Agreement No. 07-312

Developing a California Inventory for Ozone Depleting Substances (ODS) and Hydrofluorocarbon (HFC) Foam Banks and Emissions from Foams

Final Report

Prepared by:

Arnie A. J. Vetter & Paul K. Ashford
Caleb Management Services Limited
The Stables
Somerset House
Church Road
Tormarton
Badminton
GL9 1HT
United Kingdom

14th March 2011

Prepared for:

The California Air Resources Board and the California Environmental Protection Agency

Disclaimer

Acknowledgments

Caleb thanks Glenn Gallagher at the California Air Resources Board for his advice during this project and his commentary on its findings. Caleb also thanks the following individuals and organizations for being part of its project team and assisting with the delivery of this project:

Dr. Assaad Zoughaib
Armines

Kathy Smith
Caleb Group

Dr. Jason Yapp
Caleb Group

Hookyung Kim
Caleb Group

Bert Veenendaal
Rappa Inc.

Robert Russell
RJR Consulting Inc.

Nancy Woods
Robert Penny Enterprises (RPE)

Robert H. Lee
Survey Research Center
University of California Berkeley (SRC)

This report was submitted in fulfillment of Project 07-312: ***Developing a California Inventory for Ozone Depleting Substances (ODS) and Hydrofluorocarbon (HFC) Foam Banks and Emissions from Foams*** by Caleb Management Services Limited under the sponsorship of the California Air Resources Board. Work was completed as of 14th March 2011.

Table of Contents

List of Figures:

List of Tables

Abstract

Caleb and its project team undertook the development of an inventory of foams and their related blowing agents for California. The inventory provides data on greenhouse gas emissions and banks (greenhouse gases contained in existing foam, and not yet released to the atmosphere). The data and research findings will be used in support of establishing baselines and potential emission reduction approaches (if feasible and cost-effective) to meet the goals of AB 32, the Global Warming Solutions Act of 2006.

The inventory involved the development of a comprehensive foam characterization requiring the following elements:

1. An understanding of the current building stock, appliance inventories and other items containing foam and related blowing agents in California by type and age profile
2. An historic picture of annual foam sales and installations in the State of California
3. An historic understanding of the blowing agents used in these foams and the timing of any transitions that may have occurred
4. A current inventory of foam processing activities being practiced in California

A number of sources were consulted including foam manufacturers, blowing agent suppliers, specifiers, users and end-of-life operators such as refrigerator recyclers, demolition contractors and waste processors.

The project focused on characterizing the populations of these groups and, by means of pre-selection, screening interviews and in-depth follow-up interviews with key sources, sought to establish the inputs required to generate a State-wide model. This was then used to assess current emissions and forecast future emissions from on-going activity and existing banks. In addition, the model was used to assess the value of a number of mitigation strategies.

Executive Summary

Background

The central proposition behind this project is that it could make environmental sense from a climate policy perspective to mitigate emissions by either reducing current reliance on high-global warming potential (GWP) blowing agents and by separating and diverting ozone-depleting substance (ODS) and hydro fluorocarbon (HFC) containing foams out of the waste stream to be processed in ways that avoid ozone depletion and greenhouse gas emissions and that it is practicable to do so. The inventory and assessment of potential mitigation strategies are designed to help confirm or dismiss this proposition prior to a more in depth assessment of policy options which, in itself, is outside of the scope of this project. The outputs from this project will assist the California Air Resources Board (CARB or ARB) in developing and implementing strategies that contribute to the State of California reaching its goal of carbon dioxide-equivalent (CO_2-eq) greenhouse gas (GHG) emission reductions to 1990 levels by 2020.

Methods

The project involved the surveying of 302 organizations responsible for the production, installation, use, and end-of-life management of foams that contain ODSs or HFCs. Based on the survey findings, a foam banks and emissions model was developed. The model characterized the distribution of foams and their greenhouse gas containing blowing agents across different end-use sectors and the foam life-cycle. The model also helped identify potential greenhouse gas mitigation options and their climate impact in 2020. The project methodology involved the study of the existing literature, the development of a research plan, the development of tools and materials to be used in the survey process, an extensive survey process, the analysis of results and the development of the spreadsheet based blowing agent banks and emissions model.

Results

The ODS/HFC foam bank peaked in 1996 at nearly 364 million tCO_2-eq. and has been gradually decreasing since then. In 2005 it was around 315 million tCO_2-eq.The buildings end-use accounted for 85% and the appliances end-use accounted for 9% of the 2005 bank. Other applications – Transport Refrigerated Units and Marine buoyancy accounted for the remaining 6%. Greenhouse Gas emissions from the 2005 bank were just over 6 million tCO_2-eq. – with 66% arising from the buildings end-use and 20% from the appliances end-use.

By 2020, the foam bank is estimated to be 236 million tCO_2-eq., but annual emissions are estimated at just under 8 million tCO_2-eq (2.43 million from HFC, and 5.38 million from ODS). Taking due account of the size and dynamics of banks and emissions, the project team identified six mitigation scenarios for high GWP gases in California. These fell into the two key categories of end-of-life management and early phase-out of HFC use. End-of-life management would consist of removing or separating foam from buildings, appliances, and other sources at the time of disposal or recycling, and recovering the GHG-containing foam expansion agents before they are emitted. Recovered GHGs could be re-used or destroyed. In the mitigation scenarios developed, it is assumed that end-of-life measures require the shortest lead-times and can be initiated as early as 2012, with full implementation in place by 2014. The end-of-life scenarios include a 100% (technical potential) and a 50% (realistic potential) management of all domestic and commercial appliances, polyurethane steel faced insulation panels and other insulating foams from buildings.

Since there is no current federal constraint on the continued manufacture of products containing HFCs, it would be expected that any decision to introduce a phase-down or phase-out in HFC use, even at State level, would need substantial consultation. It has therefore been assumed that any such measure could only commence in 2014 and would not be fully achieved before 2017. The phase-out should apply to all domestic and commercial appliances, extruded polystyrene insulation foam and polyurethane spray foam.

Conclusions

There is technical potential to reduce 25-35% of the baseline annual emissions of high GWP gas emissions from the foam sector in 2020 equating to 1.45 -1.65 million tCO_2-eq. of HFCs, and another 0.56-1.11 million tCO_2-eq. of ODS. The HFC reductions would account for 0.8-0.92% of the overall target of the California Air Resources Board's Climate Action Plan. The absolute potential will be influenced by the average life-cycles of the products and equipment involved, many of which will be contained in buildings and therefore influenced by the variation in age profiles and lifecycles of the buildings themselves.

The Central Proposition that it could make environmental sense from a climate policy perspective to mitigate emissions by either reducing current reliance on high-GWP blowing agents or by separating and diverting ODS and HFC containing foams out of the waste stream is met in some instances. Major short-term and medium-term opportunities exist in the accelerated phase-out of HFCs in the foam sector and the potential for end-of-life management of appliances. In other instances, meeting the Central Proposition could be more challenging. As an example, the management of building foams at end-of-life provides a significant opportunity (>35%) for mitigation even at 2020, but the cost may be prohibitive when compared with other options available to the Climate Action Plan.

One key recommendation from this project is for a further evaluation of the potential for leveraging voluntary carbon finance for ODS bank management. There should be a particular focus on the underpinning of the climate value of these savings and a commitment to promote the sound practices specified by the current Climate Action Reserve protocol.

1. Introduction

1.1. Background

The Assembly Bill 32 (AB 32) “Global Warming Solutions Act of 2006” established the California Air Resources Board’s responsibility for developing and implementing strategies to enable the State of California to reach its goal of CO_2-eq greenhouse gas (GHG) emission reductions to 1990 levels by 2020. The AB 32 Scoping Plan identified foam insulation containing high-global warming potential (GWP) greenhouse gases as a sector of interest for possible mitigation efforts, as summarized in the Scoping Plan measure for Foam Recovery and Destruction.

Sources of high-GWP foam insulation include building insulation, appliances such as refrigerator-freezers and water heaters, transport refrigerated units (TRUs or “reefers”), and miscellaneous uses such as marine buoyancy. Typically, the high-GWP GHGs within the foam are released when the product reaches its useful end-of-life and it becomes a waste material.

Historically, insulating foam has been manufactured using foam blowing agents (also called foam expansion agents) that are high-GWP GHGs, which include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs). These foam expansion agents typically have global warming potentials thousands of times greater than carbon dioxide. In addition to being high-GWP greenhouse gases, CFCs and HCFCs are also ozone-depleting substances (ODSs) that destroy the protective stratospheric ozone layer. In response to the destructive nature of ODSs, the production of CFCs has been banned according to timelines established by the Montreal Protocol, and the production of most HCFCs will be banned by 2020.

The California Climate Action Team (C-CAT) initially examined hydrofluorocarbon (HFC) reduction strategies, but also realized that greater GHG reductions would be possible if Ozone Depleting Substances (ODSs) were considered in addition to HFCs. While not included in the Kyoto Protocol, nor in AB 32, ODSs have a large and ongoing impact because large banks of these chemicals still exist in the building stock and elsewhere. These banks will eventually be emitted into the atmosphere during use or at end-of-life or thereafter if not properly recovered and destroyed.

National estimates of banked and emitted ODSs and HFCs were made available by the US EPA for 2005 from the US EPA Vintaging Model[1]. The Vintaging Model estimates indicate that ODSs and HFCs from foam applications account for 61% of the total (ODS and HFC) banks in the USA.

Significant emission reductions may be possible if emissions during foam production, installation, and use phases are controlled, or if the GWPs of blowing agents used in foams are reduced where feasible. End-of-life management (EOL) measures also offer a substantial savings (emission reductions) opportunity when applied to demolition material and to all appliances.

This necessitates the identification and quantification in California of foam banks and emissions arising from applications such as buildings, appliances, other stationary refrigeration units, transport refrigerated units (TRUs) and marine buoyancy uses. The foam banks and emissions quantification and the exploration of management options are the purpose of this project.

1.2. Problem Statement

As Caleb has pointed out in its project proposal, the worldwide bank of blowing agents contained in foams was estimated to exceed 11 billion tons CO_2-eq in 2002 and is likely to remain above 9 billion tons CO_2-eq in 2015 under most business-as-usual scenarios. However, following the phase-out of the more emissive foam applications that were still using CFCs in the late 1990s, the emissions from foam banks are expected to settle in the range of 180 million tons CO_2-eq annually over the next few decades – i.e., 2% of banked quantities per year. This means that losses from foams could continue well into the future – perhaps for in excess of 100 years – particularly if some of those foams are land-filled. However, because the annual baseline loss rate is relatively low, attention typically switches to preventing emissions from more emissive banks – e.g., refrigerants, where loss rates are often well in excess of 20% of banked quantities annually. This trend persists despite the fact that the foam banks are larger overall. It reflects the fact that measures can be more cost-effective and easier to introduce when preventing refrigerant emissions. Nevertheless, the opportunity for the mitigation of emissions from foams remains highly significant, particularly at end-of-life.

Based on the US EPA model data, a 5 billion metric ton CO_2-eq bank from ODS/HFC foam sources could be estimated for the USA in 2005, with annual emissions in the

---

[1] The U.S. EPA's Vintaging Model was developed as a tool for estimating the annual chemical emissions from industrial sectors that have historically used ODSs such as CFCs, HCFCs, and halons in their products. The Vintaging Model also estimates emissions from ODS substitutes such as HFCs. The model name refers to the fact that it tracks the use and emissions of annual "vintages" of equipment that enter service or are disposed in each of several end- uses that make up an industrial sector (Godwin, 2003).

region of 92 million metric tons CO_2-eq. By applying a population factor of 12.8% for California, based on the US census, the California ODS/HFC banks could be estimated at 640 million tons CO_2-eq with 12 million tons CO_2-eq being emitted per annum from ODS and HFC foam sources (US EPA, 2005). Original Air Resources Board estimates in 2007 noted that approximately 60% of the total bank of high-global warming potential greenhouse gases is from foam sources, with most of the remaining banks from refrigerants. CARB estimated that the foam banks account for some 385 million tons CO_2-eq and generate an annual emission of approximately 9 million tons CO_2-eq. (CARB, 2007a).

1.3. Central Proposition

The central proposition behind this project is that it could make environmental sense from a climate policy perspective to mitigate emissions by either reducing current reliance on high-GWP blowing agents or by separating and diverting ODS and HFC containing foams out of the waste stream to be processed in ways that avoid ozone depletion and GHG emissions and that it is practicable to do so. The inventory and assessment of potential mitigation strategies are designed to help confirm or dismiss this proposition prior to a more in depth assessment of policy options which, in itself, is outside of the scope of this project.

1.4. Project Purpose

The project purpose is as follows:

- Characterize foam blowing agent banks according to product/application
- Characterize current foam production, use, and end-of-life fate according to the main foam using sectors
- Characterize ODS phase-out, replacement, and not-in-kind technology trends according to product/application
- Develop an emissions model based on collected blowing agent, foam and phase-out data to indicate emissions now and in 2020 under BAU and other scenarios

The key project outputs will be draft and final reports including discussions and analyses, as well as a bank and emissions model based on a life cycle assessment showing BAU and the impacts of potential control strategies in 2020. The project will culminate in a technical seminar for key stakeholders upon the completion of the Project Report.

1.5. Project Scope

The project should identify, for each product/application, average product or insulation system lifetimes, their emission rates (during foam production, installation and lifetime), the stock turnover rates, the end-of-life disposal options, the sector-growth rates, and the historic blowing agent substitution trends.

The project should assess and document bank development rates, showing the timescales associated with emissions from foams during lifetimes and at end-of-life.

The project should examine mitigating strategies in terms of their potential for reducing ODS/HFC banks and emissions as well as the climate impact or a range of control strategies, including:

a) emission reductions associated with foam production, installation and lifetimes;

b) low-global warming potential (GWP) blowing agents and not-in-kind (NIK) alternatives to use instead of high GWP blowing agents in specific foam applications;

c) end-of-life recovery of blowing agent and/or thermal destruction of high GWP foams

The project should examine emissions scenarios based on business-as-usual (BAU) as well as those incorporating various control strategies in the year 2020 to estimate possible CO_2 equivalent GHG reductions and the associated costs, based on Life Cycle Assessments.

1.6. Previous Research

A variety of research has been published over the last ten years on foam and blowing agent usage, characteristics and impacts, but only a very few were specific to California, and none have taken a holistic ‘bottom-up’ approach to the identification of foam based emissions in the State. Caleb has taken account of California specific research by CARB on estimated foam bank size and distribution, on estimated emissions from foam banks, on Appliances end-of-life fate and on in-state TRU/Reefer populations (CARB, 2008).

Beyond California, there have been a variety of studies in the USA relevant to foam blowing agent use, banks and emissions, such as on Polyurethane blowing agents, (Skeist Inc. 2004), and on a US high GWP inventory (US EPA, 2001a). Internationally, there have been a series of studies completed on characterizing banks, emissions and management options, on defining a global emission function for blowing agents (AFEAS, 2000) and on the collection and treatment of unwanted ODS (ICF International, 2008). The studies were completed for the United Nations Environment

Programme (UNEP), the Intergovernmental Panel on Climate Change (IPCC), and the Technical and Economic Assessment Panel (TEAP) of UNEP. There have also been studies specific to the European situation, including a study on regulatory options (Milieu 2007), and a study on characterizing building foam banks and emissions in the United Kingdom (BRE 2010). Caleb was, in whole or in part, responsible for much of this research and has reviewed and drawn upon the work as part of the Literature Review process. This review process has continued throughout this project in order to keep updated with the latest findings.

1.7. Report Structure

In Section 2 of this draft report, Caleb sets out the methodology, tools and work stages used to determine the blowing agent banks and emissions arising from a variety of foam applications. In Section 3 the report explains the project’s findings and how these are used to develop the banks and emissions model. In Section 4 Caleb explores how the findings support or fail to support the central proposition that controlling the HFC and ODS emissions from the foam banks in California is practicable and environmentally beneficial. In Sections 5 and 6, Caleb sets out its conclusions on potential mitigation strategies that might be employed to reduce the ODS and HFC emissions associated with business as usual practices and makes recommendations on the next steps. The Appendices contain the list of respondents to screening interviews, the list of respondents to technical interviews and the data used to generate the figures shown in the main sections of the report.

2. Methods and Approaches

The Project was implemented in a series of stages including a review of the literature; the completion of a project research plan taking account of literature review findings; preparation of survey tools and materials; a survey process and a data analysis process. This was then followed by an emission modeling process and finally this current reporting process. The individual stages are briefly outlined below:

2.1. Task 1: Literature Review

Caleb assembled literature that might be of relevance to the Foams Inventory Project from the time of completing the project Request for Proposal (RFP). This literature was supplemented with materials from Caleb's archives. From this collection, a master list was created and Caleb then 'mapped' the sources against key research themes (Applications, Foam Insulation, Blowing Agents, high GWP GHG Banks and Emissions).

In this way, a quick overview could be created as to the areas where there were data gaps. Areas where data gaps were identified received special attention during the project's research stages. All sources were also filtered for geographical relevance (e.g., California specific; USA, and International sources).

Following a more detailed scanning of the literature, Caleb filtered source materials according to 'to be cited'; 'not cited' and 'for contact information' categories and then placed contact details into our database, and placed the 'not cited' in our archives. Caleb then concentrated on reviewing the 'to be cited' sources for the literature review report on the basis of their potential relevance for this Project.

Caleb prepared and submitted the ***Literature Review Report*** to California Air Resources Board in February 2009.

2.2. Task 2: Revised Research Plan

The research plan took account of the outcomes from a 'kick-off' meeting held in Sacramento at the end of July 2008 plus the negotiated work agreements with sub-contractors Armines, Robert Penny Enterprises (RPE), Survey Research Center (SRC), RJR Inc. and Rappa Inc. It also took account of findings from Caleb's Literature Review.

The plan, budget and project schedule underpinned the delivery of the Foams Inventory Project. Among other factors, the plan elaborated the approach to identifying research questions, development of questionnaires, identifying interview targets and the logistics for obtaining the necessary data for the project.

Caleb prepared and submitted the ***Revised Research Plan*** to California Air Resources Board in April 2009.

2.3. Task 3: Compilation of Project Tools and Materials

The project team completed further background research to better characterize foam based applications in the State of California. The work provided some of the required input data for Caleb's ongoing work. It also provides important background information that helped to effectively frame screening and technical interview questionnaires and scripts.

RPE completed telephone research with building standard/code professionals to:
a) obtain interviewee details and b) make a basic determination of Title 24 building energy performance code influences in California.

The project team obtained background information from web-based research and spent time transforming available research findings into data relevant for California. Data gaps for non-domestic appliances, water heaters and the lesser application of marine buoyancy were identified. These were subsequently filled by a combination of interviews and additional desk research as necessary.

One essential ingredient of Caleb's preparation work was the identification of possible interviewees and the development of a comprehensive contacts database. The database that was assembled consisted of approximately 1,360 individual records covering Californian and US organizations from different parts of the foams life cycle. In many instances it was possible to pool resources with delivery partners to generate application-specific lists. In other instances, the records were obtained from public directories and from private directories (Dun & Bradstreet). In instances where records were incomplete, RPE completed telephone follow-ups to determine contact names and details for senior personnel in targeted organizations.

The contacts database remained a 'live' document in the sense that Caleb was able to continuously update it during the remainder of the interview/data gathering stages of the project. Caleb made these updates and kept project team members informed of changes and additions. SRC also reviewed the database and made recommendations for changes that led to improvements.

In the lead-up to the interview stages, Caleb made a determination on how the call lists were allocated within the project team. It was important that individual team members took responsibility for managing the calls from ‘their’ part of the list, and that they kept Caleb informed of any difficulties or inconsistencies involving the database.

Caleb prepared an Excel contacts database structured around the life-cycle stages of the main applications as follows:

Table 2-1 DESCRIPTION OF CONTACTS DATABASE SCOPE

LCA STAGE	APPLICATIONS	DESCRIPTIONS
PRODUCTION	CHEMICAL SUPPLIERS	Incl. Blowing Agent Suppliers
	SYSTEMS HOUSES	
	FOAM MANUFACTURERS	Incl. Foam Insulation Producers
	OEM MANUFACTURERS	Incl. Modular Building Manufacturers
INSTALLATION	PRODUCT/SYSTEMS SPECIFIERS	Incl. Architects; Property Developers
	PRODUCT/SYSTEM INSTALLERS & DISTRIBUTORS	Incl. Builders; General Contractors
	REGULATORY/ADVOCACY	Incl. Building Code officials; Appliance Code agencies; Governmental and non-governmental bodies; Trade Associations; Commissioning Utilities
USE	USERS/MAINTENANCE/REFURB	Incl. Property Managers; Landlords; Institutional Owners; Refurbishment Contractors
END-OF-LIFE MANAGEMENT	DEMOLITION CONTRACTORS	
	RECYCLERS	Incl. Metal shredders, appliances recyclers
	WASTE TREATMENT	Incl. Waste to Energy Sites; Waste Incinerators
	WASTE DISPOSAL	Incl. Municipal Solid Waste (MSW) and other Landfill Sites;

In sourcing its lists, Caleb tried to make the database representative in terms of applications, sectors and life cycle stages. In the event, most of the contacts were found in buildings related sectors, among product and systems specifiers and for the end-of-life parts of the foam life-cycle. This reflected Caleb’s understanding that most of the foam/blowing agent banks were in the built environment, and that the largest opportunity for mitigation was likely to occur at a product’s or building’s decommissioning.

Other important ingredients were the questionnaires, supporting scripts and materials that were prepared and used during the interviewing stages. These were also helpful in the post-interview assessment of findings. These documents proved particularly useful in guiding the conversations between the project team and the interviewees during the screening interview process and beyond.

Caleb updated the implementation timetable for the interview, data analysis and data modeling to reflect a revised project schedule following a temporary project stoppage while the California budget was confirmed.

Caleb prepared and submitted a draft ***Compendium Report: Data, Interview Database & Questionnaires*** to California Air Resources Board in August 2009. The final report was submitted in November 2009.

2.4. Tasks 4, 5 & 6: Interviews & Data Analysis

2.4.1. Screening Interviews

Screening and technical interviews were designed to provide bottom-up data inputs to the project, from which a model could be developed to illustrate the foam related banks, emissions and control strategies.

302 screening interviews were completed with respondents across the foam containing applications and life cycle – summarized as follows:

Figure 2-1 SCREENING INTERVIEWS BY LIFE CYCLE STAGE

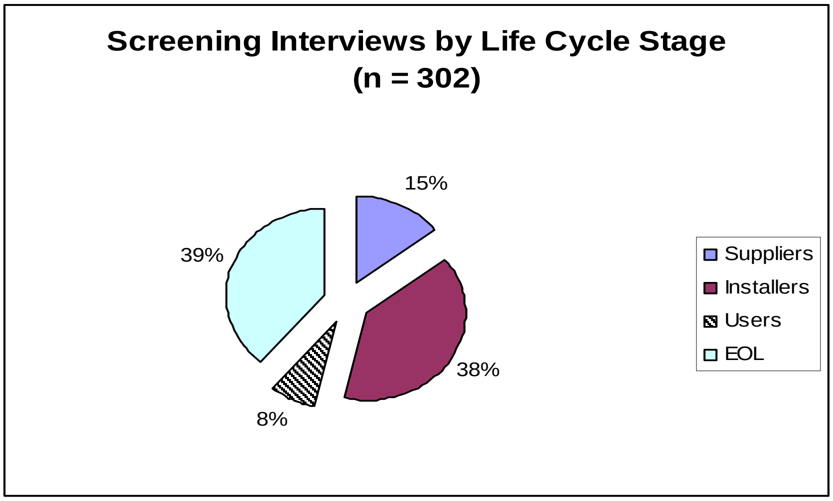
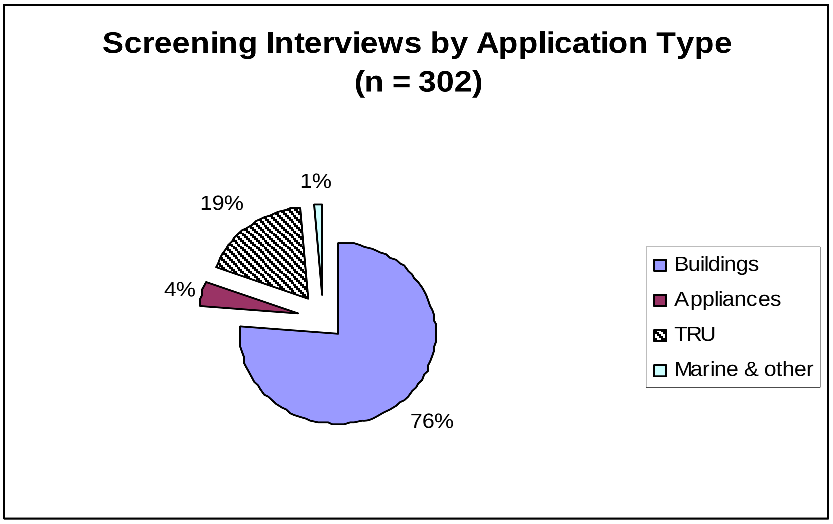


Figure 2-2 SCREENING INTERVIEWS BY APPLICATION TYPE



Prior to the completion of the bulk of the screening interviews, the project plan called for the completion of 30 orientation interviews by SRC. In the event, SRC provided a detailed commentary on the Compendium Report, with particular reference to the flow and consistency of the questionnaires. Caleb made a number of changes to the questionnaires on the basis of this helpful input. Due to the technical nature of the questionnaires, Caleb and SRC concluded that the more appropriate approach was for Caleb to conduct these 30 interviews as part of the wider screening interview process.

The project team initially carried out screening interviews across all the main applications and life cycle stages, but eventually began to focus on buildings and end-of-life management aspects. *See Appendix 1 for a list of respondents.*

Alongside the telephone interviews, the project team also conducted face-to-face interviews with groups that were more generic in nature – as opposed to technically based. In its database, Caleb had defined these as ‘Regulatory & Advocacy’ respondents, and many of these were interviewed in order to obtain relevant background information.

It became clear quite quickly that it was also relevant for the project team to conduct technical interviews in parallel with the screening interviews. Candidates for technical interviews became available fairly early on and it therefore made sense for time and logistical reasons to pursue these interviews directly.

Wherever possible, detailed summaries of interviews were provided by the project team – especially for buildings at the demolition stage. There was also focus on appliances across the life-cycle and for both building and appliance applications at waste processing and disposal stages. In other instances, such as foam production and supply, specification of foam products by architects, presence of foam in landfills, the transport refrigerated units and the marine applications, the data were aggregated in the form of summary reports to Caleb. All inputs were reviewed for data gaps to be addressed via more targeted technical interviews.

