not only meet but to exceed the commitments outlined in the Montreal Protocol. And at the same time, U.S. companies have shown great leadership with the development and deployment of a range of alternatives. Many of these programs have served as models for other countries, who regularly consult with EPA for our technical expertise.

In wake of the Montreal Protocol and Title VI of the Clean Air Act, the U.S. has been substituting ozone depleting substances with alternatives, including to a large extent with HFCs. Meanwhile, as global demand for refrigeration and air conditioning increases, more HFCs are being used as substitutes, particularly in cooling applications. While HFCs do not deplete the ozone layer, most HFCs are potent greenhouse gases.

The AIM Act, as drafted, would establish new domestic authority to phase down the production and consumption of HFCs. If signed into law, the AIM Act would require the EPA to do many of the same types of activities for HFCs that we have done and continue to do for the ozone-depleting substances.

The bill would require EPA to publish a list of HFCs and their exchange values, which are defined in the bill. It would subsequently require affected entities to periodically report to the EPA the amount of regulated substances produced, imported, exported, reclaimed, destroyed, used and consumed in the manufacture of other chemicals, or used as process agents. It would establish a baseline which would then be used to help create an allowance and trading program to phase down production and consumption of HFCs. The EPA Administrator would then bear responsibility for allocating allowances on either an annual basis or for multiple years based upon a schedule for the phase down of production and consumption of HFCs. Transfer of allowances between companies would be allowed. The Administrator may be petitioned to increase the speed of the scheduled phase down.

The Administrator also would be required to promulgate regulations to establish standards for the management of HFCs to control, as appropriate, practices, processes or activities for servicing, repairing, disposing, or installing equipment involving regulated substances. Furthermore, the Administrator would be authorized to facilitate transitions to next-generation technologies by establishing restrictions on specific uses of HFCs and evaluating availability of substitutes for the regulated HFCs. These are the same actions we do today for ozone-depleting substances.

Again, while the EPA does not have a position on the legislation, I am here on behalf of the Agency to discuss the technical aspects of the Committee's bill and provide a perspective on how current EPA stratospheric protection programs are being implemented.

In conclusion, the AIM Act of 2020 would directly provide EPA the authority and direction to phase down production and consumption of HFCs in the United States, as well as authority to establish complementary programs to address HFC management and use. Thank you again for the opportunity to testify. I look forward to answering your questions regarding details of the bill.

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Overview of CFC and HCFC Phaseout

The United States completed the phase out of chlorofluorocarbons (CFCs) in 1996, and the hydrochlorofluorocarbons (HCFC) phaseout is underway. The United States has used a suite of statutory provisions that implement stepwise reduction schedules and additional complementary measures. The mechanisms used for the CFC phaseout were slightly different than those for the HCFC phaseout, and each are discussed.

The central component of both the CFC and HCFC phaseouts was the establishment of an allowance system for production and import that reduced the number of allowances over time. The EPA limited how much of these ozone-depleting substances (ODS) could enter the market to meet the Montreal Protocol and Clean Air Act phaseout schedules. To smooth the phaseout steps, EPA also took complementary actions to reduce the demand for ODS, allow for continued servicing of existing equipment to avoid stranding existing equipment, and encouraged transition to safer alternatives. With this comprehensive approach, the United States has phased out more than a dozen different ODS that were used in many sectors of the economy.

This paper provides information on how the United States transitioned from CFCs and HCFCs and summarizes past cost analysis.

Mechanisms

CFC Phaseout

The time between the passage of the Clean Air Act (CAA) Amendments and the total phaseout was less than six years. The complementary measures in CAA Title VI supported the United States completing the CFC phaseout with minimum disruption. EPA also worked with industry to encourage a nascent market for used refrigerants (which were recycled or reclaimed) and, where appropriate, stockpiling/managing supplies.