2.4.2. Technical Interviews

One of the purposes of the screening interviews was to identify potential contacts for more in-depth interviews later. Most of these were face-to-face, but there was also a provision for conducting longer technical interviews by phone where this was preferable. This was in fact often the case – especially with chemicals suppliers, foam producers and systems houses. The screening interview scripts, questionnaires and templates contained standard questions on follow-up interviews and the team members asked for follow-ups where they found an informative and approachable respondent. Team members also asked interviewees for their opinions on likely further contacts and/or data sources that the project team could then pursue.

The project team completed 84 technical interviews. Project team members Armines, Caleb, RAPPA Inc. and RJR Inc. were able to pursue contacts in their own networks to arrange technical interviews where appropriate and other targets emerged from screening interviews. *See Appendix 2 for a list of interviewees.*

These interviews went into more depth on buildings, refrigeration and other foam using sectors and to filled data gaps identified previously.

The results from these interviews were combined with the records generated from the screening interviews and assessed for quality. Key data were prepared for inputs into the emissions model that was completed by Caleb.

The technical interviews are distributed as summarized below:

Figure 2-3 TECHNICAL INTERVIEWS BY LIFE CYCLE STAGE

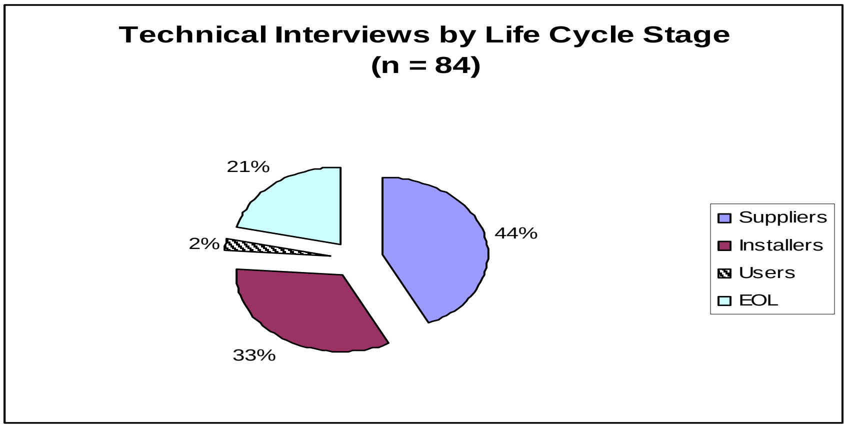
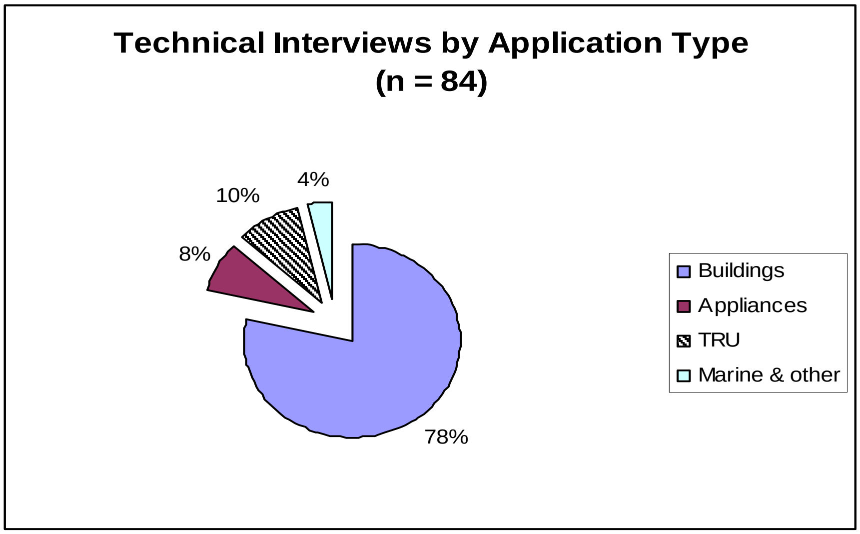


Figure 2-4 TECHNICAL INTERVIEWS BY APPLICATION TYPE



2.5. *Using existing and new literature*

In addition to the initial literature search, Caleb also completed further on-line research on the key foam containing applications. The main focus was on sourcing essential data on buildings, appliances, structural and non-structural cold stores, and transport refrigerated units. Most of the data were for stock and production, but there were instances where the project team obtained data for other life-cycle stages. Project team member Armines was able to provide many data on appliances and non-structural cold stores.

The project team continued to contribute information from web-based research and Caleb also spent time transforming available research findings into data relevant for California. There were data gaps for non-domestic appliances, water heaters and the lesser application of marine buoyancy. These were filled by a combination of interviews and additional research as necessary.

During the interview stages Caleb also came across additional literature, either specific to California, the USA, or North America (ACC, 2006), (PURRC, 2005). Where appropriate, we have referred to data and findings from these sources.

Since starting this project, Caleb has also been actively involved in characterizing building-related foam and ODS data, plus the evaluation of management options in

Europe, and especially the United Kingdom. While findings there are not directly relevant to California, the methodology for characterizing the foam bank and the modeling approach taken to identify the bank and emissions plus possible mitigation strategies has proved relevant to this project. In particular, the UK project provided an important opportunity for peer review of the Caleb approach prior to the completion of the California model.

Caleb prepared and submitted the ***Screening & Technical Interview Report*** to California Air Resources Board in May 2010.

2.6. Bank and Emissions Modeling

Preparing the California foam banks and emissions model was a two-part process. In the first instance, a **Preliminary model** was prepared and submitted to the California Air Resources Board in April 2010. In this model Caleb was able to ascertain ODS/HFC/HC volumes in metric tons per main application, and offer segmentation by banks and various sources of emissions. The model was based on 'bottom up' stock data and provided average foam and blowing agent content per unit in stock over time.

The outputs from Caleb's **Full model** are provided as part of this draft final report. This further disaggregates the stock, foam and blowing agent volumes, and adds a distribution by blowing agent species and product type. It also adds a more up to date set of values for leakage rates across the foam life cycle. The combination of additions and improvements assist in ascertaining GHG emissions in terms of CO_2-eq. from BAU and the potential control strategies.

2.7. Rationale for the Project Design

There was a clear need for a 'bottom-up' assessment of the potential impacts and opportunities arising from better management of California's foam ODS/HFC banks as a counterpoint to the 2005 US EPA's Vintaging model, which was essentially a 'top down' tool (US EPA, 2004).

The foam and ODS/HFC inventories had to be characterized from available industry data. Where these data were not available or inconclusive, the survey/interview process was needed to fill the gaps.
Specifically, this required a better understanding of key applications (buildings, appliances etc.) and key management options (End-of-Life separation) that could only be identified through original research.

The combined data from literature evaluations and survey/interview results enabled Caleb to prepare a more detailed bank and emissions model and explore the impact associated with Business As Usual (BAU) as well as the impact of potential mitigation strategies.

2.8. Project Limitations

The main challenge in gaining a better quantitative understanding of the sources of GHG emissions and the potential options to mitigate impacts arises from the diffuse nature of the ODS/HFC bank sources. This applies to all the foam containing applications reviewed by this project, but was particularly challenging for transport refrigerated units and the lesser applications of marine buoyancy and consumer products like cooler boxes. As a consequence, the project team did need to make assumptions on historical stock development. These assumptions are shown in the main body of the report where relevant, and also in summary Table 3-28 in Section 3.7.1.

Apart from obtaining stock data from the 1960's onward, the project also had to capture foam and blowing agent content and changes over the decades. Many of the screening interview respondents were unable to be specific on stock and insulation volumes or changes within their sectors. Neither were they well informed about *the impact* of underlying drivers (such as Title 24 for building insulation content) affecting foam use over time. Nor was this information always available from foam producers. As a consequence, the project team had to rely on published data combined with assumptions on foam consumption growth rates.

2.9. Implementation Controls

Within the project team there were regular teleconferences and email exchanges to communicate about project progress and content, including the quality and reliability of data. The project team was also invited to comment on the draft reports and draft models prepared by Caleb.

Caleb provided regular written reports to California Air Resources Board together with updated budgets as required. Team members traveling to California to complete field work and technical interviews completed four meetings with the California Air Resources Board contract manager to discuss the project delivery in detail.

2.10. Summary of Data Quality

The project team was able to arrive at high quality data for the buildings and appliances applications which are understood to be the predominant sources of the California ODS/HFC banks and emissions. Data were less robust for the TRU application, on account of the potentially high volume of 'stored' reefers at California ports. Data were also less robust in the minor applications (marine leisure; consumer products – cooler boxes). This has resulted in the project team making assumptions on stock turnover, foam and ODS content, leakage rates and end-of-life fate for these applications. A list of assumptions and relevant references, where available, can be found in Section 3.7 later in this Report. In the table below, Caleb sets out an assessment of data quality by data source:

Key:

1) **A** = Official Statistics; **B** = Survey & modeling inputs from research institutes; universities; consultancy reports; **C** = Project survey results, emission modeling results and Project Team estimates
2) **1** = good quality; **2** = medium quality; **3** = poor quality

Table 2-2 SUMMARY OF DATA SOURCES & QUALITY

Data Type	**Application Type**	**Data Sources**	**Assessment of Data Quality**	
			Data Source[1]	**Quality of Data**[2]
Stock & Population Data				
Building Types	Buildings	2005 Building Energy Efficiency Standards, Non-Residential Compliance Manual (CEC 2005)	B	1
Building Stock Numbers, Floor Area & Stock Additions	Buildings	California State-Wide Residential Appliance Saturation Study, 2006. (CEC, 2006).	A	1
		California Energy Commission 2009 Forecast Floor Space Data	A	1
		US Census Bureau http://quickfacts.census.gov/qfd/states/06000.html	A	1
		US Department of Commerce; Bureau of Economic Analysis; Table 1.1.1 Percent Change from Preceding Period in Real GDP (1960-2008)	A	1

Data Type	**Application Type**	**Data Sources**	**Assessment of Data Quality**	
			Data Source[1]	**Quality of Data**[2]
Building Vintage	Buildings	Construction Statistics Data User's Conference; US Bureau of the Census; 1979	A	1
Building Codes	Buildings	Building Codes Assistance Project (BCAP) – http://bcap-energy.org	B	2
		Building Energy Efficiency Standards for Residential and Non-Residential Buildings, 1998, 2005, 2008; California Energy Commission	A	1
Construction market	Buildings	Polystyrene and Polyurethane Foam Insulation Products in U.S. Building and Construction; SBI Energy, 2008	B	1
Insulation market	Buildings	Data & estimates from delivery team members; findings from interviews	C	1
Demolition market & rates	Buildings	Survey on actual service lives for North American buildings; J. O'Connor; Forintek Canada Corp.; 2004	B	2
		Findings from interviews	C	2
Building Useful Life	Buildings	2001 California Non-Residential Energy Standards; CEC 2000	B	2
Building End-of-Life Management	Buildings	End of Life Options for Steel based Building Envelope Systems; Kingspan Insulated Panels; 2006	B	1
Appliance Types	Appliances	Data & estimates from delivery team members; findings from interviews	C	1
Appliance Numbers	Appliances	Data & estimates from delivery team members; findings from interviews	C	1
Appliance Codes	Appliances	Data & estimates from delivery team members; findings from interviews	C	2
Appliance market	Appliances	Data & estimates from delivery team members; findings from interviews	C	2
Appliance Useful Life & turnover	Appliances	Data & estimates from delivery team members; findings from interviews	C	1
End-of-Life Appliance management	Appliances	How Electric Customers Dispose of Used Refrigerators and Why they Choose a Utility Program: S. Westberg, et al. 2007 – Energy Program Evaluation Conference, Chicago http://www.cee1.org/eval/db_pdf/652.pdf	B	2
TRU Types	TRU	Staff Report: Initial Statement of Reason for Proposed Rulemaking: Airborne Toxic Control Measure for the In-Use Diesel Fueled Transport Refrigerated Units (TRU) and TRU Generator Sets and Facilities where TRUs Operate; CARB, 2003	B	2

Data Type	Application Type	Data Sources	Assessment of Data Quality	
			Data Source[1]	Quality of Data[2]
TRU Numbers	TRU	Defining & Determining Emissions for Refrigerated Shipping Containers and the Total Re-generation process in the vicinity of Shipping Ports; CARB White Paper, 2009	B	2
TRU market	TRU	Data & estimates from delivery team members; findings from interviews	C	2
TRU Useful Life & turnover	TRU	Data & estimates from delivery team members; findings from interviews	C	2
Marine & Other Registrations or Stocks	Marine	2005 US Recreational Boating Registration Statistics 2006 Recreational Boating: Statistical Abstract; National Marine Manufacturers Association (NMMA)	A A	1 1
Marine & Other markets	Marine	Data & estimates from delivery team members; findings from interviews	C	2
Marine & Other Useful Life & turnover	Marine	Skeist Inc.,	B	2
Foam Data				
Foam Types & Applications	All	Skeist Inc., 2004 Data & estimates from delivery team members; findings from interviews	B C	2 2
Foam Volumes by Application	All	Skeist Inc., 2004 Data & estimates from delivery team members; findings from interviews	B C	2 2
Foam Volumes in Waste Stream	All	California 2008 State-Wide Waste Characterization Study; California Integrated Waste Management Board (CIWMB), 2009 Data & estimates from delivery team members; findings from interviews	A C	1 2
Foam End-of-Life management options	All	IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System; UNEP/TEAP, 2005 Data & estimates from delivery team members; findings from interviews	B C	1 2

Data Type	Application Type	Data Sources	Assessment of Data Quality	
			Data Source[1]	Quality of Data[2]
Blowing Agents				
Blowing Agents by Application	All	Skeist Inc., 2004 Data & estimates from delivery team members; findings from interviews	B C	2 2
Blowing Agents by Product type	All	Skeist Inc., 2004 Data & estimates from delivery team members; findings from interviews	B C	2 2
Blowing Agent substitutions	All	Skeist Inc., 2004 Data & estimates from delivery team members; findings from interviews	B C	2 2
Blowing Agent disposal & treatment	All	Attenuation of Fluorocarbons Released from Foam Insulation in Landfills; Technical University of Denmark, 2007 Disposal of Refrigerators-Freezers in the US: State of the Practice; L.R. Wethje, P/E.; Appliance Research Consortium, 2005	B B	2 2
Blowing Agent Banks by Application	All	Data & estimates from delivery team members; findings from interviews; data modeling	C	1
Blowing Agent Emissions by Application	All	Data & estimates from delivery team members; findings from interviews; data modeling	C	1
GHG Banks & Emissions				
GHG banks by Applications	All	Data & estimates from delivery team members; findings from interviews; data modeling	C	1
GHG emissions by Applications	All	Data & estimates from delivery team members; findings from interviews; data modeling	C	1
GHG emissions by Life Cycle	All	Data & estimates from delivery team members; findings from interviews; data modeling	C	2
GHG Banks & emissions under BAU	All	Developing a California Inventory for ODS and HFC Banks and Emissions from Foams; CARB 2006 Analysis of Costs to Abate International ODS Substitute Emissions; US EPA, 2004 Cost & emission reduction analysis of HFC emissions from foams in the USA; US EPA, 2001	B A B	1 1 2
GHG Banks & emissions under Control Strategies	All	Data & estimates from delivery team members; findings from interviews; data modeling	C	2

3. Results

In the following Sections 3.1 through 3.6, Caleb describes its findings from the Literature Review, from further Desk Research on California Building Codes, and from the Interview process. This is followed by a summary of inputs to the Banks and Emissions Model in Section 3.7, before Caleb describes the model outputs in Section 3.8, and concludes with mitigation options in Section 3.9.

3.1. Findings from the Literature Review

3.1.1. General Findings

The most important conclusion was that there were considerable data gaps at various levels that needed to be filled in order to successfully characterize and quantify California's foam insulation high GWP GHG banks and emissions and management options. The following sections provide an outline of our main findings by key areas of research.

3.1.2. Foam Containing Applications

There was a lack of California specific literature on foam containing applications, which was one of the reasons for ARB commissioning a 'bottom-up' foams inventory in the first place. Buildings, appliances, and other smaller applications were fully researched and characterized as part of the project. The main aim of this part of the project was to 'map' and quantify foam *containing* products and infrastructure in California, in order to then help quantify the likely foam banks and the emissions that arise from these banks over the life-cycle.

While Caleb understands the underlying factors that affect the prevalence of and market-place for foam based insulation in its wider context, the project team had to find out more about the California-specific situation. The literature offered no comprehensive details on foam production, use and disposal volumes or the distribution of these across the applications in California. The project therefore needed to generate data in these areas. There were no specific data on the impacts of buildings and appliances codes on the foam insulation market-place. The project team developed an understanding of these potential impacts and Caleb has taken them into consideration when developing the banks and emissions model under Task 7 of the Project.

In terms of end-of-life fate, it was clear that the majority of insulation foams that arise from the buildings sector were being land-filled. The project team needed to identify specific volumes and the factors that underpinned these data. It also needed to identify the extent to which any existing voluntary programs already addressed foams end-of-life. The literature suggested that there were efforts underway in the United Kingdom and elsewhere to better understand voluntary options for managing buildings based foams at end-of-life. Lessons from these efforts included the value of having a pre-existing infrastructure capable of handling foams; the need for clear guidance on the management and handling of foams at the end-of-life, and the need to optimize transportation logistics to deal with waste foam.

3.1.3. Foam Types & Uses

Polyurethane (PUR), Polyisocyanurate (PIR) and Extruded Polystyrene (XPS) foams created with ODS or HFC blowing agents are used in a variety of forms and application areas as shown in the table below. By far the most common use for these closed cell foams is for thermal insulation, but they are also used as structural cores that provide buoyancy within marine applications.

Table 3-1 SUMMARY OF FOAM TYPES BY APPLICATION AREA

Foam Type	**Insulation Product Type**	**Application Areas**								
		Buildings & Building Services					**Appliances**		**Transport**	**Other**
		Wall	**Roof**	**Floor**	**Pipe**	**Cold Stores**	**Domestic Appliances**	**Other Appliances**	**Reefers**	**Marine & Leisure**
Polyurethane; Polyiso - cyanurate	Injected/Pour in Place (PiP)	X			X		X	X	X	X
	Boardstock	X	X							
	Continuous Panel	X	X						X	
	Discontinuous Panel	X	X			X			X	
	Continuous Block				X	X			X	
	Discontinuous Block				X	X			X	
	Spray Foam	X	X					X		
Extruded Polystyrene	Board		X	X		X			X	X

3.1.4. Blowing Agent Use

The literature on current production and use of blowing agents is fairly extensive, but there are limited data that are specific to California. The Foams Inventory project needed to substantiate the position that applies to California. The Literature on alternatives and substitutes is also fairly extensive and the project was able to build on these data to develop a California specific picture that helped to fully characterize the bank.

3.1.5. ODS/HFC Banks & Emissions

There is considerable literature on global and US high GWP GHG foam banks and emissions. The California data on banks and emissions are currently ‘top-down’ – being mainly derived from the US EPA Vintaging model by means of applying a population share factor. The Foams Inventory Project was designed to approach the subject from a ‘bottom up’ vantage point, thereby providing an alternative view grounded in California specific data. The project developed a California bank and emissions profile for 2020 by virtue of building up a detailed picture of applications containing foams. From this emerged a characterization of insulation foams and a quantification of blowing agent use. The project built up a detailed profile of ODS and HFC banks and emissions plus the factors that impact on these data. From this, a further series of steps allowed the characterization and quantification of high-GWP GHG banks and emissions for California and the exploration of the greenhouse gas reduction potential of various mitigation options.

3.2. Findings from further Desk Research relating to Building Codes

3.2.1. Building Energy Codes

3.2.1.1. Building Code changes

The first state-wide energy requirements were established in 1975 by the Department of Housing and Community Development for all low-rise residential buildings. In 1974 the California legislature passed the Warren-Alquist Act establishing the California Energy Commission and authorizing the Commission to establish energy requirements for both residential and commercial buildings.

The so-called “First Generation” Standards for non-residential buildings took effect in 1978, and remained in effect for all non-residential occupancies until the late 1980s, when the “Second Generation” Standards took effect for offices, retail and wholesale stores. The next major revision occurred in 1992 when the requirements were simplified and consolidated for all building types. At this time, major changes were made to the lighting requirements; the building envelope and fenestration (window) requirements; as well as the heating, ventilation, and air-conditioning (HVAC) and mechanical requirements. Structural changes made in 1992 set the way for federal standards and other states.

The Standards went through minor revisions in 1995, but in 1998, the lighting power limits were reduced significantly, because at that time, electronic ballasts and T-8 lamps were cost effective and becoming common practice in non-residential buildings. The California electricity crisis of 2000 resulted in rolling blackouts through much of the State and escalating energy prices at the wholesale market, and in some areas of the State in the retail market as well. The Legislature responded with AB 970 (Ducheny, 2000; Electrical Energy: thermal power plants: permits), which required the California Energy Commission to update the Energy Efficiency Standards through an emergency rulemaking. This was achieved within the 120 days prescribed by the Legislature and the 2001 Standards (or the AB 970 Standards) took effect mid-year 2001. The 2001 Standards included requirements for high performance windows throughout the State, more stringent lighting requirements and miscellaneous other changes (CEC, 2005).

Executive Order S-20-04 was issued in 2004, and is known as the Green Building Initiative. It laid out a comprehensive set of actions for California to take in order to improve energy efficiency in non-residential buildings. The California Energy Commission was directed to undertake all actions within its authority to increase the efficiency requirements in the California Building Energy Efficiency Standards for non-residential buildings by 20% by 2015.

The California Energy Commission (CEC) has completed the rulemaking process for the 2008 Energy Efficiency Standards for Residential and Non-residential Buildings (Title 24, Part 6, of the California Code of Regulations). The Energy Commission adopted the 2008 Standards in April 2008, and the Building Standards Commission approved them for publication in September 2008.

A first analysis of the 2008 code by the Building Codes Assistance Project (BCAP, 2010) revealed an average energy performance at least 21% more efficient than the voluntary code developed by the American Society of Heating, Refrigeration & Air Conditioning Engineers (ASHRAE) 90.1-2004 (Energy Standard for Buildings Except Low-Rise Residential Buildings). Even better results are likely after more definitive testing, and they are anticipated to be more stringent than the 2009 International Energy Conservation Code (IECC) and ASHRAE Standard 90.1-2007 (Energy Standard for Buildings Except Low-Rise Residential Buildings [2007 version]).The effective date for the new standards was pushed back from August 2009 to January 2010. This was largely due to the fact that the California Energy Commission experienced delays in completing the public domain compliance software.

3.2.1.2. Relevance of Building Code changes

Caleb's assessment based on a comparison between the 1998, 2005 and 2008 prescriptive requirements for High Rise Residential Buildings & Guest Rooms in Climate Zones 1 and 16 (*for example*) shows an improvement of thermal conductivity values as follows: -

Table 3-2 CALIFORNIA BUILDING CODE CHANGES 1998 - 2008[2]

	u-values (W/m²K) (a)			
YEAR	ROOFS/ CEILINGS	WOOD FRAMED WALLS	METAL FRAMED WALLS	FLOORS & SOFFITS (b)
1998	0.037	0.063	0.14	0.05
2005	0.036	0.074	0.183	0.048
2008	0.034	0.059	0.105	0.034

Table notes:
a): The u-value is the overall heat transfer coefficient, and describes how well a building element conducts heat. The lower the u-value, the better the insulation. Therefore, a u-value of zero would be a perfect insulator, conducting no heat.

b): A soffit is the underside of any construction element, such as the underside of a flight of stairs.

Changes in prescribed insulation levels from building code improvements since the 1970s will have an impact on the size of foam banks and emissions. Typically, insulation improvements present themselves via increased material thicknesses as well as a further penetration of insulation into the existing building stock. In compiling the banks and emissions model under Task 7, the project team has factored in changes in insulation thicknesses arising from building code improvements.

3.3. Findings & Analysis: In-State Foam Production

3.3.1. Section Content

In this Section, Caleb briefly outlines findings on In-State foam production related to Extruded Polystyrene board stock, Polyurethane Panels, Polyurethane Spray Foam and Polyurethane board stock and Pour-In-Place (PiP) foam. This is for background information only, and a more detailed breakdown of production emissions for foams consumed in California will be provided later in this Report in Section 3.8.

3.3.2. In-State Foam Production

3.3.2.1. Extruded Polystyrene

This category involves estimating greenhouse gas emissions over the studied timeframe for foam products actually produced in the state of California. There was one known manufacturing plant producing extruded polystyrene sheathing in California. The plant operated between 1960 and 2009. During this period it produced

---

[2] Building Energy Efficiency Standards for Residential and Non-Residential Buildings; California Energy Commission, 1998, 2005, 2008

11 million cubic meters of foam and used over 35,500 tons of blowing agents. From 1960 to 1989, it used CFC-12 and thereafter an 80/20 HCFC-142b and HCFC-22 share. An estimated 4,970 tons of blowing agent was emitted over this period, corresponding to a 1st year emission rate of 10 -14%. This is made up from die emissions during manufacturing: (typically 5-7%); curing emissions while the foam is cooling down, curing and becoming stable: (typically another 4-5%) and the rest of the annual emissions from year 1: (approximately 1-2%). If it was realistically much higher than that companies would have installed capture and condensing technology to gather and re-use blowing agents as they have become more expensive through their evolution of CFC--HCFC--HFC.[3]

Based on an average 25% XPS market share in the buildings application, this plant would have met practically all of California's XPS demand over the period 1960 to 2009.

Please note that in-state production of expanded polystyrene (EPS) was not considered by this project. This type of foam is generally used for packaging applications and has never used ozone depleting substances or HFCs as blowing agents. It therefore falls outside the scope of the inventory.

3.3.2.2. Polyurethane

Throughout the years, there have been a number of small foam manufacturing operations in California – largely in packaging foam. Companies have come and gone in this sector making it difficult to gain a consistent picture of activity for the foam sector. There is no record of collective foam volume produced across a multiple product mix, but emissions would be relatively small. The majority of these products switched to hydrocarbons as early as 20 years ago. There is no bank to be considered here.

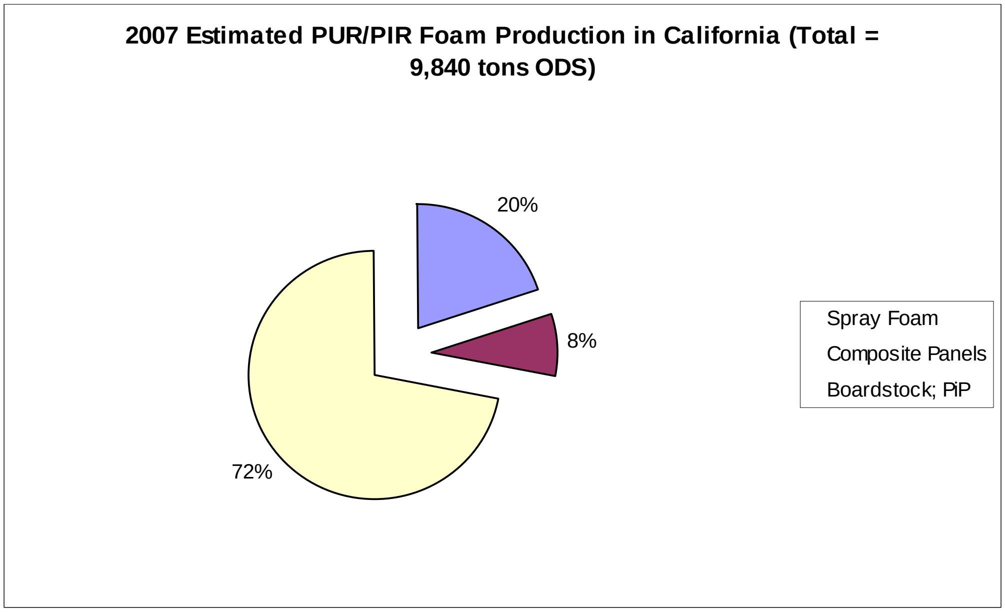
At this time, there are two PU panel producers in California and there are at least 20 spray-foam contractors, together producing an estimated 9,800 tons of PUR/PIR foam/year[4]. PUR Spray foam is using HFC-245fa and PUR panels use pentane blends. They all changed from HCFC-141b around 2005. Polyisocyanurate (PIR) formulations have historically used CFC-11, before switching to HCFC-141b and then eventually converted to hydrocarbons about 10 years ago. The total emissions are relatively insignificant for a boardstock plant running continuously.

---

[3] Comment from Robert Russell of RJR Consulting Inc. (November 2010)

[4] Caleb calculation based on: Polystyrene and Polyurethane Foam Insulation Products in U.S. Building and Construction; SBI Energy, 2008 (*2007 estimate based on a 10% share of US PU construction foam shipments worth $492 million, and PU foam cost at $5/kg).*

Figure 3-1 2007 IN-STATE POLYURETHANE/POLYISOCYANURATE PRODUCTION



Production for the period 1960 – 1969 grew by 8%/year, and for 1970 – 1979 it grew by 5%/year, as it did for the period 1980 to 1989. For the period 1990 to 2009, production grew by around 3%/year (rounded down for no growth from 2007).

3.3.3. Findings & Analysis: Buildings

In this Section, Caleb reviews building stock data and describes building-related foam and blowing agent consumption, before identifying blowing agent substitutions for the different foam categories. Caleb also briefly describes not-in-kind alternatives, before reviewing current and alternative end-of-life practices.

3.3.4. Building Stock

Caleb has obtained detailed buildings stock data for residential, non-residential and commercial buildings from a variety of sources, including the California State-wide Residential Appliance Saturation Study (RASS) (CEC, 2006), the Construction Statistics Data User's Conference (US Census Bureau, 1997), and the California Energy Commission's 2009 Forecast Floor Space Data (CEC, 2009). Building stock, stock turnover, stock additions and vintage data have been integrated and further developed in Caleb's banks and emissions model. There were over 16 million buildings in California in 2008, of which the majority was residential single-family dwellings.

The table below gives a breakdown of the stock by type of use.

Figure 3-2 CALEB ESTIMATES OF BUILDING STOCK DISTRIBUTION

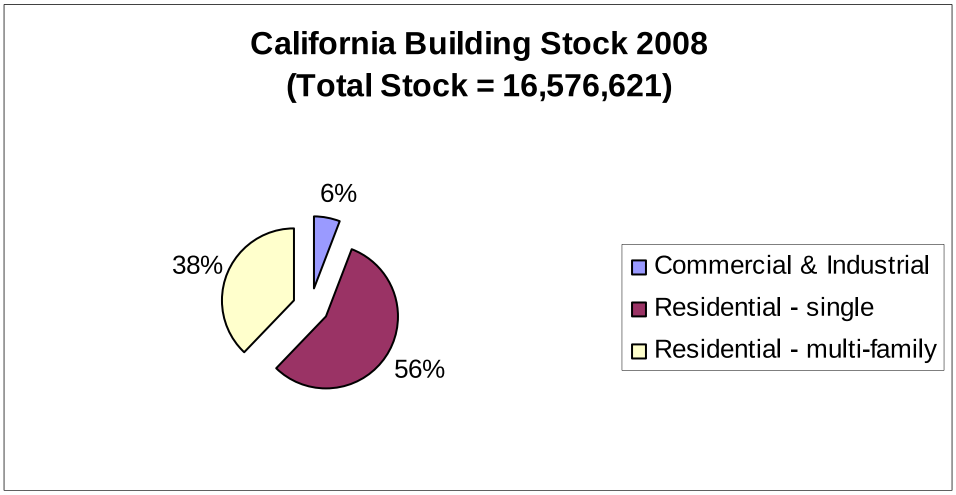


Table 3-3 2008 CALEB ESTIMATE OF BUILDING STOCK (NUMBER OF BUILDINGS)

Building Use	Existing Stock	New Starts	Demolition	Revised Stock
Single Family Homes	9,179,595	224,798	91,796	9,312,597
Multi Family Homes	6,100,700	237,743	61,007	6,277,436
Commercial	944,436	61,041	18,889	986,588
Total	***16,224,730***	***523,583***	***171,692***	***16,576,621***

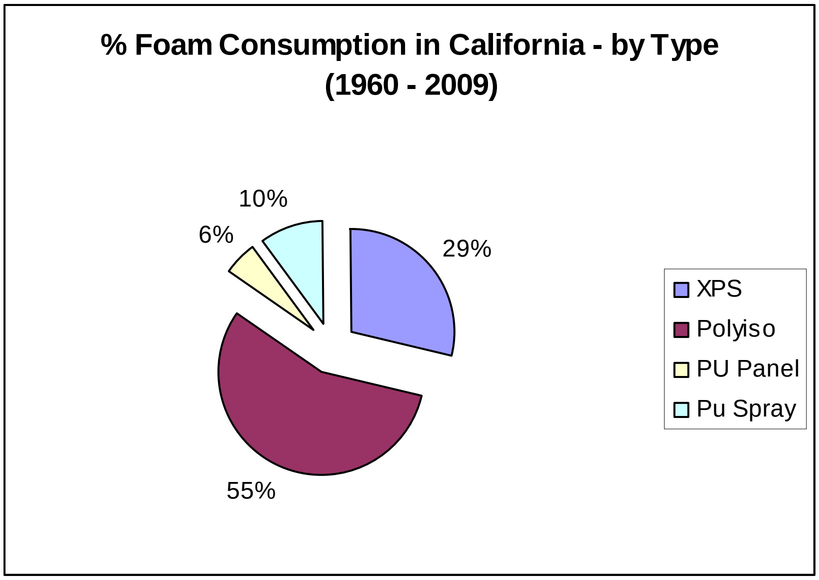
For low rise residential, the building life was assumed to be 30 years (CEC, 2000). The useful life of non-residential buildings can range from 25 years for steel framed buildings to 70 for wood framed buildings (O’Connor, 2004). Caleb estimates an average 30 year life time for non-residential buildings.

3.3.5. Foam Types & Volumes

In California insulation foams occur in a wide range of building products. For example, they occur as the core material of panels in cold stores or refrigerated warehouses, or as the primary insulation materials contained within brickwork or steel, or spray-applied in retrofit internal and external insulation. The use of these foams began in the 1960s and became commonplace in the 1970s and 1980s, largely in response to the energy crises of that period.

A variety of foam types are used in building insulation, including Polyisocyanurate, and Extruded Polystyrene board stock, Polyurethane Panels, and Polyurethane Spray Foam. The relative market shares of these foams in California building insulation have altered over the years, driven by building code changes as well as wider supply, demand and cost factors. The figure below shows a Caleb estimate of the average percent share of total insulation foam consumption for the period 1960 to 2009 for new building and refurbishment efforts in California:

Figure 3-3 CALIFORNIA FOAM CONSUMPTION - BY TYPE (1960-2009)



Board stock is prominently used in roof and wall insulation in commercial buildings. Sandwich panels, where the foam is sandwiched between facing materials such as steel and aluminum, are used for insulating cold stores, cold rooms and doors. Spray foams are made at the point of use and are literally sprayed into place. They are highly suitable for the insulation of uneven or inaccessible surfaces and are used in pipe work and roof spaces. Increasingly, companies are using pentane --a hydrocarbon-- as an alternative blowing agent for both board stock and sandwich panels. Pentane has a relatively low GWP value of 17, and hydrocarbon foam blowing agents typically have GWP values of 25 or less, a GWP reduction of 98 percent compared to common HFC foam blowing agents.

In order to determine the flow of total foam through the Building Stock in any given year, Caleb calculated the foam content (in m^3) in the existing stock (Foam in Buildings). By adding the volume of new foams and refurbishment foams and then subtracting the decommissioned foam, Caleb could estimate a revised volume for the total foam banked in buildings for the *following* year (Revised Foam in Buildings). In the table below the calculation shows the volume change between 2007 and 2008.

Table 3-4 2008 - CALEB ESTIMATES OF FOAM VOLUME IN BUILDINGS (m^3)

Building Use	Foam in Buildings	New Foam	Refurbishment Foam	Decommissioned Foam	Foam in Buildings - Revised
Single Family Homes	9,802,172	513,816	20,982	162,726	10,499,696
Multi Family Homes	12,763,393	905,673	23,240	161,976	13,854,282
Commercial	12,338,548	985,537	30,488	120,298	13,474,871
Total	***34,904,113***	***2,405,026***	***74,710***	***445,000***	***37,828,849***

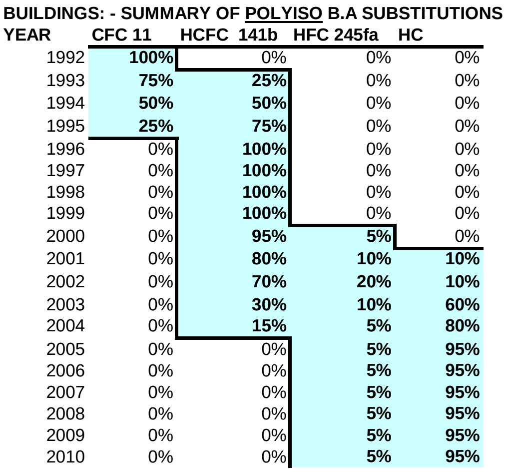
Caleb estimates that, in 2008, the proportion of California newly built and refurbished buildings that use insulation foam ranges from around 16% for Multi-Family Homes to 78% for Structural Cold Stores. This proportion has grown substantially in the last few decades and will continue to grow as energy codes are strengthened.

3.3.6. Blowing Agent Use & Substitutions

Major US building insulation producing companies, such as Atlas Roofing, Firestone, RMAX, and Johns Manville have shifted from HCFC-141b to using pentane. They have concluded that pentane is less costly than HFC-245fa and that given the high GWP of these substances, pentane is environmentally more sustainable.

Substitution rates are specific to foam types and Caleb has summarized the changes over time, as can be seen in the tables below.

Table 3-5 POLYISO BLOWING AGENT SUBSTITUTIONS



BUILDINGS: - SUMMARY OF POLYISO B.A SUBSTITUTIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0%	0%	0%
1993	**75%**	**25%**	0%	0%
1994	**50%**	**50%**	0%	0%
1995	**25%**	**75%**	0%	0%
1996	0%	**100%**	0%	0%
1997	0%	**100%**	0%	0%
1998	0%	**100%**	0%	0%
1999	0%	**100%**	0%	0%
2000	0%	**95%**	**5%**	0%
2001	0%	**80%**	**10%**	**10%**
2002	0%	**70%**	**20%**	**10%**
2003	0%	**30%**	**10%**	**60%**
2004	0%	**15%**	**5%**	**80%**
2005	0%	0%	**5%**	**95%**
2006	0%	0%	**5%**	**95%**
2007	0%	0%	**5%**	**95%**
2008	0%	0%	**5%**	**95%**
2009	0%	0%	**5%**	**95%**
2010	0%	0%	**5%**	**95%**

Table 3-6 BLOWING AGENT SUBSTITUTIONS

BUILDINGS: - SUMMARY OF XPS B.A SUBSTITUTIONS

YEAR	CFC 12	HCFC 142b	HCFC 22	HFC 134a
1992	**100%**	0%	0%	0%
1993	**75%**	**16%**	**9%**	0%
1994	**50%**	**33%**	**18%**	0%
1995	**25%**	**49%**	**26%**	0%
1996	0%	**65%**	**35%**	0%
1997	0%	**65%**	**35%**	0%
1998	0%	**65%**	**35%**	0%
1999	0%	**65%**	**35%**	0%
2000	0%	**65%**	**35%**	0%
2001	0%	**65%**	**35%**	0%
2002	0%	**65%**	**35%**	0%
2003	0%	**65%**	**35%**	0%
2004	0%	**65%**	**35%**	0%
2005	0%	**65%**	**35%**	0%
2006	0%	**65%**	**35%**	0%
2007	0%	**65%**	**35%**	0%
2008	0%	**49%**	**26%**	**25%**
2009	0%	**16%**	**9%**	**75%**
2010	0%	0%	0%	**100%**

Table 3-7 PU PANEL BLOWING AGENT SUBSTITUTIONS

BUILDINGS: - SUMMARY OF PU PANEL B.A SUBSTITUTIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0%	0%	0%
1993	**75%**	**25%**	0%	0%
1994	**50%**	**50%**	0%	0%
1995	**25%**	**75%**	0%	0%
1996	0%	**100%**	0%	0%
1997	0%	**100%**	0%	0%
1998	0%	**100%**	0%	0%
1999	0%	**100%**	0%	0%
2000	0%	**95%**	**5%**	0%
2001	0%	**80%**	**15%**	**5%**
2002	0%	**70%**	**20%**	**10%**
2003	0%	**30%**	**40%**	**30%**
2004	0%	**15%**	**45%**	**40%**
2005	0%	0%	**50%**	**50%**
2006	0%	0%	**50%**	**50%**
2007	0%	0%	**50%**	**50%**
2008	0%	0%	**50%**	**50%**
2009	0%	0%	**50%**	**50%**
2010	0%	0%	**50%**	**50%**

Table 3-8 PU SPRAY FOAM BLOWING AGENT SUBSITUTIONS

BUILDINGS: - SUMMARY OF PU SPRAY B.A SUBSTITUTIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0%	0%	0%
1993	**75%**	**25%**	0%	0%
1994	**50%**	**50%**	0%	0%
1995	**25%**	**75%**	0%	0%
1996	0%	**100%**	0%	0%
1997	0%	**100%**	0%	0%
1998	0%	**100%**	0%	0%
1999	0%	**100%**	0%	0%
2000	0%	**95%**	**5%**	0%
2001	0%	**80%**	**20%**	0%
2002	0%	**70%**	**30%**	0%
2003	0%	**30%**	**70%**	0%
2004	0%	**15%**	**85%**	0%
2005	0%	0%	**100%**	0%
2006	0%	0%	**100%**	0%
2007	0%	0%	**100%**	0%
2008	0%	0%	**100%**	0%
2009	0%	0%	**100%**	0%
2010	0%	0%	**100%**	0%

3.3.7. Not-In-Kind (NIK) Alternatives

For thermal insulation applications (the majority of rigid foam use), mineral fiber alternatives (e.g., glass fiber [fiberglass] and mineral wool) have been, and continue to be, major not-in-kind alternatives. Their relative benefits and limitations vary substantially, both between products within a category and between applications. This makes a generic conclusion about preferences impossible. The current thermal insulation market supports a variety of solutions (at least 15 major product types), and this reflects the range of requirements demanded for the applications served (IPCC/TEAP, 2005).

3.3.8. Current End-of-Life Practices

3.3.8.1. Waste Characterization

In terms of the California Construction & Demolition (C&D) waste stream, foam insulation is an extremely small piece of the pie. It doesn't have a special designation and is seen as non-hazardous. Typically it is land-filled without prior diversion.

California has a total waste arising of 40 million tons/year. Sixteen percent of this is Construction & Demolition (C&D)[5] waste – i.e., – 6.4 million tons/year with the largest part being demolition waste (CIWMB, 2009a). Asbestos gets separated at the demolition site for special disposal, although roofing asbestos is now a declining issue. Demolition cycles would be in the region of 30 years for residential, and one might expect a least one re-roof during that period. The commercial cycle is faster, especially for smaller buildings that get 'repurposed' (CIWMB, 2009b).

Some foam may end up as municipal solid waste (MSW) delivered to waste-to-energy plants, but C&D waste typically gets separated at waste transfer stations and therefore would not end up in the MSW waste stream destined for waste to energy plants.

The small amount of foam that is seen at landfill sites usually comes in with C&D mixed waste loads, and is not segregated in any way or disposed of in any different way to other C&D waste. There aren’t many data available on foam waste. The 2008 Waste Characterization Study identifies fiberglass insulation separately in the waste stream (0.2% or 6,025 tons/year applied to four metropolitan areas covered by the waste characterization study). If scaled for California, then this waste stream would be approximately 12,700 tons/year. Foam insulation is not tracked separately, but is likely to be contained in the ‘Remainder/Composite Plastics’ category (0.23% of C&D waste stream; 7,174 tons/year in four metropolitan areas – or up to 15,130 tons/year state-wide).This is broadly consistent with Caleb’s assessment of decommissioned foam, where 445,000 m^3 of foam waste per year equates to 15,575 tons[6].

3.3.8.2. End-of-Life Practices

A wide variety of responses were received from demolition contractors. Estimated demolition rate/year is 1% for residential and 2% for commercial buildings. About 47% of the decommissioned foam is from residential buildings and the remainder from commercial and industrial buildings.

---

[6] Caleb calculation: (foam volume)*(avg. foam density)/1000; therefore (445,000)* (35)/1000 = 15,575

At this time, the most prevalent practice for demolition foam is for it to be land filled together with other mixed C&D waste. This is unlikely to change in the foreseeable future for a variety of reasons including:

- land fill space appearing to be readily accessible in most instances
- general failure to segregate demolition waste unless there is a specific mandate
- appearing to be the least cost option ($39 – $60/ton)
- the complexities of separating foams from other C&D waste fractions

While there are a series of better practices (from an ozone and climate perspective), there is currently no requirement to make changes. There is a countywide waste diversion goal of 75% (either weight *or* volume) for Alameda County - but this is not typical for California. Other parts also have strong policies – e.g., – Los Angeles County has a zero waste goal. Individual cities in Alameda also have zero waste goals. The typical diversion goal is 50% of the waste, but this does not tend to cover insulation foams.

Contractors will respond to the recycling ordinances from cities, but nobody is mandating the removal of foams. The sorts of waste fractions that get diverted would be asbestos (legal requirement) and anything that has secondary value (wood, steel). Waste is crushed and broken up before going to the Materials Recovery Facility (MRF) - so even if there were any foam, the damage to the foam would be substantial, potentially leading to significant emissions, although rarely total loss at the processing stage.

Insulation foam remains a minute waste stream, and right now it mostly goes to landfill because it has no intrinsic value out of the building. A further complication with foam waste is its relatively low weight to volume ratio, making the economics of handling and transportation less attractive than is the case for many other waste materials.

The cost of disposal to landfill remains relatively low. The gate fee for C&D waste in an unsorted state is $60/ton, while public garbage is $115/ton and public wood waste is $26/cubic yard, or $60/ton.

Older buildings from the early 1970’s typically don't contain foam insulation, although there could be large quantities of foam in cold storage structures. According to a number of respondents there used to be many cold stores (especially in the Oakland area), but many have already been demolished. According to one respondent, much of the insulation they see is at sites is of the spray on foam variety and also fiberglass in residential and commercial buildings. By their estimate, not even 2% of what they find is rigid foam when compared with other insulation. When they do find it, it tends to be 2-4 inches thick - typically contained in commercial steel framed buildings.

Another respondent sees blown cellulose fiber in residential properties and sees foam sometimes in exterior type panels in built up systems (as opposed to sandwich panel systems). Another respondent estimated that based on more than 100 buildings demolished, typically about 50% will have some type of closed cell insulation, often in roofs. Their work is concentrated on commercial buildings in southern California. In a 10000 sq ft demolition job, they might have 2 truck loads of this material. It is light and doesn't compact well because of its rigidity. Rigid insulation in a typical 6000-7000 sq ft factory might be found in the roof – where there typically are 2 inches of foam. Rigid foams in walls are fairly uncommon.

Yet another respondent saw rigid foam maybe 4 to 5 times per year. They do 500 to 600 projects per year - always commercial and industrial buildings that were started in the 1970s. Typically, they find 2 inches of solid foam. These foams are in the larger buildings over 20,000 sq ft. They do buildings ranging from 5000 to 100,000 sq ft. The foam is always land filled and it costs $40/ton to dispose of as a mixed load. The weight of insulation might be 8 - 10 tons in each mixed load.

Less than 1% of the total business of another respondent is foam insulation. This is mostly in roofs and in commercial buildings around 20,000 sq ft. They see 2 to 3 inches of foam in buildings from the 1970s and 80s. The foam ends up in landfills. Buildings from the 1960s contain fiberglass insulation, and buildings from before then don't have much, if any, insulation.

Another respondent found that they only came across rigid foam when they demolished distribution centers or cold rooms. Most of the time they saw fiberglass and drywall. In residential buildings, they mostly saw blown paper product. In commercial buildings they saw rolled insulation/mineral wool. Their business was 95% commercial, and 5% residential.

Another respondent was involved in the demolition of large industrial and commercial buildings. As an example of a recent building they were involved with, they mentioned a 387,000 sq ft building with 4 inches equivalent of foam = 4740 cubic yards of foam. They estimated that 155 tons of the material out of that building would have been foam. The insulation weight (estimate 1lb/ sq ft) was low when compared to the asphalt shingles it was attached to. One might expect 5-7 lb/ sq ft for asphalt shingles and foams together. It would be very costly to separate, when one takes into account the $12 - $14/hour labor cost - or up to 3 times that amount for public projects. Their personal observations lead them to believe that there is plenty of foam in commercial buildings from the 1960s onwards, and that older buildings from the 1920s that had re-roofs done from the 1960s shouldn’t be ignored.

<u>Estimated Building Foam Disposal Routes - 2009</u>

Building Demolition Foams

92% direct to landfill	8% to shredder, followed by landfill

3.3.9. Alternative Options for managing construction & demolition waste

The physical characteristics of the ODS/HFC-containing foam wastes that affect possible treatment/disposal options include the weight, volume, and material composition. The demolition processes and segregation of wastes on demolition sites will impact on, for instance, the size of individual pieces of waste and its level of contamination.

From a waste management perspective, these different ODS/HFC-containing foam wastes are unlikely to be handled as separate waste streams. There may be some exceptions to this if there are potential reuse opportunities for specific high quality products. However, in considering future waste management scenarios, we have assumed that the waste will generally be handled as one waste stream or possibly two streams; namely ‘PU Panels’ and ‘all other products’.

PU Panels are comprised of foam cores between rigid facings. Facing materials are typically steel, aluminum or glass fiber reinforced plastic sheets. PU Panels which are faced with steel or aluminum are more attractive to recyclers owing to the metal content. PU Panels are typically comprised of 80% metal by weight.

“All other products” will predominately consist of foam material. In terms of waste handling and transport of wastes, it is important to recognize that these wastes are voluminous, low density materials. As a result, transportation will be relatively expensive per ton of material handled. The average density of this collective waste stream (PU Panels and all other products) is estimated at 0.0354 ton/m^3 (about 2 lb/cubic foot). Losses from the demolition process are estimated as 10 to 11% of the remaining blowing agent charge. (BRE 2010)

While foam waste represents a challenge (and opportunity) in terms of its impact on the stratospheric ozone layer and the atmosphere, it does not currently present a problem for the California waste management sector. The only foam that is being recovered and treated in California is appliances foam via dedicated appliance recyclers, who recover blowing agents from the foam, and send the recovered CFC or HCFC blowing agents to a recycling or destruction facility. The added cost of appliance foam recovery and recycling or destruction is paid for by the Electric Utilities and achieves a diversion of about 12% to 15%/year as a proportion of total units discarded. The remaining 85% to 88% of appliances reaching end-of-life are recycled by certified appliance recyclers or metal shredders who typically do not recover the foam prior to shredding and recycling.

The general consensus amongst demolition interview respondents was that at the moment only those materials that are practical to recover from the general demolition waste stream are those which have an economic value, or those materials that are required to be segregated as a result of regulation (e.g., asbestos) or city ordinances (e.g., wood, steel). The segregation of ODS/HFC-containing foam is only likely to happen if it is policed or the demolition contractors see financial benefits for the recovery. Demolition contractors prefer fiscal incentives to encourage them to recover ODS/HFC-containing foams as opposed to regulatory options.

The cost premiums involved in alternative treatment approaches to end-of-life foam across the main applications are not insignificant. In instances where foam recovery and destruction programs are already in place, e.g., for refrigerators/freezers, additional stimulation would be needed to achieve a higher diversion rate. This could be via expanded utility funding or the carbon market.

A higher level of recovery followed by destruction of waste foam might emerge as a credible option because it is the only approach that can legitimately qualify for carbon credits. CAR – the Climate Action Reserve – will consider credits from direct foam incineration (waste to energy, or WTE) where the identity of the blowing agent is clear and the concentration has been established to be consistent by frequent monitoring.

In the buildings application, the cost and practicalities of diversion would be more problematic, particularly within the context of relatively low landfill disposal costs. Carbon credits would have to be sufficiently high (and stable) to stimulate recovery and destruction in the face of the significant costs that are involved in foam separation at the demolition site or recycling facility, transportation costs to the destruction facility, and potentially increased costs at the destruction facility due to the need to re-orient their combustion cycles to accommodate an increased quantity of foam. There may, nevertheless, be a case for combusting waste foams directly, or combusting the blowing agents following recovery, as this would be a more effective method of mitigating ODS emissions than would be possible from land filling. Combusting foams directly in WTE facilities would offer the additional benefit of harnessing the high heat content of foams for purposes of energy generation.

Alternatively, land filling end-of-life foam may be considered a better option. This applies to situations where landfill gas combustion plants could potentially achieve high levels of ODS/HFC destruction, or where the conditions for natural biological attenuation of the foam blowing agents within the landfill could be created and sustained. It would, however, be impossible for landfill-based mitigation to be quantified, and carbon credits would therefore not be available for such an option.

3.3.9.1. Description of potential options

Combustion in Waste To Energy (WTE) Facilities

Polymer-based insulation (e.g., polyurethane foams) can be incinerated in order to recover energy and to reduce its volume (to approx. <1%). Polymers have a high calorific value and can be burned with energy recovery, without giving off toxic or environmentally damaging fumes (if managed properly).

It is also expensive to transport these lightweight wastes over long distances, possibly negating the environmental benefit of recovery. However, it may be one of the most favorable solutions for polymer-based insulation waste, particularly in the short-to-medium term. The material would still need to be recovered and segregated at end of life, but issues of contamination are likely to be of less importance.