EPA established the ODS licensing and allowance system and took complementary measures to reduce the demand for CFCs and other ODS. CAA Section 604 establishes the phaseout schedule for CFCs and many other ODS (e.g., halons, methyl chloroform). For CFCs, the implementing regulations required CFC producers and importers to reduce production and import to zero initially by January 1, 2000 and this date was later accelerated to January 1, 1996. The licensing and allocation system tracked CFC production and import, and allowed for trades among companies. The phaseout regulations also established provisions for certain exemptions such as for CFCs used for feedstock and medical devices.

Multiple provisions of CAA Title VI included complementary measures to reduce demand for CFCs.

- Under Section 610, EPA banned certain “nonessential” products containing ODS where alternatives existed. For example, CFCs were prohibited from being used as a propellant in various aerosols and as a blowing agent in flexible foams. These restrictions were effective by the end of 1992.
- Under Section 611, manufacturers of products containing or manufactured with a CFC after 1993 were required to have a label prominently displayed informing the customer that the product they were considering purchasing contained a substance known to deplete

stratospheric ozone. Public awareness of the ozone hole led consumers to choose alternative products.
- Under Section 613, the Federal Acquisition Regulations required Federal Government agencies to purchase alternatives to CFCs.

Another crucial element of smoothing the transition was allowing for the continued use of existing equipment containing an ODS.

- Under Section 608, EPA established a refrigerant management program to reduce the use and emissions of CFCs used as a refrigerant in stationary appliances. This program also supported development of a market for used and reclaimed refrigerant to support availability of a CFC supply after the phaseout for the continued use in existing equipment. Even today some appliances continue to use reclaimed CFCs as a refrigerant.
- Section 609 established required practices and training for technicians servicing motor vehicle air conditioners to reduce refrigerant emissions.
- Section 604 contained flexibility mechanisms such as allowing for exceptions for continuing use where alternatives were not available in the short six-year timeframe. Similarly, the CAA allowed for the stockpiling of material produced or imported, which provided supplies beyond the phaseout date.

To successfully phase out a substance, Title VI established a program to identify suitable alternatives.

- The Significant New Alternatives Policy (SNAP) program under Section 612 of the CAA provides for the review and approval of safer alternatives to ODS to support a smooth transition. The listings under SNAP ensure access to information about available and potentially available alternatives, as well as alternatives determined to be unacceptable, and serve as a guide for those transitioning to alternatives.

In addition to CAA provisions, the Treasury Department implemented an import duty and floor tax on CFCs which provided a financial incentive for importers to transition from CFCs.

<u>HCFC Phaseout</u>

The main drivers of the successful phaseout of CFCs (reducing demand, allowing the continued use of equipment, and developing alternatives) also applied to the phaseout of HCFCs.

While concern for the ozone layer prompted quick action to phaseout CFCs, HCFCs were recognized as transitional substances with lower ozone-depleting potentials (ODPs) and thus were granted a longer time to transition. EPA took advantage of that additional lead-time by establishing a domestic licensing and allocation system and implemented a phaseout schedule that focused on the HCFCs with the highest ODPs first.[*] This is referred to as the ‘worst first’ approach. Many of the key features of the HCFC licensing and allocation system are similar to the CFC system. The United States established an incremental reduction of HCFC consumption and production, which will culminate in a complete HCFC

[*] The 1990 CAA Amendments directed EPA to establish an HCFC phaseout. After the Montreal Protocol was amended in 1992 to create a global phaseout of HCFCs, EPA aligned the domestic phaseout steps through regulation.

phaseout in 2030. This ordering of chemicals correlated generally with an ordering of end uses as well (e.g., solvents and foams before air-conditioning).