Sanitation Districts of Los Angeles County operate a WTE facility in Commerce and have a share of another facility also. The Commerce facility can handle up to 500 tons/day and they already take foam from appliance recyclers – typically 1-2 tons/day. They could combust segregated C&D foam waste provided it wasn't patched through at more than about 30 tons/day. Volumes over this level would create problems with the combustion cycle in the plant. They offer guaranteed ODS destruction certificates for clients who use these to generate carbon credits – which acts as a stimulus for such efforts. The cost of disposing waste through this WTE plant is $65/ton (slightly more than landfill, but not by a wide margin). Certified destruction would cost in the region of $220/ton.

Foam can be considered a residual waste only, because it has no value once the wood and other valuables have been stripped out. The City of Commerce facility in Los Angeles took 140 tons of appliance foams in 2007 and 185 tons in 2008. That unit processes 500 tons/per day of MSW wastes and up to 1 or 2 tons of foam per day - about 0.4% or less of the waste stream. By comparison, another facility in Spokane took 30 tons of appliance foam in 2007 and 90 tons in 2008. Covanta in Stanislaus has an 800 tons/day capacity, and combusted 170 tons of appliances foam in 2007 and 100 tons in 2008 (about 0.05% of the waste stream). There are larger plants in the north-eastern US, handling 2000-3000 tons/day - so they may be able to handle more foam, although the transport costs and impacts would probably make this unviable for California from economic and environmental perspectives.

Other operators were less positive about the prospect of taking foam waste in anything other than very small quantities. WTE plants are listed by heat input. One ton of foam would displace 3 tons of garbage. Halogens attached to the foam are freed in the combustion process, and are corrosive to the MSW plant. This has to be paid for and would therefore be reflected in the pricing. It would not be possible to take all the foam currently in California's banks. Given that nobody can guarantee the foam volumes coming out of the bank, it would be difficult to justify building 'merchant plants'.

According to one respondent, the C&D waste stream doesn't really work with the California and US plant structure. The chances for getting new facilities set up are very low. Some plants - like Covanta Stanislaus - could build more capacity, but it would be difficult to get permits from the local Air Pollution Control District. Additionally, if AB 32 takes organics out of the waste stream, then this would raise the heat value of the remainder - making it more difficult to manage foam disposal without exceeding licensed British thermal unit (Btu) limits.

Dealing with foam is essentially a legacy issue and it would be necessary to take account of current service agreements between plants and communities when evaluating the potential for handing foam through waste to energy facilities. The capacity may simply not be there for anything other than a marginal uptake. In summary, the technical possibility is there to use WTE facilities for foam based waste, but the cost of separation, transportation and certificated destruction would be substantially higher than standard disposal via landfill. Any carbon credit or other stimulus would have to be of a sufficient level to stimulate such an effort. Any demolition load heavier than 30 tons would need to be held separately, either at the demolition site or at the combustion site and this could incur additional storage, handling and transportation costs.

Managed Attenuation

Two studies conducted by the Technical University of Denmark investigated the potential for microbial attenuation of ODS (CFC and HCFC) and HFC blowing agents in landfills (Scheutz 2003; and Scheutz 2007). These studies analyzed foam samples from simulated landfill conditions to see how effective methanogenic bacterial microbes in landfill soil are at breaking down CFC-11 and HCFC -141b. The 2007 study (Scheutz, 2007) reported a nearly 100% breakdown of the CFC-11 within 10 to 14 days in the sample, although the breakdown of the HCFC-141b was much slower. HFCs did not attenuate in measurable amounts. Attenuation has only been observed in landfills under anaerobic conditions in the presence of methanogenic bacteria. Anaerobic conditions do not develop immediately in landfills. Managed attenuation may have the potential to destroy CFC foam blowing agents in landfills to 90% efficiency. Although the cited studies indicate that attenuation in landfills may effectively reduce CFCs found in waste insulating foam, the attenuation of HCFCs was significantly slower than for CFCs. No attenuation of HFCs was observed in the studies. Additionally, the studies took place in simulated landfill conditions and not actual landfills, which may have resulted in different outcomes than expected under actual landfill conditions. Further studies are required to confirm the properties of the specific microbes responsible for the degradation.

Another study identified two foam disposal scenarios that explore landfill foam handling options (Wethje, 2005).

In the Wethje study, the calculations of the fate of the released CFC after disposal at landfill were evaluated via two different scenarios. The first scenario represented the existing situation where the shredded foam waste was stockpiled for a short period prior to land-filling. After land-filling the foam waste was driven over by a landfill compactor to reduce volume of the foam waste and other wastes disposed of together with the foam waste. This could be expected to lead to an additional instantaneous release which will lead to CFC release entering un-attenuated into the atmosphere. After final disposal using normal procedures it is well-known that the onset of straight anaerobic conditions would take a few months. In this period the CFC destruction by micro organisms was not very likely due to too high redox potentials within the waste layers.

The second scenario represented the situation where the instantaneous landfill release was reduced by avoiding working the foam waste with landfill compactors and where anaerobic waste was mixed with the foam to speed up the onset of the microbial destruction of the CFC (managed attenuation). Table 3-9 gives details for the two scenarios in respect to the above mentioned factors. For both scenarios, laboratory-determined degradation rates were used together with a value ten times lower representing the fact that degradation in full scale may not be as efficient as in a small scale lab test. Also the effect of having a ten times higher diffusion coefficient than the lab-determined long term diffusion in intact closed cell foam was evaluated, representing a scenario where hammer milling and landfill compacting activities have led to a more open foam structure. In the calculations the model MOCLA-FOAM was used[7]. Based on information on total units disposed of yearly and the total mass of waste being disposed of at US landfills, a more representative ratio was calculated (Table 3.9) for Scenario 1. For Scenario 2, special cells of the landfill might be constructed for the managed attenuation with higher foam volume to waste volume. The following tables are adapted from Wethje, 2005.

---

[7] MOCLA-FOAM (Model for Organic Chemicals in Landfills, Foam) is a model that estimates the distribution and fate of organic chemicals from waste foam in a landfill.

Table 3-9 CHARACTERISTICS OF ODS ATTENUATION SCENARIOS

	Scenario 1	Scenario 2
Time before disposal of foam at landfill	1 week	1 week
Time before onset of microbially active period	6 months	0 months
Instantaneous release due to landfill compaction	15% of content at disposal	5% of content at disposal

Table 3-10 2001: FOAM DISPOSAL AT US LANDFILLS

Foam volume disposed of annually in USA (million liters)[1]	2830
Foam volume disposed of in USA (million m^3) (converted 2830 million liters to 2.83 million m^3; i.e., 1 cubic meter [m^3] contains 1000 liters)	2.83
Mass of MSW disposed of in USA, 2001 (million tons per year[2])	128
Estimated total waste mass disposed of in USA (million tons per year[3])	192
Landfilled volume (million m^3/year[4])	213
Average foam content (m^3 foam/m^3 landfill)	0.013
Number of landfills in USA[2]	1858
Average annual waste volume on one landfill (million m^3)	0.115
Number of units disposed of annually on one landfill	5,400
Foam volume disposed of annually on one landfill (m^3)	1,520

1. Scheutz & Kjelsden (2002)
2. reference US EPA (2001b)
3. non-MSW disposal mass estmimated to be 50% of MSW mass
4. using a wet bulk density of 0.9 tons/m^3

The inventory project did not identify any California specific studies or research pertaining to managed attenuation.

<u>Landfill Gas Combustion</u>

While continued land filling may emerge as a possible option, there is a need for gas profiles at California landfill sites in order to determine whether there are ODS/HFC emission losses. This could be tested by finding 3 or 4 landfills that take C&D waste and doing an evaluation of emissions. California MSW landfills are equipped with landfill gas collection and combustion systems, and there could be an opportunity to test the raw gas and the combustion exhaust gas. Although there are no studies available that show ODS/HFC emissions or reductions for California landfills, several studies conducted in Canada indicate that when using similar types of landfill gas collection and combustion systems as used in California, more than 90 percent of captured CFCs and HCFCs were reduced in the landfill combustion systems (Environment Canada 1999, 2000a, 2000b, 2000c, 2002, 2005).

Co-Incineration

A possible management route is the co-incineration of ODS/HFC-containing foam in cement kilns. However, the chlorine content of ODS-containing foam waste may be considered too high for their facilities. This can result in contamination of the cement products or operational problems in relation to control of atmospheric emissions. Cement kilns prefer a consistent and secure supply of waste materials to avoid any re-incurring costs associated with running trials for burning waste materials. ODS-containing foam waste from demolition activities may not be able to meet this requirement.

Processing through Appliance Recycling Facilities

Based on European experience, the processing of building demolition waste foams via appliances recycling facilities has only really been relevant in case of composite panels containing ODS. European regulations have required the recovery and treatment of appliances foam for some time, and this has led to the presence of an infrastructure that is also potentially available for the recovery and treatment of ODS blown demolition composite panel foams.

In Europe, commercially viable end of life solutions are now available using existing refrigerator recycling plants for the recovery of ODS blowing agents from steel-faced insulated panels manufactured prior to 2004. At present, due to the excellent long-term thermal and structural performance properties of insulated panels, the waste stream levels for pre-2004 products are very low. It is also important to recognize that the majority of these panels are less than 50 mm in thickness with a correspondingly low ODS content. However, in the United Kingdom, the Panel Industry has carried out trials to assess suitable options for ODS disposal (Kingspan, 2006a). This has led to the development of a simple process where panels are easily cut into the right size (2 meters maximum length) and fed into existing refrigerator recycling plants. Trials have successfully been carried out where panels have been processed in this way to meet European regulations. As a result of this procedure any ODS gases are captured, shredded metals are collected for recycling and the foam dust is bagged for further use or landfill. Trials indicated that the destruction cost is under \$8 per m^2, but approximately \$32 – \$45/kg (\$15 - \$20/lb) blowing agent.

There are currently no facilities in California able to process ODS-containing composite panels in this way. Currently, these panels are shredded in conventional shredders, allowing for the removal of metals, with the residue land filled or used as

Alternative Daily Cover. Most of the ODS contained in the insulation core is released to atmosphere. Non-ODS containing panels produced since 2004 are unlikely to be in the waste stream any time soon, but would be treated in the same way.

Non–composite panel foams that contain ODS/HFC (demolition foams) are currently land filled, typically as part of a mixed construction & demolition waste stream. Much of the ODS/HFC contained in the insulation is released to atmosphere during processing at demolition sites and at landfill sites.

While no specific research has been done in California on the processing of rigid demolition PU insulation, the technology for such a process may now be available in the State. JACO Environmental Inc. (an appliance recycler) has built an appliance recycling plant in Hayward, California that could handle composite panel and non-panel foam waste from construction or demolition sites. JACO operates a new degassing system that can process 250 kg of PU foam every 2 hours thereby yielding 25 kg of CFC-11 or approximately 100 metric tons of CO_2 –eq. for each batch. These systems can be built and operated according to the amount of foam available in each area. The cost per installation is approximately $520,000 and requires a small space (465 m^2) with 2 operators per shift. Currently, foam is manually removed from appliances, then put into their recovery unit, where it is milled and crushed in negative atmospheric conditions to extract the ODS using nitrogen as a carrier. The residue from their milling and crushing unit (very fine fluffy powder) is used by carpet producers as a backing product (probably co-mingled with virgin PU). A similar process could be used for composite panels, with the metal recovered for sale and the foam core processed in a similar fashion to appliances foam. Non-panel foams could also be processed, but would be less cost-effective on account of not having the value of metals to help defray the treatment costs.

While the main foam supply for this facility is in the form of appliances, it could also be used to process construction and demolition foam waste, provided a cost effective means for separation at demolition sites and transportation to Hayward are identified.

3.4. Findings & Analysis: Appliances

3.4.1. Section Content

In this Section, Caleb reviews appliances stock data and describes appliance related foam and blowing agent consumption, before identifying blowing agent substitutions for different appliance categories. Caleb also briefly describes not-in-kind alternatives, before reviewing current and alternative end-of-life practices.

3.4.2. Domestic & Commercial Appliances Stock

The project team identified detailed stock data for domestic appliances, commercial appliances, vending machines and water heaters variously from Armines archives and substantiated by interviews. One of the largest appliances groups is domestic refrigerators/freezers, for which the project team could determine disposal and treatment figures for California using Armines data.

Table 3-11 2008 APPLIANCES STOCK ESTIMATES & 2020 APPLIANCES STOCK PROJECTIONS

Appliances Stock	Existing Stock	New Additions	Decommissioned	Revised Stock
2008 Estimates				
Refrigerators/Freezers	22,142,686	2,129,442	973,422	23,298,706
Commercial Appliances	7,802	556	450	7,908
Refrigerated Vending Machines	527,641	38,055	32,779	532,917
Water Heaters	16,138,571	1,062,559	916,794	16,284,336
2020 Projections				
Refrigerators/Freezers	35,892,347	2,966,083	1,925,868	36,932,562
Commercial Appliances	8,208	595	485	8,318
Refrigerated Vending Machines	594,559	42,882	36,936	600,505
Water Heaters	15,883,665	1,096,485	1,178,230	15,801,920

The Commercial Appliances stock data covers equipment located in large ‘shed type’ stores, operated by the likes of Costco and Wal-Mart. Appliances located in other commercial premises (restaurants, hotels, cafés etc.) are contained within the refrigerated vending machine, and to a lesser extent, domestic appliances definitions.

Based on these appliance stock data, Caleb determined the foam content (in m^3) in the existing 2007 stock and projected 2019 stock (In-Appliance Foam). By adding the volume of new foams and subtracting the decommissioned foam, Caleb could estimate a revised volume for the total foam banked in appliances in 2008 and project a revised volume in 2020 (Revised In-Appliance Foam) – as shown in Table 3.12 below.

3.4.3. 2008 Appliances Foam Stocks & Flows

Table 3-12 CALEB 2008 ESTIMATES & 2020 PROJECTIONS OF FOAM VOLUME IN APPLIANCES (m^3)

Appliances Type	In-Appliance Foam	New Foam	Decommissioned Foam	revised in-Appliance Foam
2008 Estimates				
Domestic Refrigerators	7,689,229	946,955	205,441	8,430,743
Domestic Freezers	3,253,289	367,158	108,169	3,512,278
Commercial Refrigeration	546,134	38,917	31,487	553,564
Refrigerated Vending Machines	175,422	16,695	7,215	184,902
Water Heaters	1,203,505	113,199	49,917	1,266,787
Total	***12,867,579***	***1,482,924***	***402,229***	***13,948,274***
2020 Projections				
Domestic Refrigerators	15,935,335	1,319,006	830,564	16,423,777
Domestic Freezers	6,164,247	511,411	307,757	6,367,902
Commercial Refrigeration	574,537	41,660	33,970	582,227
Refrigerated Vending Machines	260,208	18,812	15,581	263,439
Water Heaters	1,710,156	121,543	109,529	1,722,170
Total	***24,644,483***	***2,012,433***	***1,297,400***	***25,359,515***

3.4.3.1. Domestic Refrigerators & Freezers

Refrigerators are insulated with unclassified polyurethane rigid foam whose density is 2 lb/ft^3 (30kg/m^3), by injecting the liquid reactants between the inner and the outer casing of the refrigerator cabinet and doors. By 2003, most producers of residential refrigerators and freezers had switched polyurethane foam blowing agent from HCFC-141b to mostly HFC-245fa.

3.4.3.2. Commercial Refrigerators

Commercial refrigerators are comprised of display cases (DC) and stand-alone equipment (SA) include low temperature single-deck, low temperature multi-deck, low and medium temperature glass door, medium temperature single-deck, medium temperature multi-deck, service cases, and specialty cases.

This market increased at 5-7%/year during the 1990s, boosted by continued proliferation of large grocery stores such as Wal-Mart, Costco, and Super Kmart. Display refrigerators and freezers for supermarkets are usually 8 ft. high, 40-45 inches deep and 10 ft. long, and are equipped with four doors. They have built-in cooling systems to maintain a temperature of 40-42°F or down to -10°F for frozen food and -20°F for ice cream. Reach-in units are typically 8-12 ft. long, 3-3 1/2 ft. wide and 3 ft. deep and cooled by a remote system.

Hussmann, a dominant producer of commercial refrigerators in the US, makes them from metal panels produced from galvanized steel with polyurethane core. The panels are 1 1/5 inches thick, 1-4 ft. wide and 2-12 ft. long and are pre-engineered to be assembled into the finished products.

3.4.3.3. Ice Makers/Vending Machines

The installed base of all vending machines was 13 million for the US (2004) among them 1.47 million were estimated to be in California - based on NAMA (National Automated Merchandising Association) data. The refrigerated vending machines are estimated to be 30% of this number, therefore 470,000 units.

Caleb's other research with the industry in California leads to an estimate that is broadly similar (500,000 refrigerated vending machines). There are two types of vending machines - a) glass door, and b) closed door, but Caleb could not find any data on the respective shares.

3.4.3.4. Water Heaters

In 2008 approximately 1.3 million water heaters were produced for use in California (AHRI/Skeist) based on US data per-capita adjusted and scaled for 3% growth from 2003. Half of these were gas and half electric. Less than 1.5% (21,000) were commercial water heaters.

The heaters are insulated, mostly with unclassified polyurethane foam, about 8 lbs. (3.64 kg) per electric heater and 5.5 lbs (2.5 kg) per gas heater, which uses some fiberglass around the combustion chamber. The foam is applied by frothing and its density is about 30-35 kg/m^3. The blowing agents used are mostly low-GWP pentane isomers.

3.4.4. Blowing Agent Use & Substitutions

Polyurethane foam insulation has been used in refrigerator-freezer applications for more than 30 years. The process of applying the polyurethane foam requires the use of a low thermal conductivity blowing agent to facilitate the flow and expansion of the chemicals as they are injected into the refrigerator-freezer casing. For many years, the almost universal blowing agent used in refrigerator-freezer applications was CFC-11. Because CFCs were linked to stratospheric ozone depletion, the decision to replace them in all products worldwide was made under the Montreal Protocol in the late 1980s. The phase-out of ozone depleting substances (ODS) in the USA was assisted by the Significant New Alternatives Program (SNAP) initiative. SNAP approves chemicals that can be used to replace ODS.

During 1994, most manufacturers of refrigerator-freezers in the U.S. converted to foams using HCFC-141b as the blowing agent. Although HCFCs are an ODS, their ozone depleting potential is significantly less than CFCs, so they were identified as the best transition blowing agent on a path leading to the total phase-out of all ozone depleting substances with emphasis on improved energy efficiency. These HCFC conversions were considered interim solutions until energy-efficient zero ODS options could be developed and implemented. Additionally, the HCFC substitutes were still potent greenhouse gases, although less so than CFC-11. More recently, HFCs have been used as the foam blowing agent in appliance insulation. Although HFCs are not ozone-depleting, they are still high-global warming potential greenhouse gases. For example, HCFC-141b with a GWP of 700 was replaced by HFC-245fa with an even higher GWP of 950. The current trend is that hydrocarbons (HCs) are beginning to replace HFCs. Hydrocarbons are not ozone-depleting, and typically have low GWPs of 25 or less, which results in a 97% reduction in the GHG impact from appliance insulation. The tables below show Caleb’s estimation of the substitution timetable.

Table 3-13 DOMESTIC REFRIGERATOR/FREEZER BLOWING AGENT SUBSTITUTIONS

Sales Year	Disposal Year	Percent of Units Disposed Annually by Blowing Agent			
		HFC-134a	HCFC-141b	HFC-245fa	HC
1996	2010	2%	98%	0%	0%
1997	2011	3%	97%	0%	0%
1998	2012	4%	96%	0%	0%
1999	2013	5%	95%	0%	0%
2000	2014	6%	94%	0%	0%
2001	2015	7%	75%	18%	0%
2002	2016	4%	45%	47%	4%
2003	2017	0%	21%	70%	9%
2004	2018	0%	0%	87%	13%
2005	2019	0%	0%	83%	17%
2006	2020	0%	0%	82%	18%
2007	2021	0%	0%	82%	18%
2008	2022	0%	0%	81%	19%
2009	2023	0%	0%	80%	20%
2010	2024	0%	0%	79%	21%
2011	2025	0%	0%	79%	21%
2012	2026	0%	0%	78%	22%
2013	2027	0%	0%	77%	23%
2014	2028	0%	0%	76%	24%
2015	2029	0%	0%	76%	24%
2016	2030	0%	0%	75%	25%

Source: Association of Home Appliance Manufacturers, (AHAM), 2010.

Table 3-14 COMMERCIAL APPLIANCES BLOWING AGENT SUBSTITUTIONS

COMMERCIAL APPLIANCES: - B.A. SUBSTITUTIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0%	0%	0.00%
1993	**75%**	**25%**	0%	0.00%
1994	**50%**	**50%**	0%	0.00%
1995	0%	**100%**	0%	0.00%
1996	0%	**100%**	0%	0.00%
1997	0%	**100%**	0%	0.00%
1998	0%	**100%**	0%	0.00%
1999	0%	**100%**	0%	0.00%
2000	0%	**95%**	**5%**	0.00%
2001	0%	**80%**	**20%**	0.00%
2002	0%	**70%**	**30%**	0.00%
2003	0%	**30%**	**70%**	0.00%
2004	0%	**15%**	**85%**	0.00%
2005	0%	0%	**100%**	0.00%
2006	0%	0%	**100%**	0.00%
2007	0%	0%	**100%**	0.00%
2008	0%	0%	**100%**	0.00%
2009	0%	0%	**100%**	0.00%
2010	0%	0%	**100%**	0.00%
2011	0%	0%	**100%**	0.00%
2012	0%	0%	**100%**	0.00%
2013	0%	0%	**100%**	0.00%
2014	0%	0%	**100%**	0.00%
2015	0%	0%	**100%**	0.00%
2016	0%	0%	**100%**	0.00%
2017	0%	0%	**100%**	0.00%
2018	0%	0%	**100%**	0.00%
2019	0%	0%	**100%**	0.00%
2020	0%	0%	**100%**	0.00%

Table 3-15 VENDING MACHINE BLOWING AGENT SUBSTITUTIONS

VENDING MACHINES: - B.A. SUBSTITUTIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0%	0%	0%
1993	**75%**	**25%**	0%	0%
1994	**50%**	**50%**	0%	0%
1995	0%	**100%**	0%	0%
1996	0%	**100%**	0%	0%
1997	0%	**100%**	0%	0%
1998	0%	**100%**	0%	0%
1999	0%	**100%**	0%	0%
2000	0%	**95%**	**5%**	0%
2001	0%	**80%**	**20%**	0%
2002	0%	**70%**	**30%**	0%
2003	0%	**30%**	**70%**	0%
2004	0%	**15%**	**85%**	0%
2005	0%	0%	**100%**	0%
2006	0%	0%	**100%**	0%
2007	0%	0%	**100%**	0%
2008	0%	0%	**100%**	0%
2009	0%	0%	**100%**	0%
2010	0%	0%	**100%**	0%
2011	0%	0%	**100%**	0%
2012	0%	0%	**100%**	0%
2013	0%	0%	**100%**	0%
2014	0%	0%	**100%**	0%
2015	0%	0%	**100%**	0%
2016	0%	0%	**100%**	0%
2017	0%	0%	**100%**	0%
2018	0%	0%	**100%**	0%
2019	0%	0%	**100%**	0%
2020	0%	0%	**100%**	0%

Table 3-16 WATER HEATER BLOWING AGENT SUBSTITUTIONS

WATER HEATERS: - SUMMARY OF B.A. SUBSTITUIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0%	0%	0%
1993	**75%**	**25%**	0%	0%
1994	**50%**	**50%**	0%	0%
1995	0%	**100%**	0%	0%
1996	0%	**100%**	0%	0%
1997	0%	**100%**	0%	0%
1998	0%	**100%**	0%	0%
1999	0%	**100%**	0%	0%
2000	0%	**95%**	0%	**5%**
2001	0%	**80%**	**5%**	**15%**
2002	0%	**70%**	**5%**	**25%**
2003	0%	**30%**	**10%**	**60%**
2004	0%	**15%**	**10%**	**75%**
2005	0%	0%	**10%**	**90%**
2006	0%	0%	**10%**	**90%**
2007	0%	0%	**10%**	**90%**
2008	0%	0%	**10%**	**90%**
2009	0%	0%	**10%**	**90%**
2010	0%	0%	**10%**	**90%**
2011	0%	0%	**10%**	**90%**
2012	0%	0%	**10%**	**90%**
2013	0%	0%	**10%**	**90%**
2014	0%	0%	**10%**	**90%**
2015	0%	0%	**10%**	**90%**
2016	0%	0%	**10%**	**90%**
2017	0%	0%	**10%**	**90%**
2018	0%	0%	**10%**	**90%**
2019	0%	0%	**10%**	**90%**
2020	0%	0%	**10%**	**90%**

3.4.5. Not-In-Kind (NIK) Alternatives

The SNAP list includes fluorocarbon, hydrocarbon, and several not-in-kind technologies. Most of the US appliance industry has adopted fluorocarbon (HFC) replacements for CFCs.

In Appliances - because of the challenging insulation and structural characteristics required for refrigerator and freezer insulation, no proven not-in-kind technologies are available at present that can meet all the requirements. Vacuum insulation panels have been used (as a supplement to the insulating foam) in limited quantities and are increasingly being used in critical locations in cabinets in Japan. However, high costs continue to limit their use.

3.4.6. End-of-Life Fate – Appliances Foam & Blowing Agents

3.4.6.1. Current recovery & recycling practices for domestic refrigerators & freezers

Over 1 million refrigerators and freezers reach their end-of-life in California every year. Waste foams from these appliances are concentrated at the point of appliance recycling locations. In the U.S., Section 608 of the Clean Air Act does not allow any refrigerant to be vented into the atmosphere during installation, service, or retirement of equipment (e.g., appliances). Therefore, when an appliance is disposed of or repaired, all of the refrigerant must be recovered and recycled (for reuse in the same system), reclaimed (reprocessed to the same purity levels as new), or destroyed. There are no regulations about the recovery of blowing agent from foam.

Appliance recycling has essentially been near-mandatory in California since 1991 for appliances that have reached end-of-life. In 1991, the California Legislature passed Assembly Bill (AB) 1760 which regulated metallic discards. AB 1760 was codified in Sections 42160-42185 of the Public Resources Code, which states in Section 42170 “no solid waste facility shall accept for disposal any major appliance, vehicle, or other metallic discard which contains enough metal to be economically feasible to salvage as determined by the solid waste facility operator” (CIWMB, 1993).