- In 1994, EPA banned nonessential aerosols and non-insulating foams through Section 610.
- In 2003, EPA phased out the production and import of HCFC-141b using authority under Section 605.
- Between 2004 and 2007, EPA through SNAP found HCFC-141b, -142b, and -22 unacceptable for use as foam blowing agents.
- In 2010, EPA limited the production and import of HCFC-142b and -22 only for the servicing of existing air conditioning and refrigeration equipment under Section 605.
- In 2015, Section 605 allowed newly produced or imported HCFCs only for use as a refrigerant in appliances manufactured before 2020 or as a fire suppression agent, effectively banning other uses such as foam blowing agents and solvents.
- In 2020, existing EPA regulations will phase out the production and import of all HCFCs except for the two with the lowest ODPs in accordance with the 'worst-first' approach and will further restrict use of these two to servicing certain existing equipment consistent with CAA and Montreal Protocol requirements.

The United States has already phased out the vast majority of regulated ODS consumption and production. Consumption today is more than 95 percent below the baseline level and will be at least 99.5 percent below the baseline level in 2020.

Costs

The EPA has conducted analyses to estimate the costs to the U.S. economy of phasing out CFCs and HCFCs. Various assumptions were used for the analyses, including the types of costs considered, how early or late different regulated ODS would be phased out, and how future costs were discounted to determine present value. A 1999 report to Congress was the most overarching of these analyses, and that report and related analyses that supported it are detailed below.

<u>1999 Report: Benefits and Costs of the Clean Air Act</u>

Under Section 812 of the Clean Air Act, the EPA provided to Congress a peer-reviewed report[1] on the costs and benefits of the CAA, including Title VI. This retrospective analysis built on cost and benefit data from previous Regulatory Impact Analyses (RIAs), and estimated the costs and benefits of the major sections of Title VI, including CFCs, halons, CH_3CCl_3 (trichloroethane or methyl chloroform), and HCFCs, but not CH_3Br (methyl bromide) or CCl_4 (carbon tetrachloride). The costs for each section were reported in 1990 dollars using discount rates of 3, 5, and 7 percent if possible to adjust, or the original 2 percent from previous RIAs if not.

Analysis of CFCs, halons, and methyl chloroform additionally included one-time costs such as capital expenditures and ongoing costs, e.g., for recycling and storing ODS and changes in energy use.

Analysis of HCFC phaseout costs included only operating costs based on substitutes for HCFCs being 10 to 50 percent more expensive. Any cost savings, e.g. from energy efficiency gains, would make total costs lower than listed.

Analysis of costs for Sections 608 and 609 considered costs of ODS recovery equipment, leak repair requirements, reclamation and storage of ODS, training and certification, and administrative costs. Section 611 costs were based on costs for development and application of new labels and administrative costs associated with compliance. The estimated cost of each section from 1990–2075 are shown in Table 1.

Table 1. Title VI Costs (Billions 1990 dollars)†

Title VI Section	Phaseout and Complementary Measures Cost Estimate (Billions 1990 dollars) with Given Discount Rate			
	2%	3%	5%	7%
Allowance allocation and reductions for CFCs, HCFCs, halons, methyl chloroform	$56	$41	$26	$18
608 refrigerant management	$1.2			
609 Motor vehicle AC servicing	$0.014			
611 labeling	$0.252*			

*Costs for Section 611 were reported for 1994–2000. Costs after this period should be negligible.

The estimates in Table 1 do not include potential cost savings from the HCFC phaseout. For example, more energy efficient air conditioning using alternatives to HCFC-22 could lower the cost estimate by $16.8 billion. Details of the RIA and Addendum upon which the estimates in Table 1 are based are below.

1992 Regulatory Impact Analysis

In its 1992 Regulatory Impact Analysis,[3] the costs of phasing out CFCs and halons were modeled in a scenario with a freeze in 1989 at 1986 production levels tapering to a complete phaseout in 2000. Other timelines were modeled as a sensitivity analysis, but this schedule was closest to the actual schedule followed. The estimates included capital costs assuming some early retirement or retrofitting of equipment, operating costs such as the possible need to use more expensive substitutes or processes, and one-time costs such as research and development and training. The costs also included costs or savings from changes in energy efficiency.