The result of AB 1760 is that discarding used appliances in California landfills plummeted quickly, because almost all appliances have enough metal to make them economically feasible to recycle. AB 1760 also mandated that toxic or environmentally harmful materials had to be removed from the appliance prior to scrap metal processing, and that these materials, which are called “materials that require special handling”, or MRSH, must be managed properly as hazardous waste or special waste. MRSH identified in AB 1760 pertinent to appliances included chlorofluorocarbons (refrigerants only, not those contained in insulating foam), ammonia and sulfur dioxide refrigerants, compressor oil, polychlorinated biphenyls (PCBs), mercury, and lead (CIWMB, 1994).

During the 1990s through 2005, appliance recycling regulations in California continued to evolve, and since 2006, appliance recycling programs and regulations have been overseen by the California Department of Toxic Substances Control (DTSC) Certified Appliance Recycling (CAR) program. All the major appliances are covered by the CAR program. Appliances have to be discarded by a certified appliance recycler who removes toxic materials (materials that require special handling) from the appliance before the appliance is put through a typical metal-shredding recycling process. The materials that require special handling now include all refrigerants (including non-ODS hydrofluorocarbons), and still include mercury, compressor oil, and PCBs, but there is still no requirement to remove the foam from these appliances prior to recycling (DTSC, 2007). The metal shredders process the appliances and recover the metal from it before land filling the residual materials (commonly referred to as “shredder fluff” or “shredder waste”), which includes foam (DTSC, 2002).

Most waste foam is land filled, with the exception of the foam recovered from appliances recycled under the US EPA’s voluntary Responsible Appliance Disposal (RAD) program, which includes utilities, municipalities, retailers, manufacturers, and other interested parties. The goal of RAD is to promote best practices for appliance recycling, which includes refrigerant recovery and foam recovery and destruction (US EPA, 2010).

Domestic Appliance disposal at End-of-Life

The table below shows the best estimate for 2008 in terms of units discarded – for reuse, for recycling with foam recovery and for recycling without foam recovery - typically via shredder facilities, with residues brought to Landfill.

Table 3-17 2008 - FATE OF DOMESTIC REFRIGERATORS & FREEZERS AT END-OF LIFE

Year	Stock	Discarded	2nd life	Recycled - foam recovery	Recycled - no foam recovery; residue Disposed
2008	23,398,708	1,020,601	398,034	145,000	477,567
		100.00%	**39.00%**	**14.00%**	**47.00%**

Project data indicates that the re-use rate is approximately 39%, which is consistent with CARB and US EPA estimates. Project data furthermore indicates that the recycled share through utility programs is approximately 13%, which is consistent with analysis prepared by CARB[8] based on an article published by S. Westberg as shown in Table 3-18 below.

---

[8] CARB interpretation of findings: How Electric Customers Dispose of Used Refrigerators and Why They Choose a Utility Program; S. Westberg, et al.; 2007 Energy Program Evaluation Conference, Chicago; (also see for paper http://www.cee1.org/eval/db_pdf/652.pdf) – (last accessed 7/16/10)

Table 3-18 REFRIGERATOR DISPOSAL PATHWAYS

Used Refrigerator Disposal Path	Percent of total	Portion re-used (not recycled) of specific path	Re-Used and Not Scrapped % of total disposal (Percent of total * Portion re-used)	Recycled % of specific disposal path	Portion recycled (of total disposed)
Dealer receives old appliance (5% are re-used)	25%	5%	1%	95%	24%
Given away (presumed to be re-used)	24%	100%	24%	0%	0%
Taken to recycle	22%	0%	0%	100%	22%
CPUC or utility-sponsored Residential Appliance Recycling Program (RARP)	12%	0%	0%	100%	12%
Sold (presumed to be re-used)	11%	100%	11%	0%	0%
Unknown (half re-used)	6%	50%	3%	50%	3%
Totals	**100%**		**39%**		**61%**

Domestic Appliance Recycling with Foam Recovery

California has two appliance recycling facilities operated by JACO Environmental, and two facilities operated by Appliance Recycling Centers of America (ARCA). They handle about 145,000 to 150 000 units per year, with the vast majority of units recycled as part of a state-wide electric utility incentive program to remove older working appliances (that are energy efficient) from the electricity grid. JACO and ARCA handle 80,000 units for Southern California Edison, 40,000 units for Pacific Gas & Electric (PG&E) and a further 25,000 units for Sacramento Municipal Utility District (SMUD). Therefore about 12- 13% of residential refrigerator-freezers reaching end-of-life in California is recycled using a comprehensive foam blowing agent recovery process.

The processing of that number of units equates to preventing the emission of between 67 – 70 ODP-weighted tons of CFC-11 blowing agent to the atmosphere, equivalent in GHG terms to preventing emissions of 250,000 to 265,000 metric tons of CO_2-eq. The cost of recovery per ODS ton varies greatly, depending on the type of operation. Currently, neither method is self-sustaining in California and requires sponsorship.

It is assumed that only 5 to 10% of the blowing agent is lost in this operation. Where ‘closed system’ automated recycling facilities are used to process appliances, the collected gases from waste foam are condensed and sent to a permitted facility where they are destroyed through high-temperature incineration. Where foam is removed from appliance carcasses in a manual process, the waste foam is bagged and destroyed in MSW incinerators.

JACO processes 2000 refrigerator-freezers/week at the Fullerton Plant in a manual process that assumes 5% ODS losses. At Fullerton, foam is stripped, bagged and then goes to a waste to energy plant where it is handled/processed in a negative atmosphere environment. JACO has 17 facilities altogether. Hayward is in an 85,000 sq ft facility and Fullerton is a 55,000 sq ft facility; other facilities are a lot smaller - typically around 20,000 sq ft. JACO has started a new foam recycling operation in Hayward (late 2009) which crushes the foam and extracts/captures the foam blowing agents in a negative atmosphere chamber. The aim is to stop sending foam in bags to waste to waste-to-energy plants, and to process the foam in-house. The facility covers the Bay Area, and could be in the market for C&D foam. The system at Hayward handles 550 lb (250 kg) of foam every two hours and should be able to handle construction and demolition foam, provided it was brought to them.

ARCA uses an automated process that crushes the foam and captures the gas at between 95 - 98% efficiency using SEG equipment (automated appliance-recycling equipment).

3.4.6.2. Current disposal practices for other Appliances

Other appliances, such as water heaters, commercial refrigeration equipment and vending machines are typically decommissioned before being channeled for disposal via shredders for metals recovery, with residue waste going to land fill.

3.4.6.3. Estimated Appliance Foam Disposal Routes - 2009

Domestic Refrigerators/Freezers

Commercial Appliances

100% processed via shredder; Degassed; Metals recovered; Residue including Foam land filled

Vending Machines

100% processed via shredder; Degassed; Metals recovered; Residue including Foam land filled

Water Heaters

100% processed via shredder; Metals recovered; Residue including Foam land filled

3.4.7. Further options for appliances recovery & recycling

To increase the volume of recovered foam blowing agents, there needs to be more of an incentive. In certain circumstances the carbon market might be a way forward. Carbon at $8.50/ton CO_2-eq. could work, with each appliance containing 5 tons of CO_2-eq, if the blowing agent used was CFC[9]. This generates a credit of $42.50 which, when combined with the utility subsidies, may help stimulate a higher volume of throughput at existing plants.

Most of the CFC-containing appliances have however already been processed or discarded. The credit is likely to be for around 0.5 tons of CO_2-eq for reclaiming HCFC or HFC blowing agents – therefore not enough to offset the cost of recovery.

---

[9] Interview with Michael Dunham, JACO Environmental Inc. – September 2009

3.5. Findings & Analysis: Transport Refrigerated Units (TRUs)

3.5.1. Estimated TRU Population

Total in-use TRU units in California during 2003 to 2009 have ranged from 30,000 to 38,000 units in operation at any given time, depending on the fate of the state economy. The average TRU life-cycle is 15 years and there has been a steady build-up of units over the years. Previous estimates identified a stock of 27,087 TRU units in California, of which 90% are truck based units (Martin Labbe LLB, 2005). Separately from this stock, there may be a build-up of ‘parked’ TRUs – apparently held at the major ports (San Diego, Long Beach, Los Angeles, Oakland) for disposal in California (CARB, 2009). This could not be substantiated by Caleb, and is therefore not included in our analysis.

Table 3-19 2008 TRU/REEFER POPULATION

TRU Type	2007 Stock	New Stock	Decomissioned Stock	2008 Stock
Road/Trailer	32,056	4,362	3,206	33,212
Rail	2,167	303	217	2,253
Sea/Reefer	1,189	150	119	1,220
Total	**35,412**	**4,815**	**3,542**	**36,685**

3.5.2. 2008 TRU Stocks & Flows

Rigid foam is used in refrigerated vans (trailers and trucks), rail refrigerated units, and ship reefers for the transportation of perishable staples such as meat, vegetables, ice cream, etc., and also for repair and maintenance of these units. During the mid-1990s, the market increased at an average rate of 19%/year owing to increased production of refrigerated vans following the great economic expansion of the 1990s.

Based on TRU stock data, Caleb determined the foam content (in m^3) in the existing 2007 stock (Foam in TRUs). By adding the volume of new foams and subtracting the decommissioned foam, Caleb could estimate a revised volume for the total foam banked in Transport Refrigerated Units in 2008 (Revised Foam in TRUs).

Table 3-20 2008 - CALEB ESTIMATES OF FOAM VOLUME IN TRUs (M^3)

TRU Type	Foam in TRUs	New Foam	Decomissioned Foam	Revised Foam in TRUs
Road/Trailer	297,956	27,262	14,164	311,054
Rail	24,329	2,271	1,256	25,344
Sea/Reefers	8,061	675	433	8,303
Total	**330,346**	**30,208**	**15,853**	**344,701**

3.5.3. Blowing Agent Substitution

The table below shows Caleb's assessment of TRU/Reefer blowing agent substitutions over time and forms an important input to the banks and emissions model which will be described later.

Table 3-21 TRU/REEFER BLOWING AGENT SUBSTITUTIONS

	TRU/REEFER: - B.A. SUBSTITUTIONS			
YEAR	**CFC 11**	**HCFC 141b**	**HFC 245fa**	**HC**
1992	**100%**	0.00%	0.00%	0.00%
1993	**100%**	0.00%	0.00%	0.00%
1994	**80%**	**20.00%**	0.00%	0.00%
1995	**60%**	**40.00%**	0.00%	0.00%
1996	0%	**100.00%**	0.00%	0.00%
1997	0%	**100.00%**	0.00%	0.00%
1998	0%	**100.00%**	0.00%	0.00%
1999	0%	**100.00%**	0.00%	0.00%
2000	0%	**100.00%**	0.00%	0.00%
2001	0%	**80.00%**	**20.00%**	0.00%
2002	0%	**40.00%**	**60.00%**	0.00%
2003	0%	0.00%	**80.00%**	**20.00%**
2004	0%	0.00%	**80.00%**	**20.00%**
2005	0%	0.00%	**80.00%**	**20.00%**
2006	0%	0.00%	**80.00%**	**20.00%**
2007	0%	0.00%	**70.00%**	**30.00%**
2008	0%	0.00%	**60.00%**	**40.00%**
2009	0%	0.00%	**50.00%**	**50.00%**
2010	0%	0.00%	**40.00%**	**60.00%**

3.5.4. End-of-Life Fate for TRU Foams and Blowing Agents

3.5.4.1. Current Recovery & Recycling Practices

There is some uncertainty about the quantity of reefers that reach their end-of-life in California. Approximately 25% experience a 'second life' at the point of disposal, and we assume a 'first life' lifespan of around 15 years. According to respondents from the scrap metal recycling sector, virtually all transport refrigerated units that reach end of life are recycled in scrap metal yards. They are treated similarly to vehicles, where in accordance with US Clean Air Act Regulation Sections 608 and 609, all refrigerant must be recovered prior to recycling by Certified Technicians. As enforcement is sometimes difficult, it is uncertain how much refrigerant is recovered and how much is vented to the atmosphere.

However, it is not mandatory to recover the blowing agent from the insulating foam from TRUs. It is shredded along with the rest of the unit. The metal and mercury from switches are recovered, and the remaining insulation is aggregated with other non-ferrous wastes and land filled as Assorted Shredded Residues (ASR).

3.5.4.2. Estimated TRU/Reefer Foam Disposal Route – 2009

TRU/Reefers

25% Second Life, some of which are exported	75% Shredded; metals recovered; residue, including. foam land filled

3.6. Findings & Analysis: Marine & Other Applications

3.6.1. Section Content

In this Section, Caleb reviews stock data for marine (leisure boats, canoes, buoys) and other applications (cool boxes, walk-in cold stores) and describes foam stocks and flows for 2007 and 2008 before identifying blowing agent substitutions for these applications. Caleb also briefly describes not-in-kind alternatives, before reviewing current and alternative end-of-life practices.

3.6.2. Marine & Other Application Population/Stock Data

After buildings, appliances and TRUs, the main other applications for foams are in the leisure marine sectors, including leisure boats, canoes and buoyancy aids. The project team also reviewed the relevance of surf boards and wind surfers, since both product types have been constructed around a Polyurethane (PU) foam core since the 1960s. The team concluded that these types of products can be discounted because they are relatively short-lived applications (typically 1 to 3 years for surf boards and under 15 years for wind surfers), thus not presenting a ODS bank. Over 77% of surf boards and wind surf boards are produced within the USA (mainly Southern California) and since the late 1980's board blanks have been water blown[10]. Approximately 23% of boards used in California are imports from Asia and from Central/South America and these too are water blown.

Other short-lived applications include cooler boxes. These are sold in large numbers and may have an average life cycle of 10 years, but have also been made with water blown foam since the 1980s.

In order to determine blowing agent and ODS/HFC content in existing hulls, we need to concentrate on the Fiberglass Reinforced Plastics/Glass Reinforced Plastics (FRP/GRP) hull type, which typically has a structural foam core that contains PU or Polystyrene foam. Other hull types do not contain foam cores and are therefore excluded from our analysis. The table below shows stock or registration data for the leisure boat, canoe, and cooler boxes and buoy sub-sectors.

---

[10] Resurf Recycling, www.resurf.org Joey Santley

Table 3-22 SUMMARY OF MARINE REGISTRATION & OTHER APPLICATION STOCKS

Estimated Product Stock	Existing Stock	New Additions	Decommissioned	Revised Stock
Leisure Boats	635,057	48,471	35,930	647,599
Canoes	207,446	15,899	11,374	211,971
Other -incl. Cooler boxes;buoys	10,944,373	836,179	618,565	11,161,986
Total	**11,786,876**	**900,549**	**665,869**	**12,021,556**

The project team identified detailed stock data for non-structural walk in cold stores from Armines archives and substantiated by interviews.

Table 3-23 2008 NON STRUCTURAL COLD STORE STOCK

Estimated Product Stock	Existing Stock	New Additions	Decommissioned	Revised Stock
Walk-In Cold Stores	11,048	700	485	11,262

3.6.3. 2008 Marine & Other Application Foam Stocks & Flows

Marine applications – recreational boats, buoys, and marine repair and retrofitting account for 54% of foam use, with coolers estimated to account for the balance. Foam charge volumes for boats range from 4kg/unit (canoes) to 25kg/unit (inboard boats). Charge volume for buoys range from as low as 0.45kg/unit to 180kg/unit. Charge volumes for coolers average at 2kg/unit. Blowing Agents used for these applications are HCFC-141b for boats and coolers to a broader range (HFC-245fa; H_2O/CO_2) for buoys as well as methyl formate, a low-GWP alternative.

Buoyancy aids, picnic coolers, and thermoses have been grouped together in our stock calculations on the basis of foam usage data from Skeist 2003. The average foam charge per unit is estimated at 2 kg. We have estimated a stock turnover of 2%/year for leisure boats, 5%/year for canoes, and 10%/year for buoyancy aids and coolers.

Table 3-24: 2008 - CALEB ESTIMATES OF FOAM VOLUME IN MARINE & OTHER APPLICATIONS (M^3)

Appliance Type	Foam in Equipment	New Foam	Decommissioned Foam	Revised Foam in Equipment
Leisure Boats	444,654	34,622	25,664	453,612
Canoes	23,191	1,817	1,300	23,708
Other - incl. Cooler boxes; buoys	612,958	47,782	35,347	625,393

The estimated foam content and changes therein for Walk-in Cold Stores are shown separately in the table below.

Table 3-25: 2008 - CALEB ESTIMATES OF FOAM VOLUME IN NON STRUCTURAL COLD STORES (M^3)

Product Type	Foam in Equipment	New Foam	Decommissioned Foam	Revised Foam in Equipment
Walk-In Cold Stores	105,628	6,996	4,955	107,669

3.6.4. Marine & Other Application Blowing Agent Substitutions

The following tables show the blowing agent substitution history for the Marine & Other applications.

Table 3-26 : MARINE & OTHER BLOWING AGENT SUBSTITUTIONS

MARINE & OTHER: - SUMMARY OF B.A. SUBSTITUTIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0.00%	0.00%	0.00%
1993	**100%**	0.00%	0.00%	0.00%
1994	**80%**	**20.00%**	0.00%	0.00%
1995	**60%**	**40.00%**	0.00%	0.00%
1996	0%	**100.00%**	0.00%	0.00%
1997	0%	**100.00%**	0.00%	0.00%
1998	0%	**100.00%**	0.00%	0.00%
1999	0%	**100.00%**	0.00%	0.00%
2000	0%	**100.00%**	0.00%	0.00%
2001	0%	**80.00%**	**20.00%**	0.00%
2002	0%	**40.00%**	**60.00%**	0.00%
2003	0%	0.00%	**80.00%**	**20.00%**
2004	0%	0.00%	**80.00%**	**20.00%**
2005	0%	0.00%	**80.00%**	**20.00%**
2006	0%	0.00%	**80.00%**	**20.00%**
2007	0%	0.00%	**70.00%**	**30.00%**
2008	0%	0.00%	**60.00%**	**40.00%**
2009	0%	0.00%	**50.00%**	**50.00%**
2010	0%	0.00%	**40.00%**	**60.00%**

Table 3-27 : NON STRUCTURAL COLD STORE BLOWING AGENT SUBSTITUTIONS

COLD STORES: - SUMMARY OF B.A. SUBSTITUIONS

YEAR	CFC 11	HCFC 141b	HFC 245fa	HC
1992	**100%**	0%	0%	0%
1993	**100%**	0%	0%	0%
1994	**80%**	**20%**	0%	0%
1995	**60%**	**40%**	0%	0%
1996	0%	**100%**	0%	0%
1997	0%	**100%**	0%	0%
1998	0%	**100%**	0%	0%
1999	0%	**100%**	0%	0%
2000	0%	**100%**	0%	0%
2001	0%	**80%**	**20%**	0%
2002	0%	**40%**	**60%**	0%
2003	0%	0%	**80%**	**20%**
2004	0%	0%	**80%**	**20%**
2005	0%	0%	**80%**	**20%**
2006	0%	0%	**80%**	**20%**
2007	0%	0%	**70%**	**30%**
2008	0%	0%	**60%**	**40%**
2009	0%	0%	**50%**	**50%**
2010	0%	0%	**40%**	**60%**

3.6.5. End of Life Fate – Marine & Other Foams & Blowing Agents

3.6.5.1. Current recovery & disposal practices

Hulls could have an average 25-30 year life cycle and the estimated/anticipated hull retirement rate is 2.0% per year (NMMA, 2006).There are no specific programs to recover and recycle hulls in California and the retired boats tend to end up at landfill sites following mechanical destruction in auto shredders.

Following the break-up of leisure boats in auto shredders or scrap metal yards, the non-reusable materials, including hull pieces containing PU foam, are land filled. If the unit has been processed through a shredder, then insulation is aggregated with other non-ferrous waste and land filled as assorted shredder residues – similarly to TRUs.

Caleb assumes that 5% of canoes are discarded per year as proportion of the stock and that 10% of coolers are assumed to be discarded every year. Caleb also assumes that 5% of leisure boats are exported.

3.6.5.2. Estimated Marine & Other Application Disposal Routes – 2009

Leisure/Recreational Boats

5% exported	95% shredded and residue including foam land filled

Canoes

100% shredded and residue including foam land filled

Buoys/Coolers

100% land filled; possibility of larger buoys being shredded first

Non-Structural Cold Stores

100% land filled; possibility of larger units being shredded first

3.7. ODS/HFC Banks & Emission Model Data Inputs

3.7.1. Modeling Assumptions

The table below summarizes the modeling assumptions Caleb has applied and identifies which source has been used, or on what basis the assumptions are made.

Table 3-28 : KEY MODEL INPUT ASSUMPTIONS

Factor	Units	Buildings	Appliances	TRUs	Marine & Other	Comments
Growth Rate - market	%	1.5 - 5	0.95 - 7.2	0.95 - 5.5	1.5 - 5	Source: Published Rates & Caleb
Growth Rate - Building Insulation	%	0.5	N/A	N/A	N/A	Source: Caleb
Growth Rate - Building Foams	%	1-2	N/A	N/A	N/A	Source: Caleb
Buildings Demolition Rate	%	1-2	N/A	N/A	N/A	1% = Residential; 2% = Commercial; Source: Interviewees
Buildings Refurbishment Rate	%	1-2	N/A	N/A	N/A	1% = Residential; 2% = Commercial; Source: Interviewees
Average foam life time	Years	30	14-15	15	10-30	Sources: CEC & Forintek Corp. (Buildings); Armines & ICF International (Appliances); CARB-ISOR (TRUs); NMMA (Marine)
Average re-use Rate	%	N/A	25	25	N/A	Sources: Armines (Appliances); CARB-ISOR (TRU)
Foam Density	kg/m^3	32-40	30-32	40	30-35	Source: Caleb
Blowing Agent content	%	5-10	7	10	7-10	Source: Caleb
End-of-Life practices						
Export	%	0	25	25	5	Source: Caleb
Re-use	%	0	25	25	0	Sources: Armines (Appliances); CARB-ISOR (TRU)
Direct Landfill	%	92	0	0	0	Source: Interviewees
Open Shredding, then Landfill	%	8	60	75	95	Source: Interviewees
Direct Destruction	%	0	15	0	0	Source: Interviewees

3.7.2. Greenhouse Gas Global Warming Potentials

In order to achieve consistency with other ARB greenhouse gas inventory and reduction analyses, the global warming potentials (GWP) used for HFCs are from the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR), 1995. (AB 32 greenhouse gas emission baselines and reduction goals were calculated using GWPs from SAR, therefore, this analysis uses SAR GWPs as a “common denominator”). Where GWPs were not available in the SAR, the value from the IPCC Third Assessment Report from 2001 are used.

Note that in most cases for foam blowing agents, additional scientific research since 1995 has revised the GWP upwards. Ozone-depleting substances (ODS) were not included in the 1990 baseline greenhouse gas emissions for AB 32, and ODS reductions are not counted towards the overall AB 32 reductions goals. However, ODS reductions do count towards ODS destruction credits as determined by the Climate Action Reserve ODS destruction credit protocol, and potentially other future destruction protocols. Therefore, to give proper credit to current or future ODS destruction credits, current GWP values are used for ODS. To be consistent with ODS destruction protocols, the most recent GWP values (October 2009) for ODS will be used, which are based on values used in the United Nations Environment Programme (UNEP) Technology and Assessment Panel (TEAP) Task Force Decision XX/7 – Phase 2 Report “Environmentally Sound Management of Banks of Ozone-Depleting Substances” (TEAP, 2009).

Table 3-29 below shows, for each foam blowing agent, the GWP values from the SAR report in 1995, the TAR report in 2001; and the 2009 UNEP TEAP Decision XX/7 Report. The column on the far right indicates the increase or decrease in GWP values between 1995 and 2009. Note that GWP values increased between 2% - 32% for seven of nine blowing agents, HFC-152a decreased 13%, and hydrocarbons remained the same.

Table 3-29 : GLOBAL WARMING POTENTIAL VALUES PER BLOWING AGENT[11]

Blowing Agent	GWP SAR (1995)	GWP TAR (2001)	TEAP XX/7 (2009)	Percent Change from 1995 to 2009
CFC-11	3800	4600	4680	23%
CFC-12	8100	10600	10720	32%
HCFC-141b	n/a	700	713	2%
HCFC-142b	1800	2400	2270	26%
HCFC-22	1500	1700	1780	19%
HFC-134a	1300	1300	1410	8%
HFC-152a	140	120	122	-13%
HFC-245fa	n/a	950	1020	7%
Hydrocarbons	n/a	n/a	25	--

---

[11] GWP values used in analyses are from the IPCC Second Assessment Report (1995) or the IPCC Third Assessment Report (2001) as noted above. The most recently available GWPs (October 2009) are from Caleb Group, based on TEAP XX/7 Task Force, 2009.

3.8. ODS/HFC Banks & Emission Model Outputs

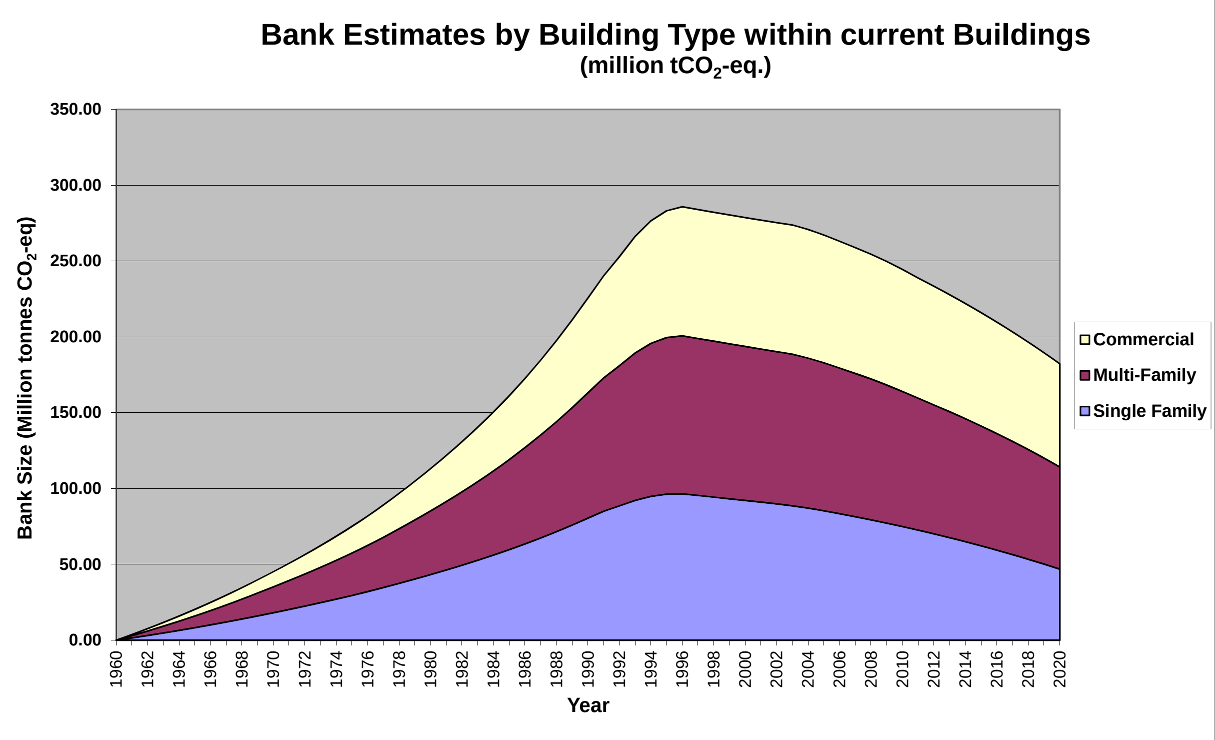
3.8.1. Buildings related Banks & Emissions

3.8.1.1. High GWP Greenhouse Gas Banks in Buildings

As CFCs have been used in insulation foams since their introduction in the 1960s and product lifecycles are generally in the order of 30 years on average, banks of high-GWP gases have accumulated significantly in buildings, reaching a peak of approximately 286 million tCO_2-eq in 1996. Since then, they have reduced by around 40 million tCO_2-eq to date and are expected to reduce by a further 60 million tCO_2-eq by 2020, as products containing high-GWP gases are partially replaced by those blown with low GWP alternatives in the typical building replacement cycle.

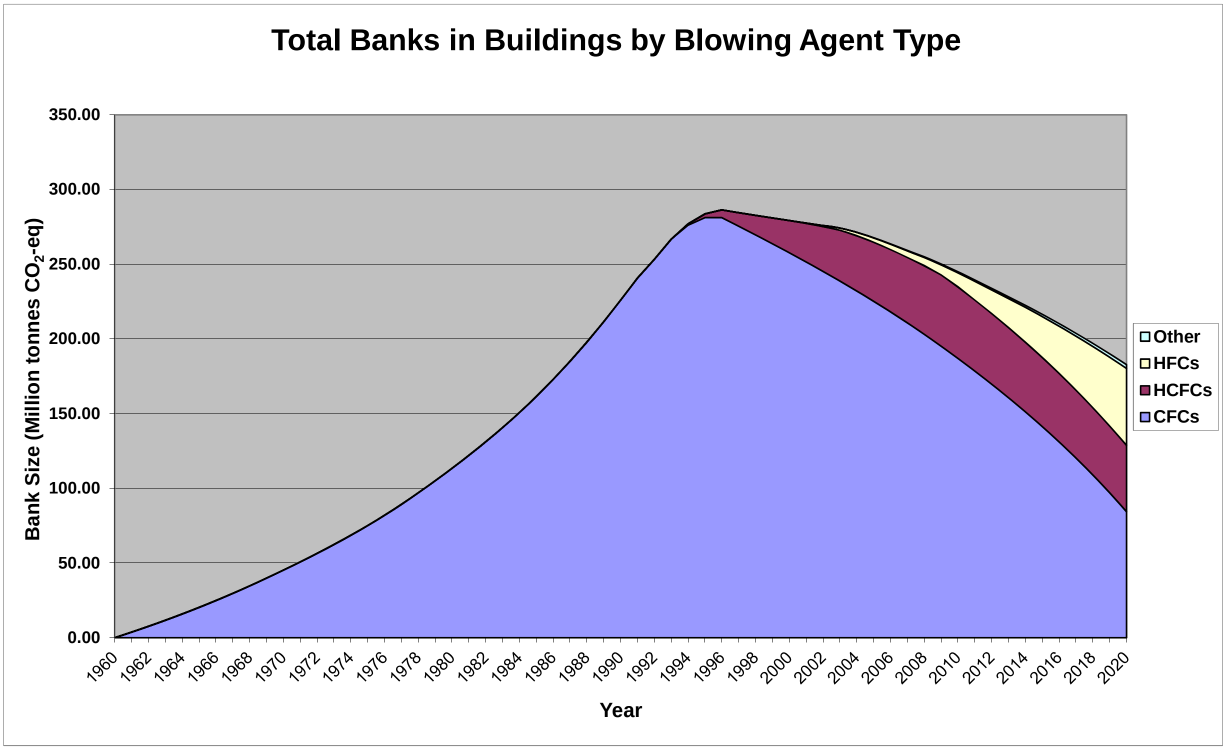
Figure 3-4 illustrates that these accumulations are relatively equally spread between single-family residences, multi-family residences and commercial/public buildings. The contribution from stand-alone cold-storage buildings is very limited, although foams are also used for walk-in cold stores within existing buildings. For clarity, the cold storage element has been left out of the graph since it would have been barely visible.

Figure 3-4 BANK ESTIMATES BY BUILDING TYPE



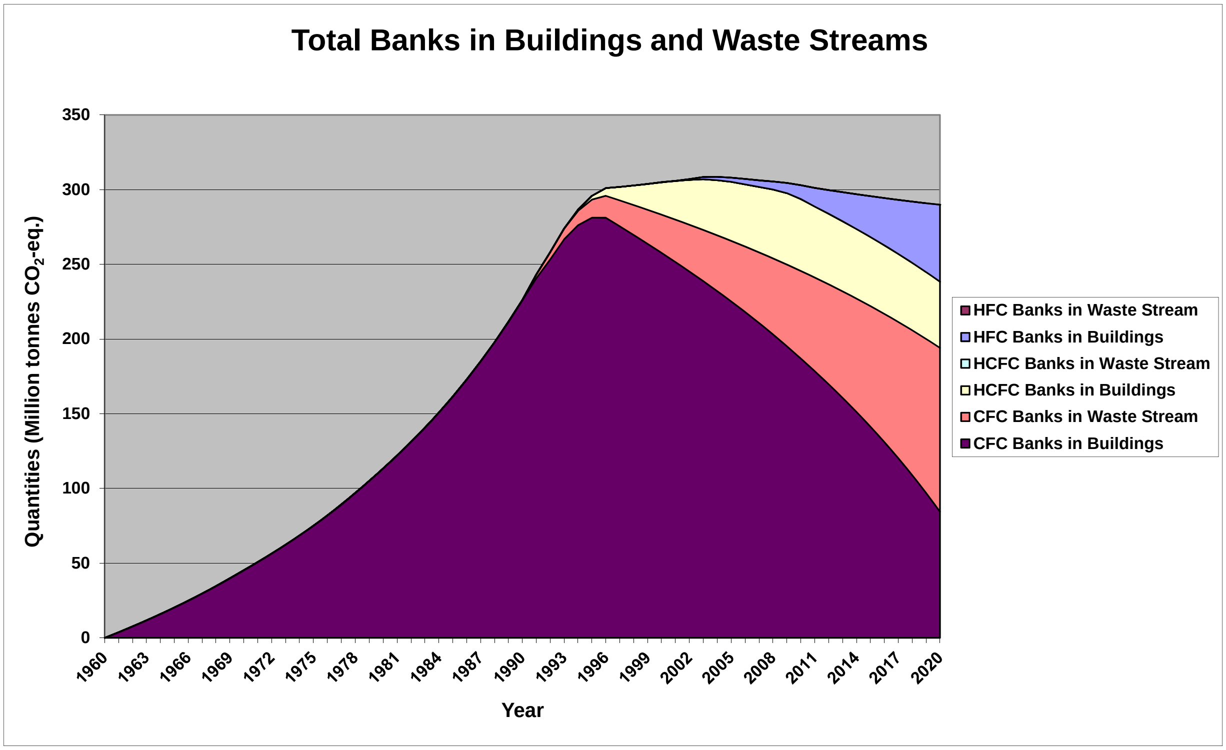
Banks of GHGs in buildings can also be expressed by blowing agent type as shown in Figure 3-5. It can be seen that the high global warming potential of CFCs is the primary cause for the overall reduction in the bank size over the next 10 years, even though new buildings will continue to use some high GWP gases (e.g., HFCs) as ODS replacements. This rapid decline in the CFC bank within buildings points to the significant opportunity that exists to avoid emissions at end-of-life. While ODS banks are decreasing, HFC banks are expected to increase from 10 million tCO_2-eq in 2010, to 54 million tCO_2-eq in 2020, over a five-fold increase in HFC banks.

Figure 3-5 TOTAL BANKS IN BUILDINGS BY BLOWING AGENT TYPE



However, in the baseline scenario, not all CFCs will be directly emitted, particularly where landfill and other less destructive end-of-life strategies are employed**.** Figure 3-6 illustrates the likely accumulation of CFCs already occurring in the waste stream. This is currently estimated at 59 million tCO_2-eq. and is expected to increase with time unless there is further intervention, with banks in waste streams reaching around 110 million tCO_2-eq. by 2020.

Figure 3-6 BANKS IN BUILDINGS & WASTE STREAMS BY BLOWING AGENT TYPE



It is noticeable that no significant HCFCs or HFCs are yet entering the waste stream under the assumption of an average 30 year life-time for most, if not all, building types.

3.8.1.2. Emissions from the Buildings Bank

Emissions from the buildings foam sector arise from three main stages of buildings foam:

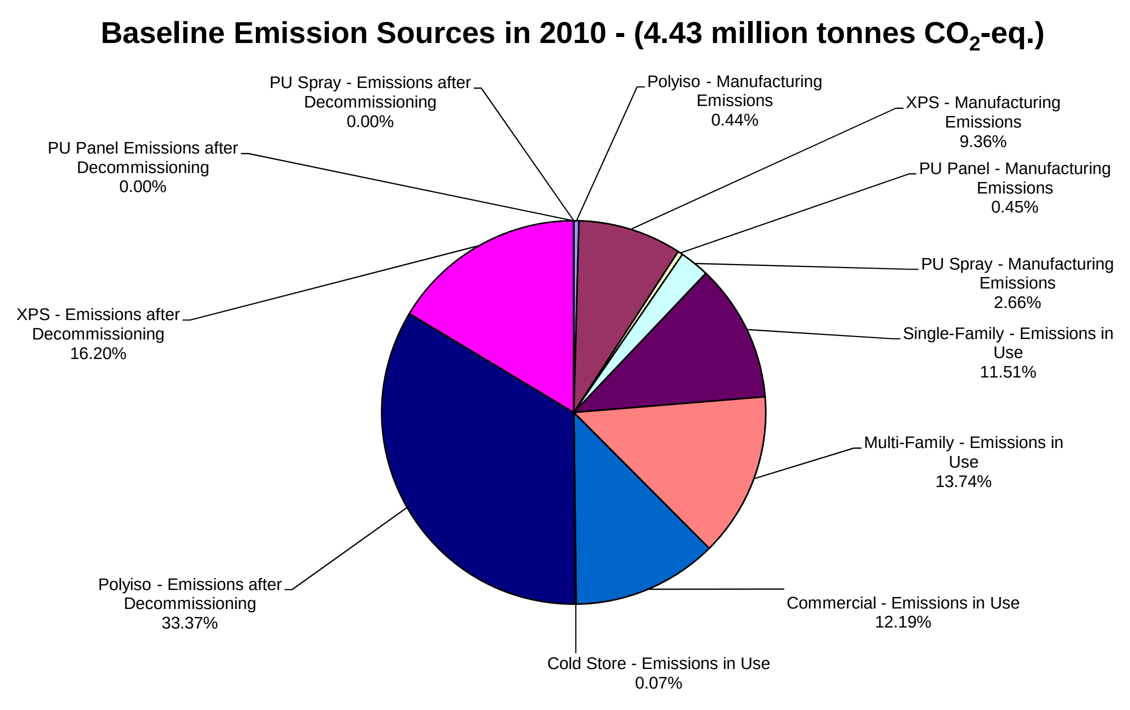
1). The manufacture of foams intended for use in California,

2). Foams already installed in buildings, and

3). The decommissioning of buildings as they reach their end-of-life.

Figure 3-7 below illustrates Caleb's estimates of current emissions from the various sources contributing to these three life-cycle stages at 4.43 million tCO_2-eq.

Figure 3-7 BASELINE EMISSION SOURCES IN 2010 - BUILDINGS



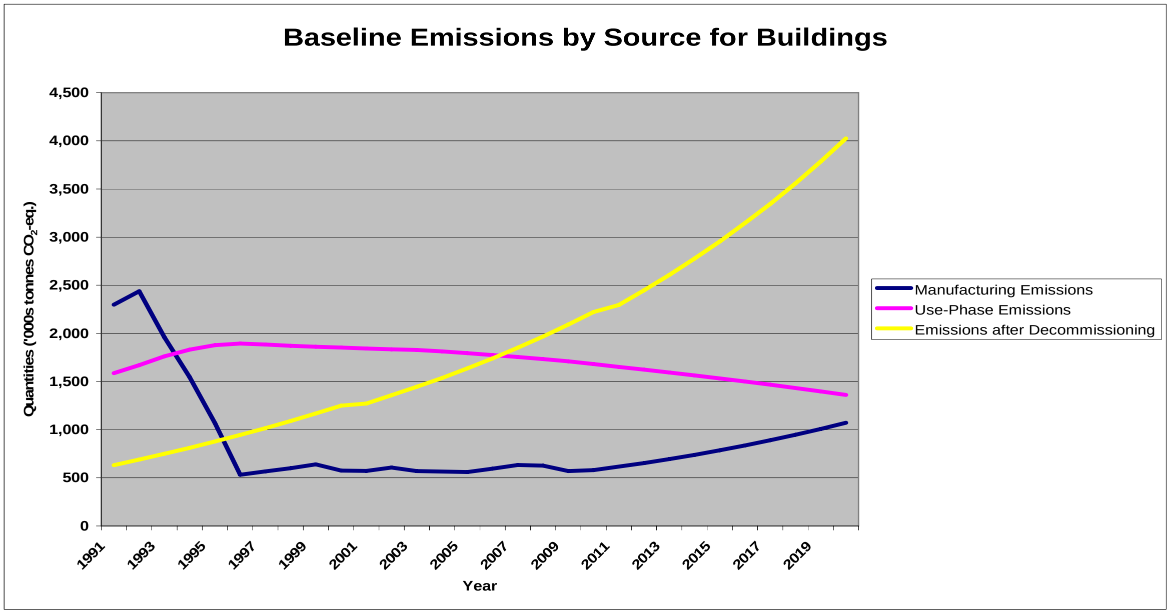
Manufacturing emissions make up around 12.9% of the total. Annual emissions in the use phase account for just over 37.5% and emissions arising from decommissioning and waste stream sources are understood to represent the remaining 49.6%.

Of the total 4.43 million metric tons of CO_2 eq ($MMTCO_2E$) baseline emission sources in 2010; 0.60 $MMTCO_2E$ are from HFCs, and 3.83 $MMTCO_2E$ from ODS.

It is interesting to note that both PU Spray Foams and PU Panels are not expected to contribute to current emissions from building decommissioning, reflecting the fact that their introduction as products in the construction sector is understood to have taken place after 1980, and assuming a 30-year life span of the average building.

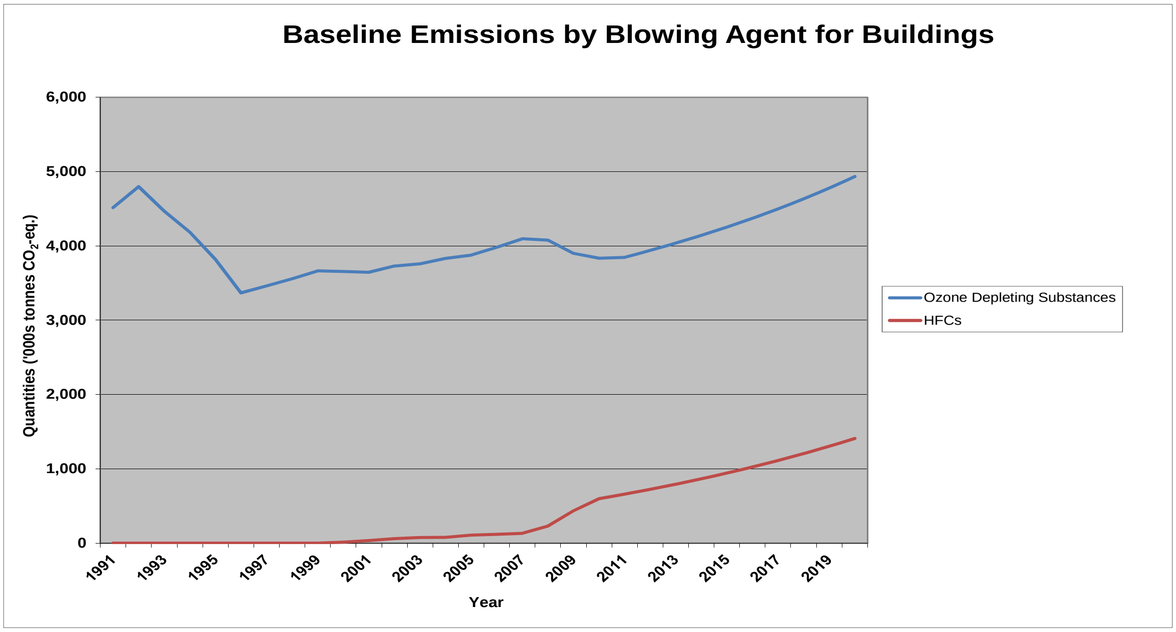
The trends of blowing agent emission from the building sector with time are shown in Figure 3-8. These reveal that emissions after decommissioning are thought to have become the largest single source of emission in 2007 and are increasing on a relatively steep curve. By 2020 they are expected to exceed 4 million tCO_2-eq. annually under the baseline scenario, all of which are associated with ozone depleting substances.

Figure 3-8 BASELINE EMISSIONS BY SOURCE FOR BUILDINGS



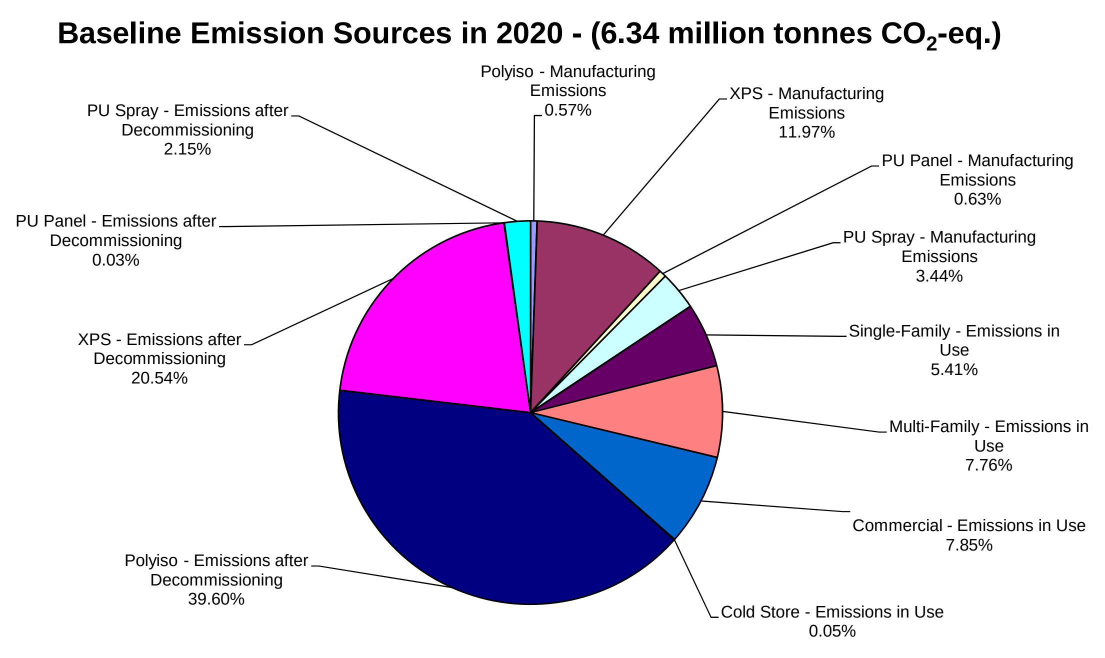
There is also expected to be some increase in the climate impact of manufacturing emissions as higher GWP HFCs replace HCFCs in a number of key applications, the most notable of which is extruded polystyrene (XPS). These emissions are expected to be spread between blowing agent types as shown in Figure 3-9.

Figure 3-9 BASELINE EMISSIONS BY BLOWING AGENT FOR BUILDINGS



Total emissions are expected to grow to 6.34 million tCO_2-eq by 2020 as detailed in Figure 3-10:

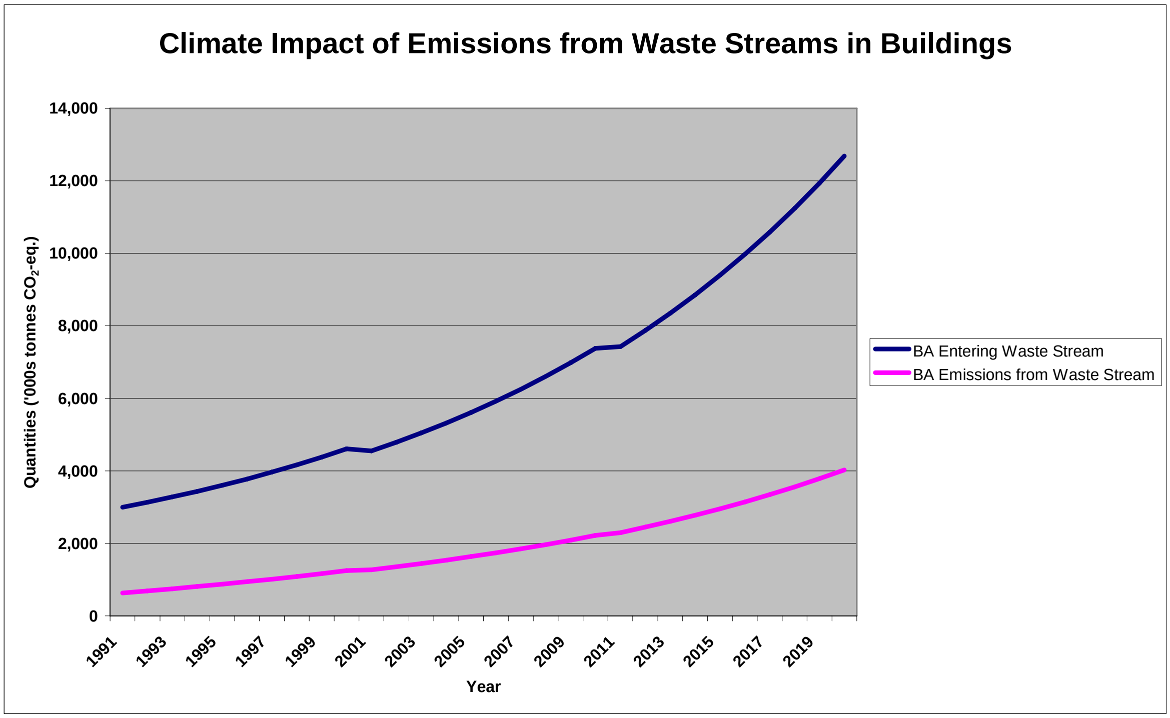
Figure 3-10 BASELINE EMISSION SOURCES IN 2020 - BUILDINGS



Of the total 6.34 million metric tons of CO_2 -eq ($MMTCO_2E$) baseline emission sources in 2020; 1.40 $MMTCO_2E$ are from HFCs, and 4.94 $MMTCO_2E$ from ODS.

It is important to note that actual emissions from products after decommissioning are considerably lower than the flows into the waste stream, as shown in Figure 3-11.

Figure 3-11 CLIMATE IMPACT OF EMISSIONS FROM THE WASTE STREAM - BUILDINGS



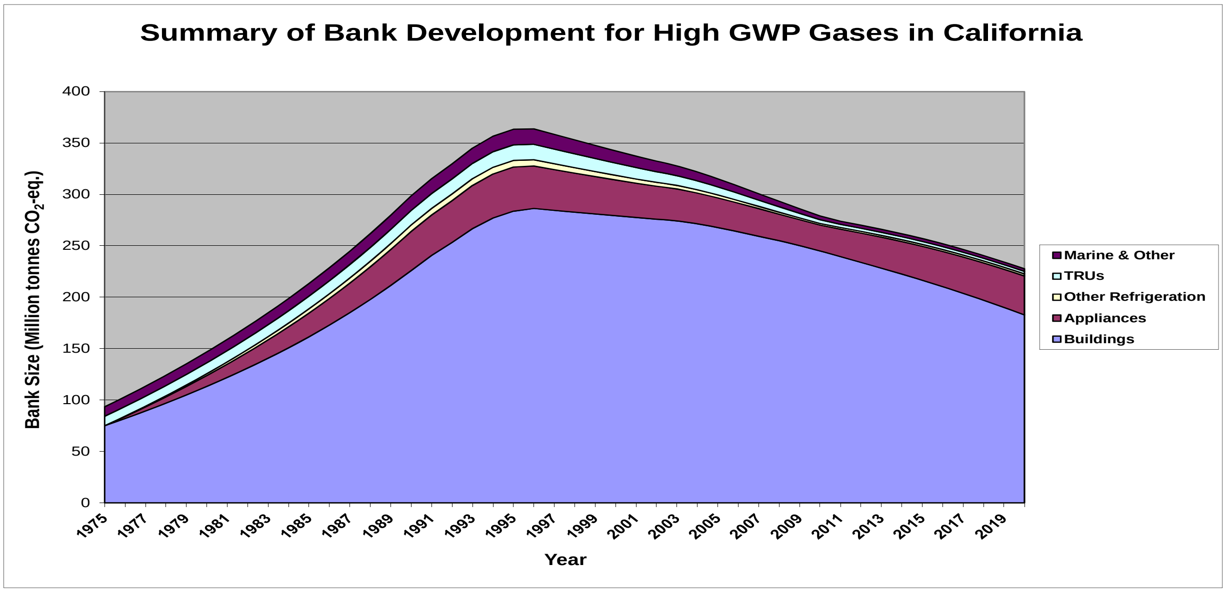
It can be seen that actual flows into the waste stream are roughly three times as great as the annual emissions arising from them in the period to 2020. This means that intervention at the point that foams reach the waste stream could have significantly greater impact than is reflected in this report. The primary reason for this is that many of the avoided emissions will be in the post-2020 period and therefore beyond the scope of this work. This matter is picked up again later in this Section and in Section 4.

3.8.2. Comparison of Buildings with other Foam – containing Sectors

Buildings constitute by far the biggest single location for ODS Banks, with refrigerated equipment such as appliances, refrigerated containers (also known as TRUs or reefers) and walk-in cold-rooms containing smaller, although potentially more emissive, banks themselves. A further use of ODS-containing foam has taken place in the marine and leisure sector but, as shown by Figure 3-12 , this represents a very small proportion of the ODS banks in California overall.

A number of the banks in the other sectors are showing rapid decline, based on the early move out of ozone depleting substances to low-GWP alternatives and also the relatively short life-cycle (when compared with buildings) of the products and equipment involved. An exception to this is the market for domestic appliances, where the widespread adoption of HFC-245fa as a substitute for HCFC-141b has resulted in a continued growth in bank size since 2005. This is covered in more detail in the next section. Nonetheless, it is of interest that the banks of all other sources combined never exceed 25% of the total.