Table 2. CFC and Halon Phaseout Costs (Billions 1985 dollars)

Years	Phaseout Costs (Billions 1985 dollars)
1989–2000	$5.4
1989–2075	$20.8

† Phaseout costs presented are the total regulatory burden, or societal costs. Societal costs are the lost productivity of society in complying with the regulations. Other costs, e.g., higher prices of CFCs as supply decreases, are faced by some sectors, but are realized as benefits by others and so are called transfer costs. Transfer costs have no net impact on society as a whole and so do not add to the regulatory burden.[2]

Addendum to the Regulatory Impact Analysis

In 1993, this RIA was updated in an Addendum[4] to estimate the costs of accelerating the phaseout of certain ODS to align with the Montreal Protocol's agreement to strengthen global phaseout. This Addendum presented estimated costs for the phaseout of CFCs and halons for four new scenarios with faster and slower schedules, and added an analysis of the costs of phasing out HCFCs. Of these four scenarios, the lead scenario matches the schedule followed in the U.S. CFC, halon and HCFC phaseout. The lead scenario assumed production and import of halons would be phased out in 1994; CFCs, carbon tetrachloride, and methyl chloroform in 1996; HCFC-141b by 2003; HCFC-22 and HCFC-142b in new equipment in 2010 and existing equipment in 2020. This is the worst-first schedule described previously. Production and import of all other HCFCs for use in new equipment would be phased out by 2015 and for service of existing equipment by 2030.

The methods and types of costs considered for CFCs and halons were the same as in the 1992 RIA, and costs are again expressed in billions of 1985 dollars. The estimates for the four scenarios, using a 2 percent discount rate, are in Table 3.

Table 3. CFC and Halon Phaseout Costs (Billions 1985 dollars)

Scenario	Phaseout Costs 1989–2000 (Billions 1985 dollars)	Phaseout Costs 1989–2075 (Billions 1985 dollars)
Lead Scenario	**$9.1**	**$26.4**
With CFC Servicing Tail	$6.4	$22.2
Slower schedule	$5.4	$20.8
Faster schedule	$17.4	$48.7

In estimating the costs for phasing out HCFCs under the four scenarios, the phaseout cost was modeled as the operating cost incurred due to the difference in price between HCFCs and the chemicals used to substitute for them. Substitutes were assumed to be 10 percent to 50 percent more expensive than the HCFCs they replaced, giving a cost range for each scenario. The analysis did not include one-time costs because the long lead-times for HCFC controls would allow equipment to be replaced or retrofitted on normal plant modification schedules and expected equipment lifetimes. The estimated costs for 1989–2075 with a discount rate of 2 percent are given in Table 4 in billions of 1985 dollars. The actual accelerated schedule for the phaseouts were similar to the lead scenario.

Table 4. HCFC Phaseout Costs 1989–2075 (Billions 1985 dollars)

Scenario	HCFC Phaseout Costs (Billions 1985 dollars)
Lead Scenario	**$3.2–15.9**
HCFC-141b Later	$3.1–15.5
Slower	$2.4–12.1
Faster	$3.6–18.2

Unlike the CFC and halon costs in Table 3, the costs in Table 4 do not include effects of changes in energy efficiency due to transition from HCFCs to substitutes. The analysis gives one example of the possible magnitude of such effects, estimating that switching from HCFC-22 to a refrigerant that lowers energy expenditure by 2 percent would decrease costs by $16.8 billion from 2010–2075. Experience with refrigerant transitions indicates this increase in energy efficiency of 2 percent is well below the norm of about a 10 percent increase per decade.[5]

Updated Scenarios for HCFC Costs Estimation (2005)

The EPA again analyzed the costs of the HCFC phaseout in 2005.[6] Three different scenarios were considered. All scenarios' results are given as cost per ODP-kg of HCFC consumed in 2005 dollars. The maximum consumption of HCFCs in the United States for any year was 14.1 million ODP-kg in 1989.[7]

The first scenario followed the methodology of modeling HCFC costs from the 1993 Addendum, considering the change in operating costs resulting from switching from an HCFC to a substitute and assuming substitutes in each sector were 10 percent to 50 percent more expensive than the HCFCs they replaced. In the sectors considered, the cost ranged from $0.20 to $400 per ODP-kg.