Figure 3-12 SUMMARY OF BANK DEVELOPMENT FOR HIGH GWP GASES IN CALIFORNIA – BY APPLICATION



This same bank information can be expressed also in terms of blowing agent type, as shown in Figure 3-13 below.

Figure 3-13 SUMMARY OF BANK DEVELOPMENT FOR HIGH GWP GASES IN CALIFORNIA – BY BLOWING AGENT TYPE

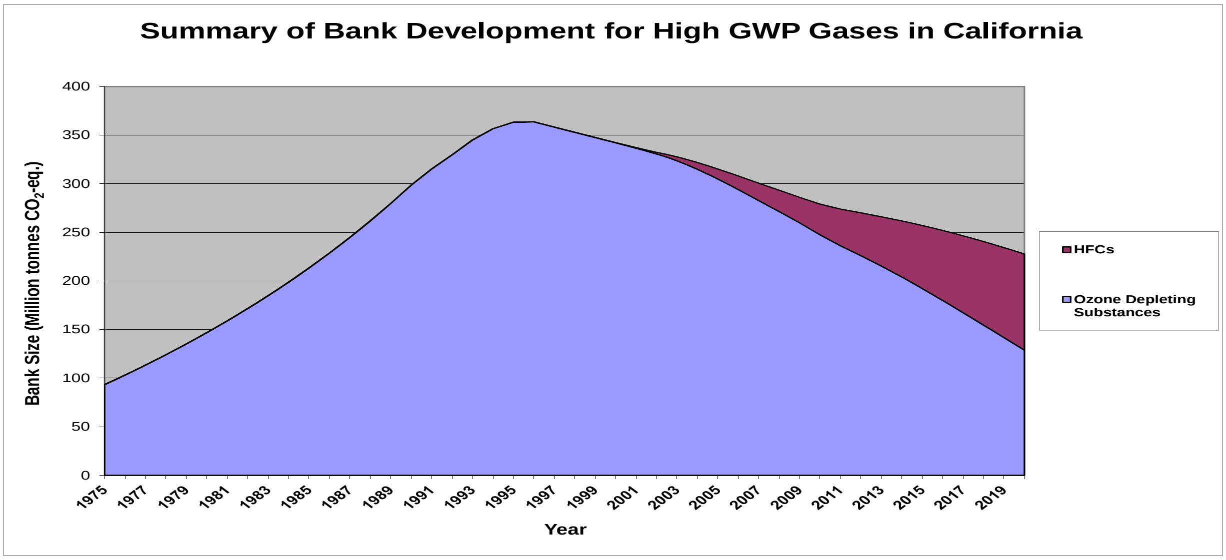
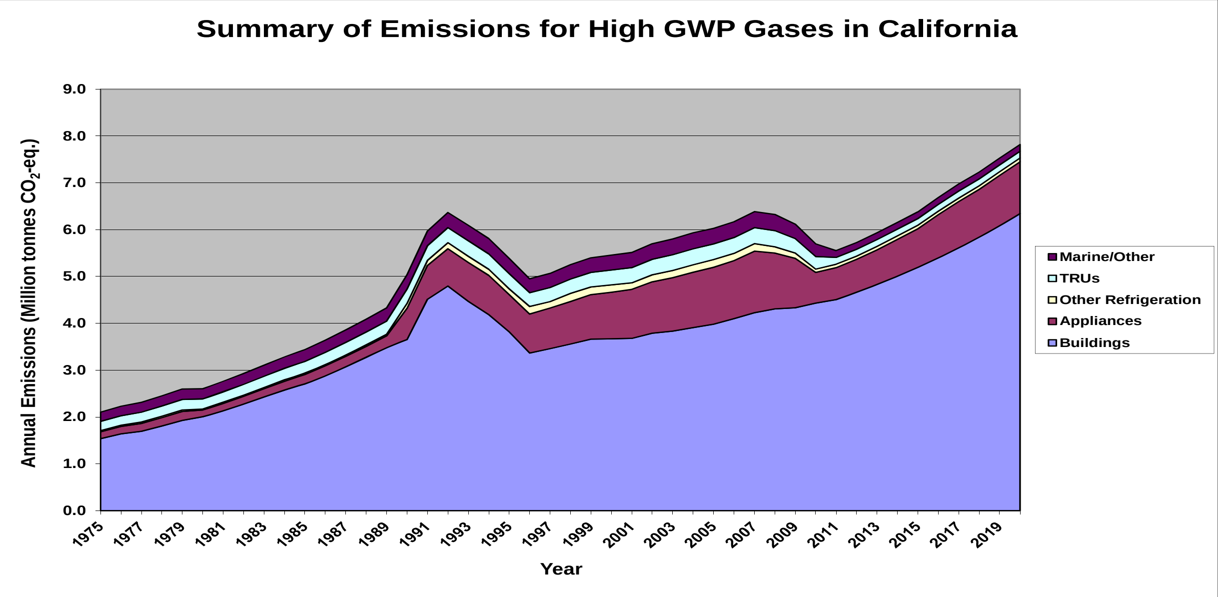


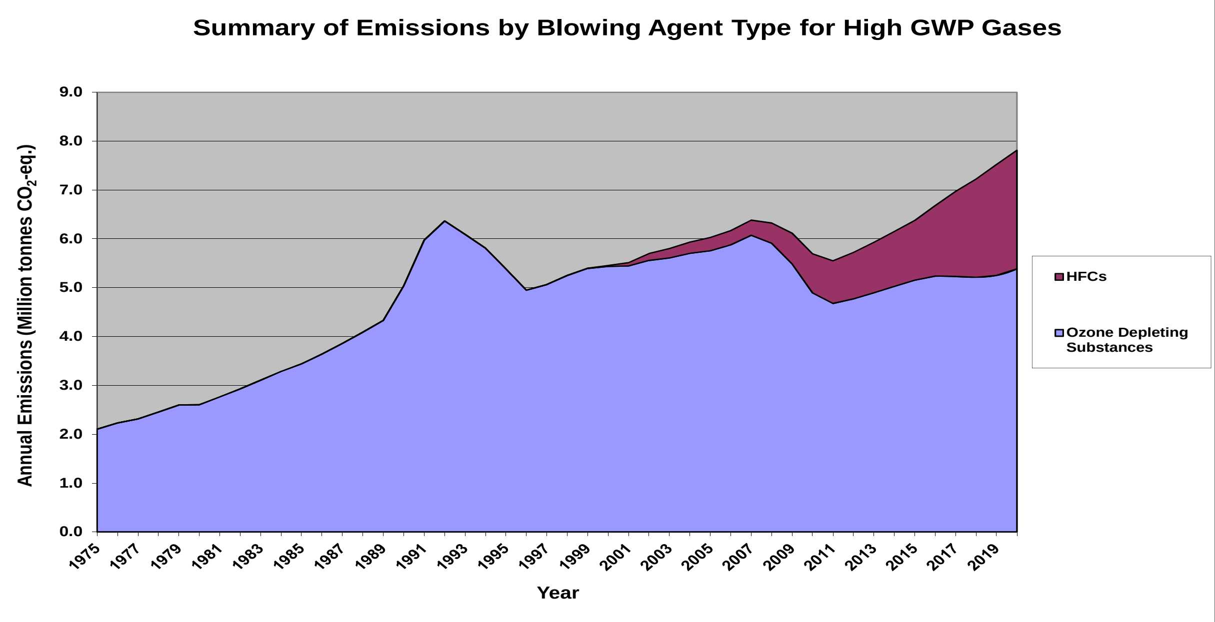
Figure 3-14 illustrates that a similar story exists for emissions, despite the shorter lifetimes associated with many of the products and equipment containing ODS-banks. At their peak, the emissions from sources other than buildings reach 34% of the total annual emissions. This is broadly as a result of the decommissioning of ODS-containing appliances during the period from 1990 to around 2010.

Figure 3-14 SUMMARY OF EMISSIONS FOR HIGH GWP GASES IN CALIFORNIA



The emissions data by blowing agent type is expressed in Figure 3-15.

Figure 3-15 SUMMARY OF EMISSIONS FOR HIGH GWP GASES BY BLOWING AGENT TYPE



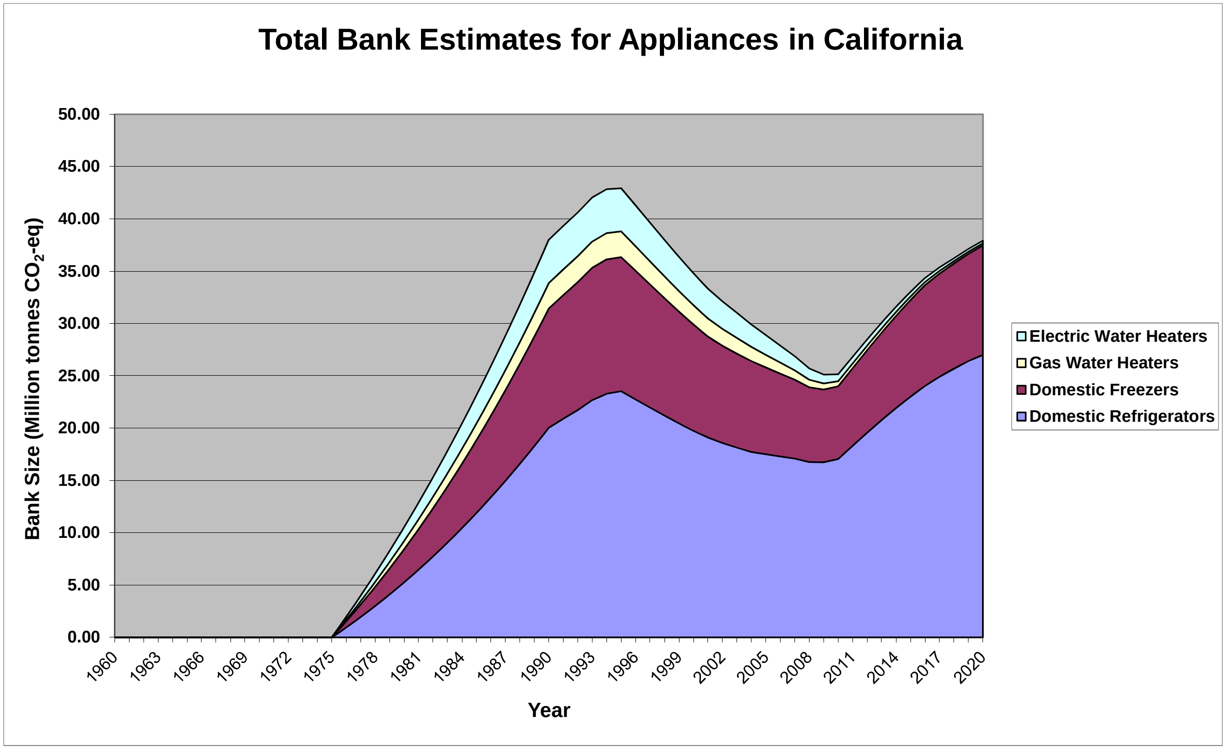
This analysis tends to indicate that the buildings sector should be the focus of most attention in policy terms, although, as will be seen later, there could be some cost-effective win-wins where significant banks of high GWP greenhouse gases still remain.

3.8.3. Appliance related Banks & Emissions

3.8.3.1. High GWP Greenhouse Gas Banks in Appliances

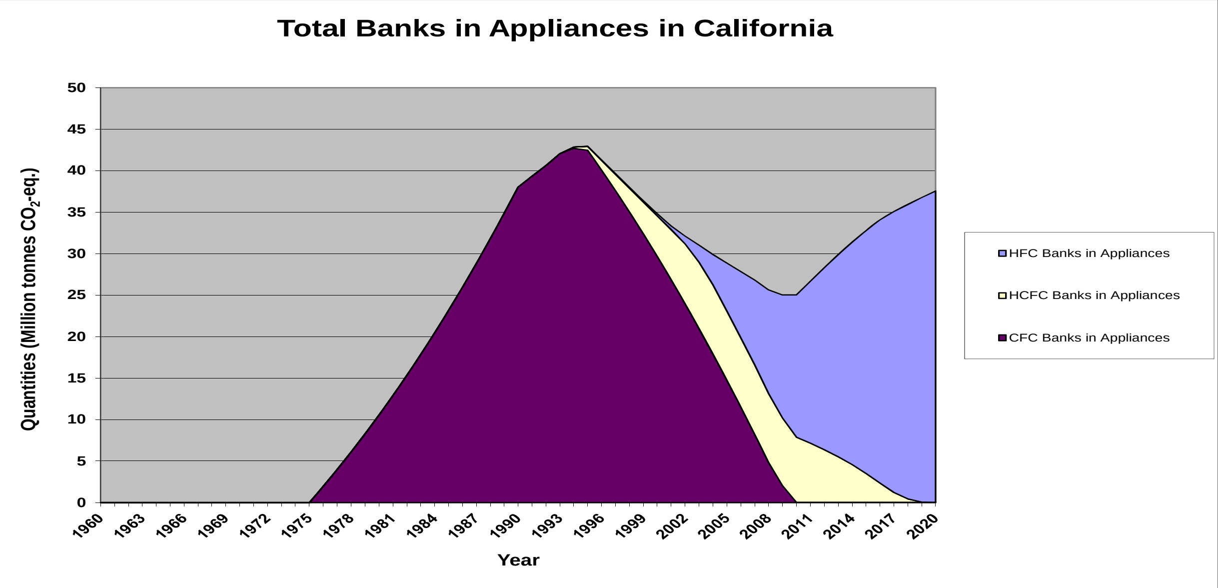
The assessment of the development of banks in the appliance sector has been based on the assumption that the average lifetime of these units is 14-15 years. This is consistent with global averages taken for modeling by TEAP and the IPCC. However, it should be recognized that average lifetimes as short as 10 years (Japan) and as long as 25 years (in areas of high re-use) can be justified. The outcome of the current assumption on bank dynamics is shown in Figure 3-16 below:

Figure 3-16 TOTAL BANK ESTIMATES FOR APPLIANCES IN CALIFORNIA



The above figure and the following figure illustrate the importance of the uptake of HFCs in the domestic refrigerator and freezer products and also show the impact of previous transitions out of high GWP gases in the water heater sector. Figure 3-17 shows the total GHG banks for appliances as in Figure 3-16, but provides the same basic information by blowing agent type (CFC, HCFC [which are both ODS], and HFC, a non-ODS). Figure 3-17 illustrates the fact that HFCs are forecast to be the only significant component of the appliances bank by 2020. This is consistent with a 15 year average lifetime assumption and the phase-out of HCFC-141b in the United States in 2005.

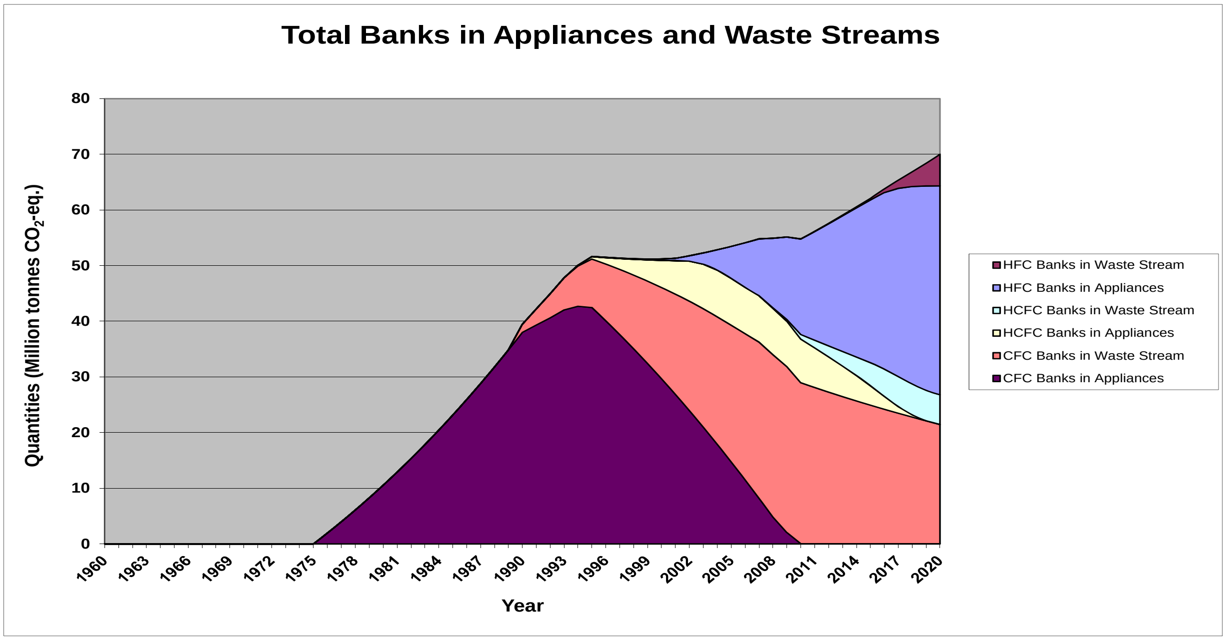
Figure 3-17 TOTAL BANKS IN APPLIANCES IN CALIFORNIA



The shorter lifetimes in the appliance sector also mean that the quantity of high GWP blowing agents in the waste stream is a significantly greater component than it is in the buildings sector.

Figure 3-18 illustrates this point.

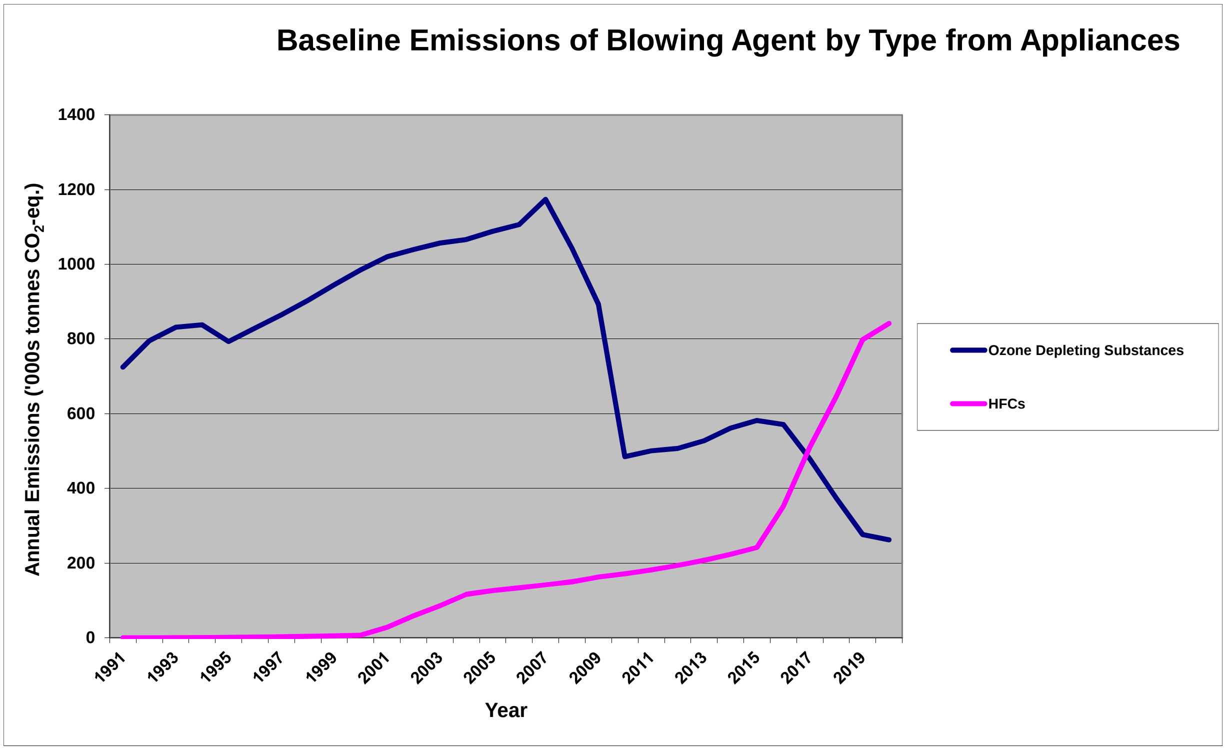
Figure 3-18 TOTAL BANKS IN APPLIANCES & WASTE STREAMS



3.8.3.2. Emissions from the Appliances Bank

With respect to emissions, the peak emission to date is likely to have taken place in 2007 at the point where the largest number of CFC-containing refrigerators was believed to have been decommissioned. The sensitivity of annual emissions to waste flows is, in large part, due to the continued use of auto-shredders for the end-of-life management of appliances. A relatively steep fall was projected through 2010, but this could be deferred, or more widely spread, in practice depending on the real average lifetime and statistical spread surrounding that average. Figure 3-19 shows the emissions from appliances predicted in the Caleb model by blowing agent category.

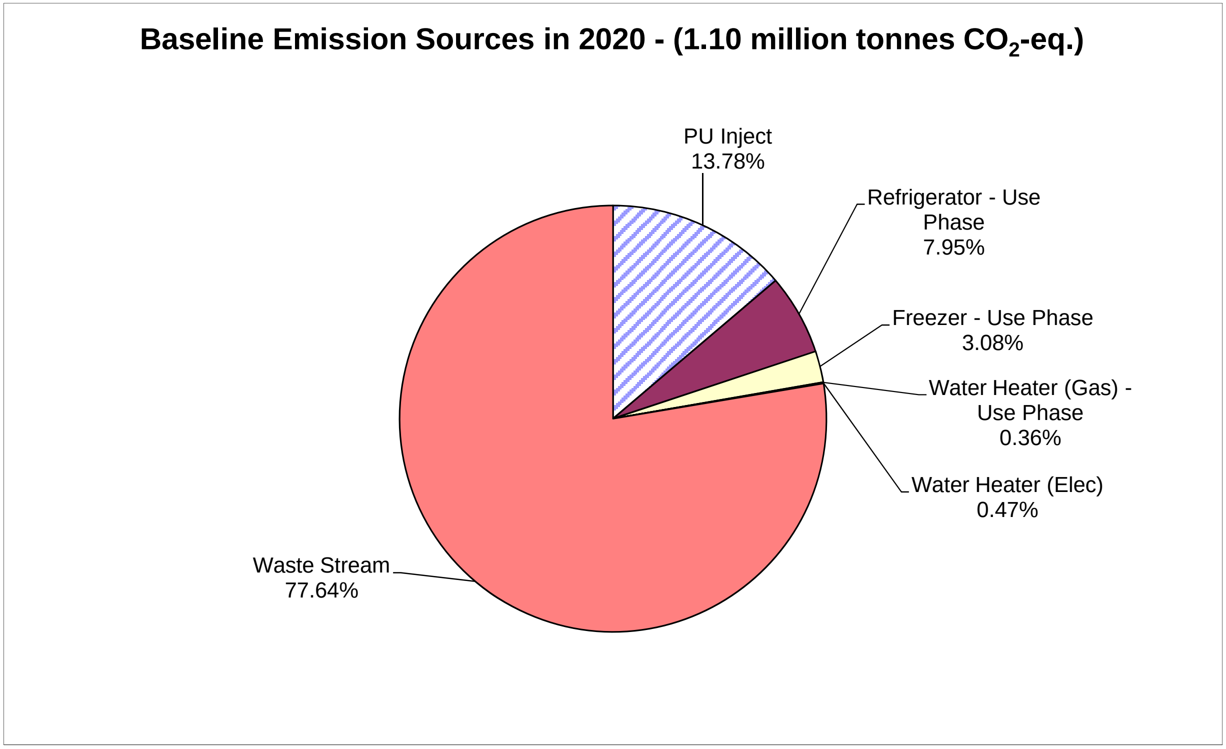
Figure 3-19 BASELINE GHG EMISSIONS FOR APPLIANCES IN CALIFORNIA 1991 - 2020



From 2010 onward, the projected growth in GHG emissions from appliances is primarily due to the ongoing manufacturing of appliances with HFC-containing foam, and the HFC emissions occurring at the appliance end-of-life as a result of recycling methods employing shredders with no foam gas recovery. HFC emissions due to appliance manufacturing will largely take place out-of-State in view of the fact that California is a significant net importer of appliances. Nonetheless, appliance manufacturing GHG emissions are included in the analysis in order to capture the emissions for which Californian consumer habits are responsible.

Figure 3-20 illustrates the projected proportion of emissions at 2020 from manufacturing, in-use phase, and decommissioning (end-of-life). The figure highlights the fact that, unless measures are taken to curb emissions, the emissions in the period after decommissioning will remain the dominant factor (~75% of total). In-use losses are predictably low, but the relatively significant share (above 15%) ascribed to manufacturing losses highlights the on-going importance of blowing agent choice in the domestic refrigerator and freezer sector. This is a subject that is returned to when mitigation options are reviewed in Section 3.9.

Figure 3-20 BASELINE FOR APPLIANCES RELATED EMISSION SOURCES IN 2020



3.8.4. Refrigerated Transport, Other Refrigeration, Marine and Other Applications – Banks and Emissions

In view of their relatively small contribution to both banks and emissions of high GWP gases, these sources are taken together in one section. ‘Other Refrigeration’ includes vending machines and other commercial refrigeration applications such as supermarket display cabinets. TRUs are typically refrigerated containers which have been foam insulated using injected polyurethane systems. Marine and other leisure uses are typically for buoyancy purposes.

Figure 3-21 provides basic information on the development of banks.