The second scenario followed the same general approach as the first, modeling based on the difference in price between HCFCs and their substitutes. However, instead of assuming substitutes were a certain percentage more expensive, actual costs of representative HCFCs and substitutes were determined in each sector. Because in some sectors substitutes were less expensive than the HCFCs they replaced, the differential was negative in these sectors. This method estimated the costs of the HCFC phaseout at between -$3.65 and $5.08 per ODP-kg.

Unlike the first two approaches, the third scenario also considered capital costs for early retirement or retrofit of equipment and other one-time costs such as for research and training. It estimated these costs by analogy with the total costs calculated for CFCs and halons in the 1993 RIA Addendum. This method estimated a range for the total costs of the HCFC phaseout of $286 to $1,432 per ODP-kg. However, given the much longer time frame for phasing out HCFCs, it is not expected that all the costs assumed in 1993 for the CFC and halon phaseout would actually apply during the HCFC phaseout. For instance, the longer time frame would avoid most if not all need for early retirement of equipment; instead, equipment changes would be expected to occur during planned factory upgrades and normal equipment lifetimes.

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4. U.S. Environmental Protection Agency (EPA). 1993. Addendum to the 1992 Phaseout Regulatory Impact Analysis: Accelerating the Phaseout of CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride, and HCFCs. September 1993.
5. ICF International. 2007. Changes in HCFC Consumption and Emissions from the U.S. Proposed Adjustment for Accelerating the HCFC Phaseout. Available at: https://www.regulations.gov/document?D=EPA-HQ-OAR-2008-0496-0010
6. ICF. 2005. Memorandum on Recommended Scenarios for HCFC Phaseout Costs Estimation. March 2005.
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History of Title IX Essential Use Exemptions (EUEs)

Essential Use ODS in ODP Tons	1996	1997	1998	1999	2000	2001	2002	2003	2004
CFCs (mostly MDIs)	437.5	415.8	2814.7	2539.7	2391	1947	550	3270	2975
Methyl Chloroform	0.29	0.37	6.01	5.96	5.84	5.84	0	0	0
Lab & Analytical Subtotal	0	29	15.7	41.1	14.3	15	13.9	0.37	54.86
Total	438	445	2836	2587	2411	1968	564	3270	3030
% of Baseline	0.13%	0.13%	0.83%	0.75%	0.70%	0.57%	0.16%	0.95%	0.88%

Essential Use ODS in ODP Tons	2005	2006	2007	2008	2009	2010	2011	2012	2013
CFCs (mostly MDIs)	1902	1100	1000	385	282	92	0	0	0
Methyl Chloroform	0	0	0	0	0	0	0	0	0
Lab & Analytical Subtotal	34.4	37.78	33.51	21.52	3.63	13.47	7.04	3.52	7.37
Total	1936	1138	1034	407	286	105	7	4	7
% of Baseline	0.56%	0.33%	0.30%	0.12%	0.08%	0.03%	0.00%	0.00%	0.00%

Essential Use ODS in ODP Tons	2014	2015	2016	2017	2018
CFCs (mostly MDIs)	0	0	0	0	0
Methyl Chloroform	0	0	0	0	0
Lab & Analytical Subtotal	2.97	4.84	4.51	2.86	4.7
Total	3	5	5	3	5
% of Baseline	0.00%	0.00%	0.00%	0.00%	0.00%

Baselines (ODP Tons)	
CFCs	305964
Carbon Tetrachloride	11924
Methyl Chloroform	25597
Subtotal Combined Baseline	343485

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