Figure 3-21 TOTAL BANKS IN OTHER REFRIGERATION & WASTE STREAMS

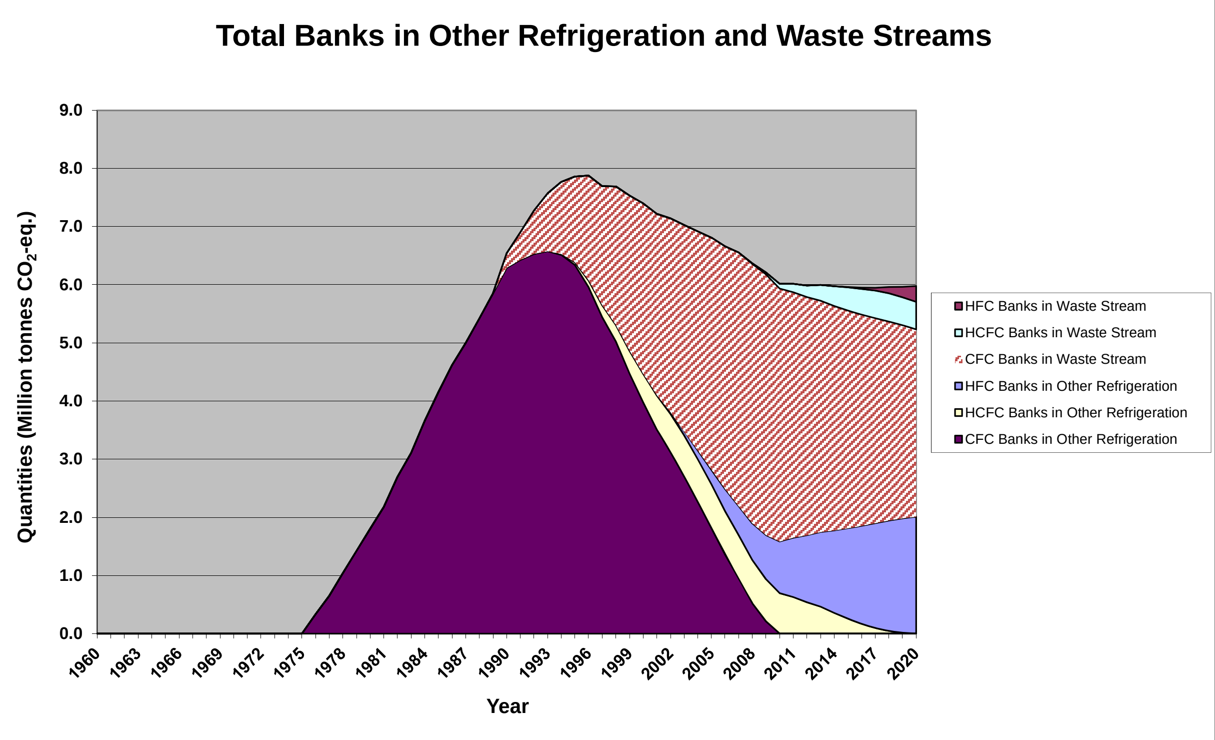


Figure 3-22 TOTAL BANKS IN TRUs & RELATED WASTE STREAMS

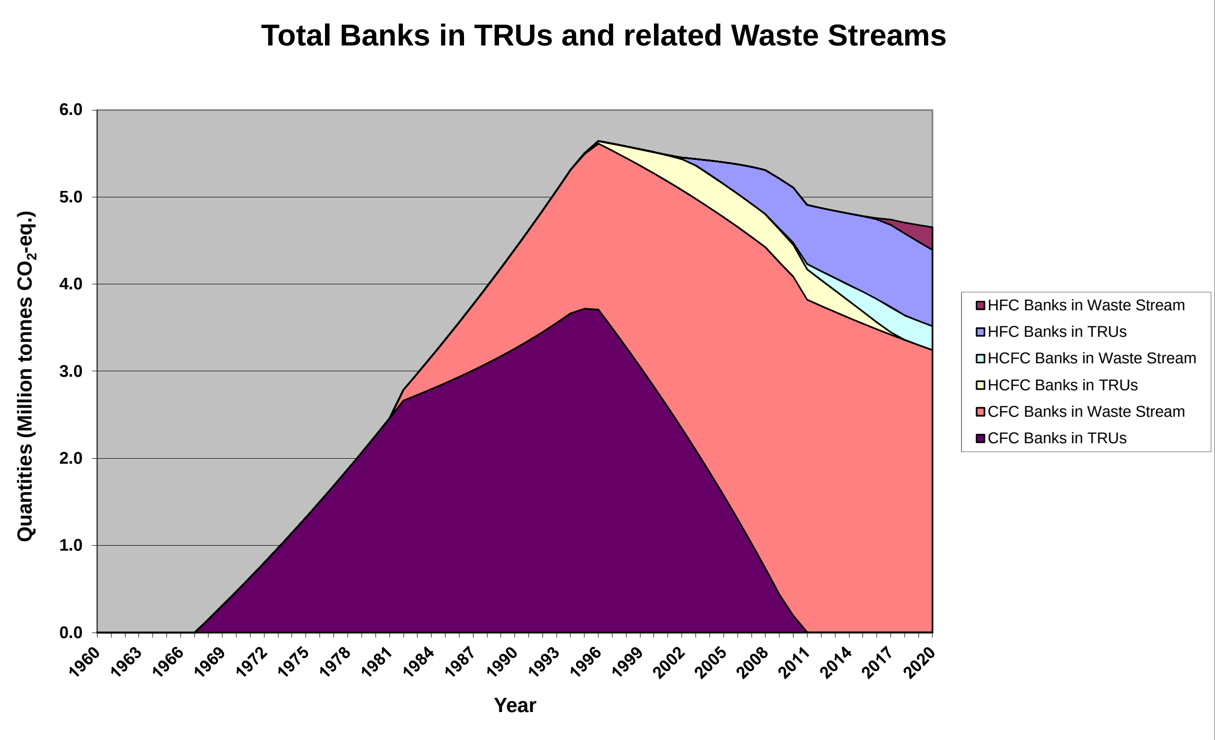
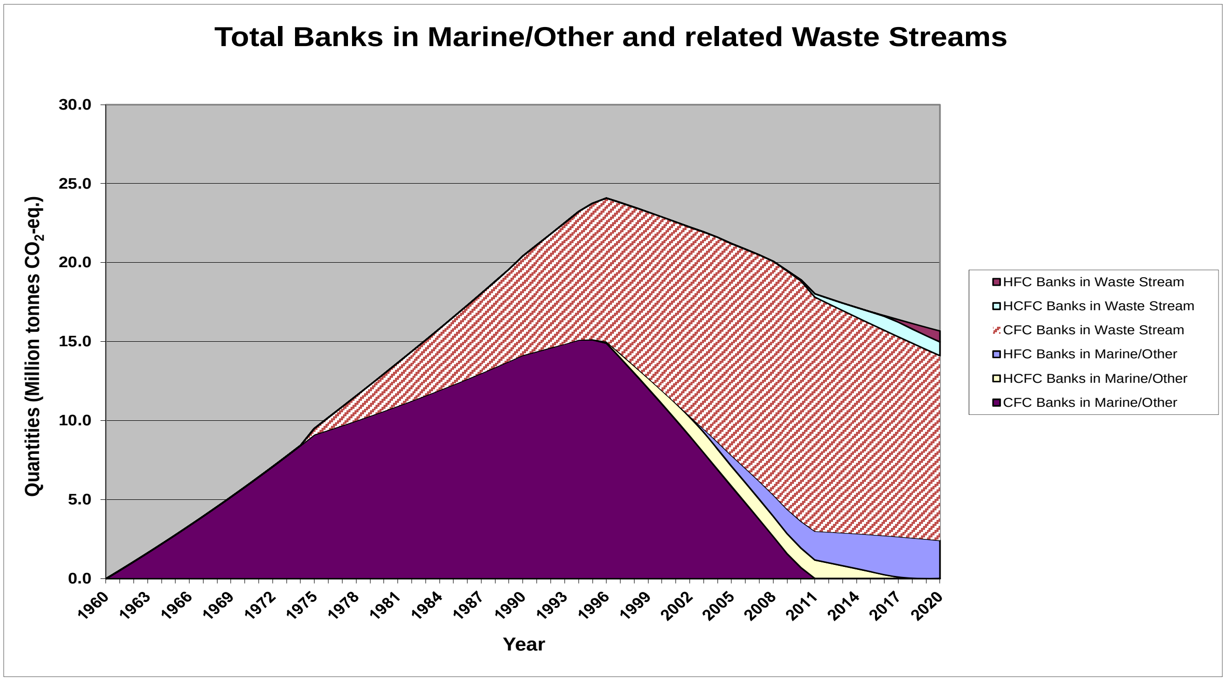


Figure 3-23 TOTAL BANKS IN MARINE/OTHER APPLICATIONS & RELATED WASTE STREAMS



The overall decrease in the bank sizes for all three sectors shows that HFCs have been a less favored alternative than for the domestic refrigerator and freezer sectors. Even in 2010, the most significant banks of high GWP gases are already in the waste stream, making these less favorable options for mitigation strategies, although the bulk of vending machines and commercial refrigeration applications could potentially be captured by any measures taken in the appliance sector.

With respect to emissions, those emanating after decommissioning (e.g., from banks in waste streams) will dominate. Figure 3-24 and Figure 3-25 illustrate the point.

Figure 3-24 BASELINE EMISSION SOURCES IN 2020 – Other Refrigeration

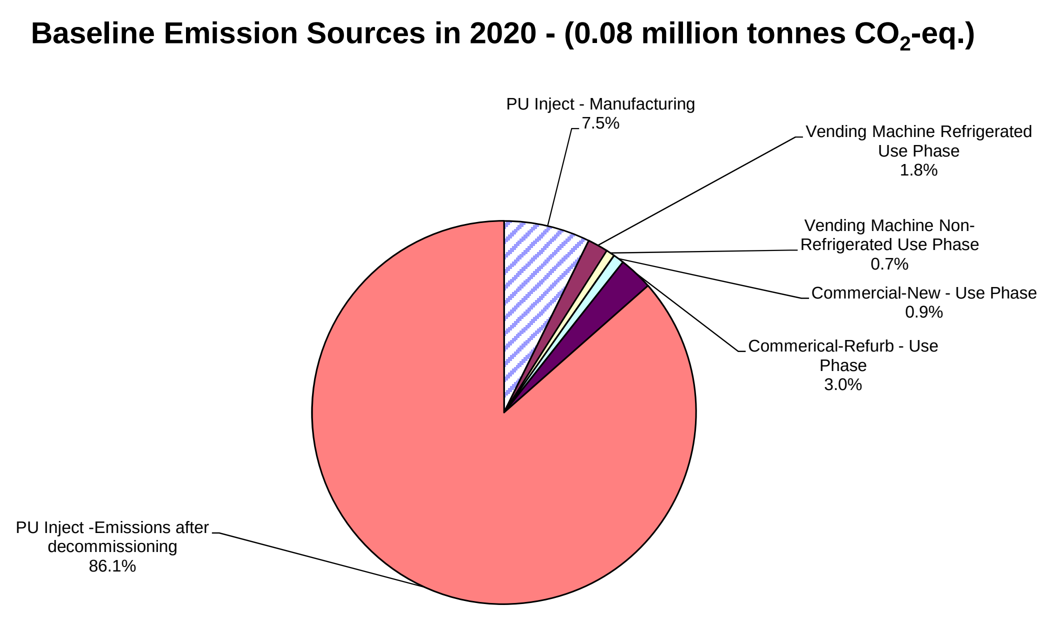
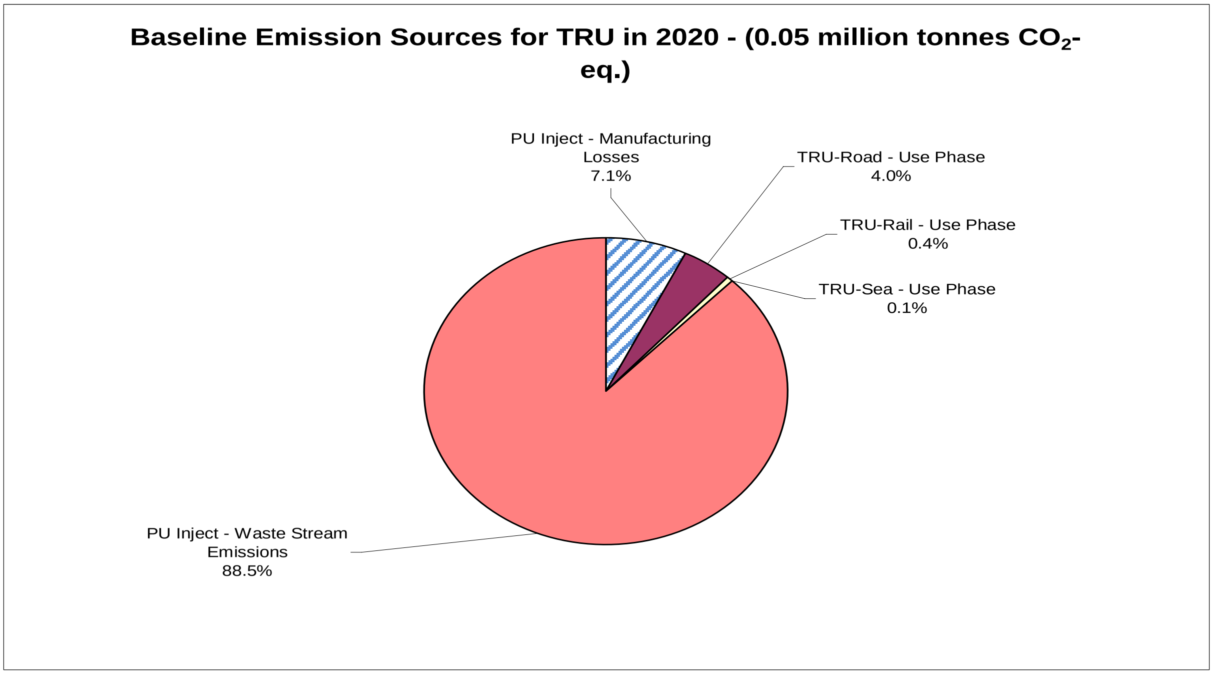


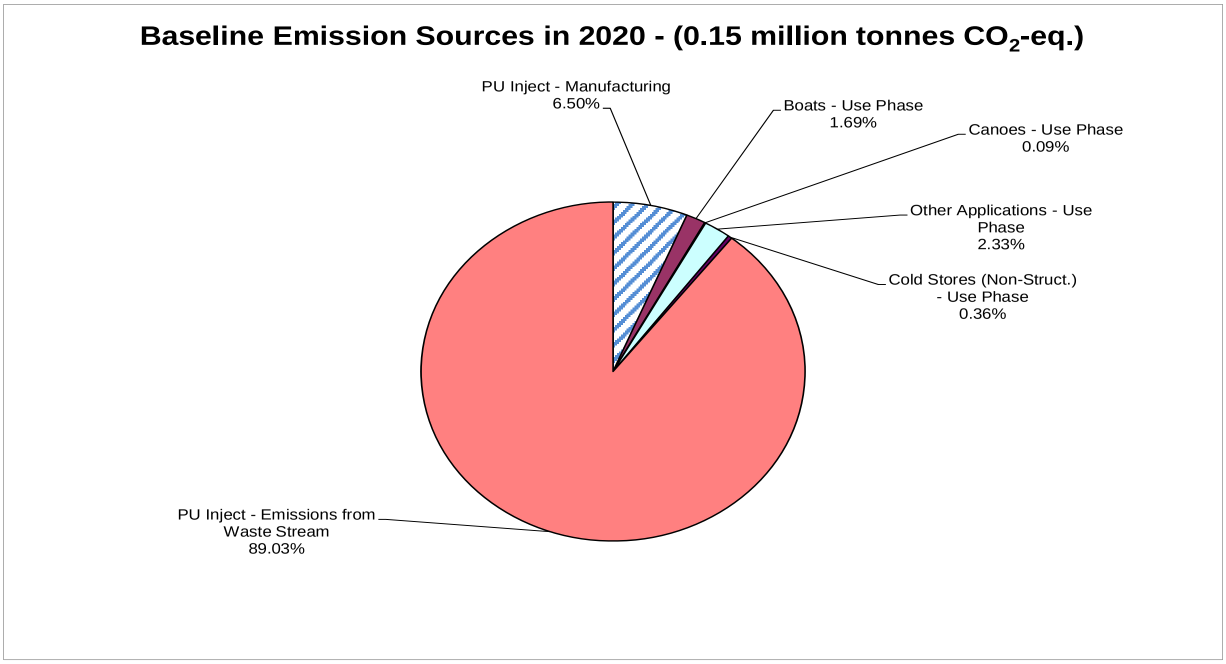
Figure 3-25 BASELINE EMISSION SOURCES IN 2020 –TRU



For marine and leisure activities, the emissions after decommissioning are equally dominant as shown in Figure 3-26.

.

Figure 3-26 BASELINE EMISSION SOURCES IN 2020 – Marine & Other



3.9. Mitigation Options Assessed within this Study

Taking due account of the size and dynamics of banks and emissions, the project team identified the six key mitigation scenarios for high GWP gases in California. These fell into the two key categories of end-of-life management and early phase-out of HFC use.

3.9.1. End-of-Life Management

In the mitigation scenarios developed, it is assumed that end-of-life measures require the shortest lead-times and can be initiated as early as 2012, with full implementation in place by 2014. The products and equipment targeted are as follows:

- All appliances (domestic refrigerators, freezers and water heaters)
- Vending machines and commercial refrigeration equipment
- PU Steel-Faced Panels
- Other insulating foams used in buildings.

For the appliances, vending machines and commercial refrigeration sectors, two scenarios have been assumed, one in which 100% of units are successfully managed (the technical potential) and one in which 50% of appliances are successfully managed. The latter is seen as the more realistic worst-case scenario, although something between the two should be achievable based on European and Japanese experience.

For building insulation, the PU Steel-Faced Panel scenario evaluates 100% recovery and destruction (the technical potential) in isolation. This is then combined with 50% recovery from other insulating foams used in buildings. Finally, a more realistic worst-case is modeled where 25% of general building insulation and 50% of panels are assumed to be managed at end-of-life.

3.9.2. Early Phase-out of HFCs

Since there is no current federal constraint on the continued manufacture of products containing HFCs, it would be expected that any decision to introduce a phase-down or phase-out in HFC use, even at State level, would need substantial consultation. It has therefore been assumed that any such measure could only commence in 2014 and would not be fully achieved before 2017. This is therefore the basis on which these scenarios have been assessed. The four sectors identified for analysis were:

- All appliances (domestic refrigerators, freezers and water heaters)
- Vending machines and commercial refrigeration equipment
- Extruded polystyrene foam (XPS)
- PU Spray Foam

The following sections describe the various impacts of these mitigation scenarios by product type.

3.9.3. Appliances and Other Refrigeration

As noted in the earlier sections, both classes of mitigation options (end-of-life management and early phase-out of HFC use) can be applied to this sector. Since the HFC phase-out measures will only impact equipment that will be decommissioned well after 2020, the measures can be considered as totally complementary to one another. For this reason, the analysis evaluates each measure in isolation and does not evaluate combinations. If the assessment period were to be extended to encompass the end-of-life of HFC-containing products manufactured after 2010 (e.g., out to 2040), then the early phase-out of HFCs would result in a reduced business-as-usual scenario later in the lifecycle.

Figure 3-27 and Figure 3-28 show the reductions achieved against baseline emissions for the appliances and other refrigeration sectors. Since the mitigation activities do not take effect until at least 2012, the four scenarios are superimposed on one another up to that point in the graph These scenarios are then summarized cumulatively and ‘as at 2020’ in Figure 3-29 and Figure 3-30.

Figure 3-27 MITIGATION OPTIONS FOR APPLIANCES IN CALIFORNIA

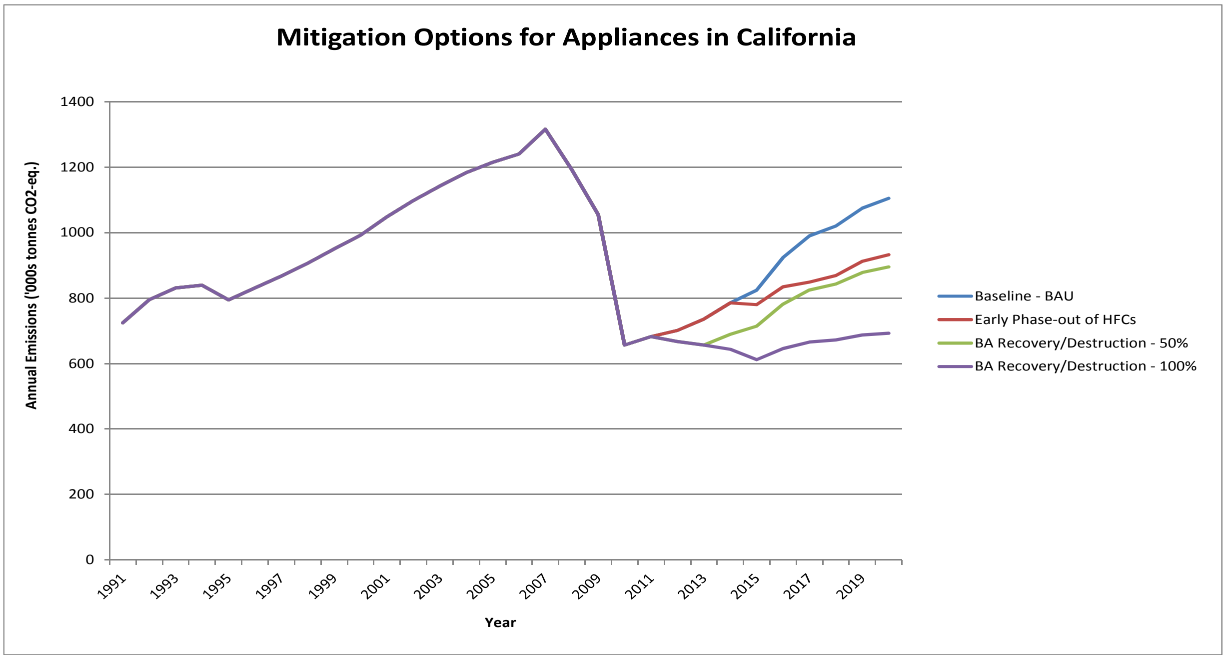
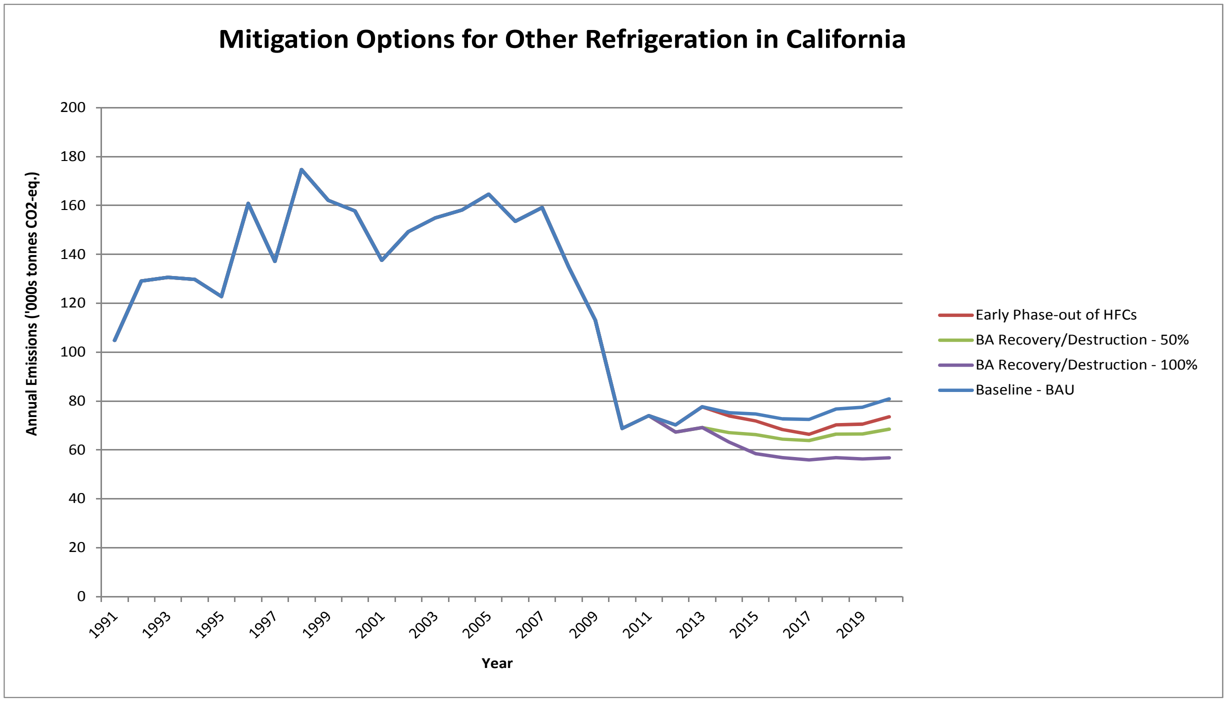


Figure 3-28 MITIGATION OPTIONS FOR OTHER REFRIGERATION IN CALIFORNIA



The impact of early HFC phase-out in ‘Other Refrigeration’ is slightly lower proportionately than for the Appliance sector because the uptake of HFCs in vending machines and foams contained in commercial refrigeration equipment has generally been lower in the baseline case.

Figure 3-29 CLIMATE IMPACT OF MITIGATION OPTIONS IN APPLIANCES

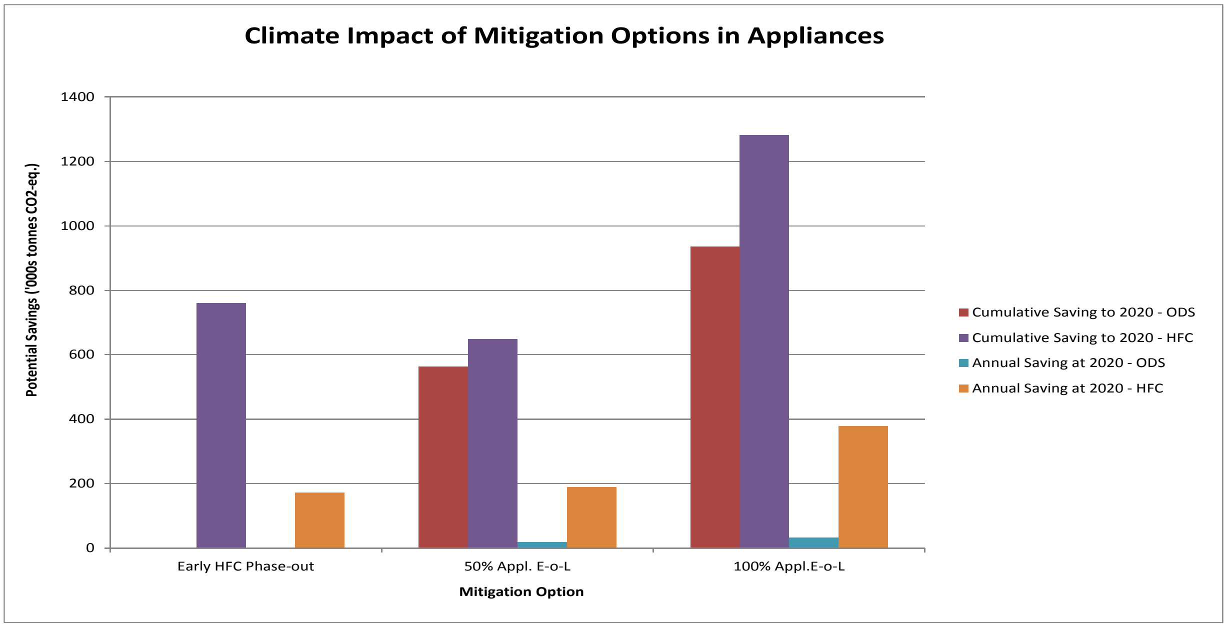
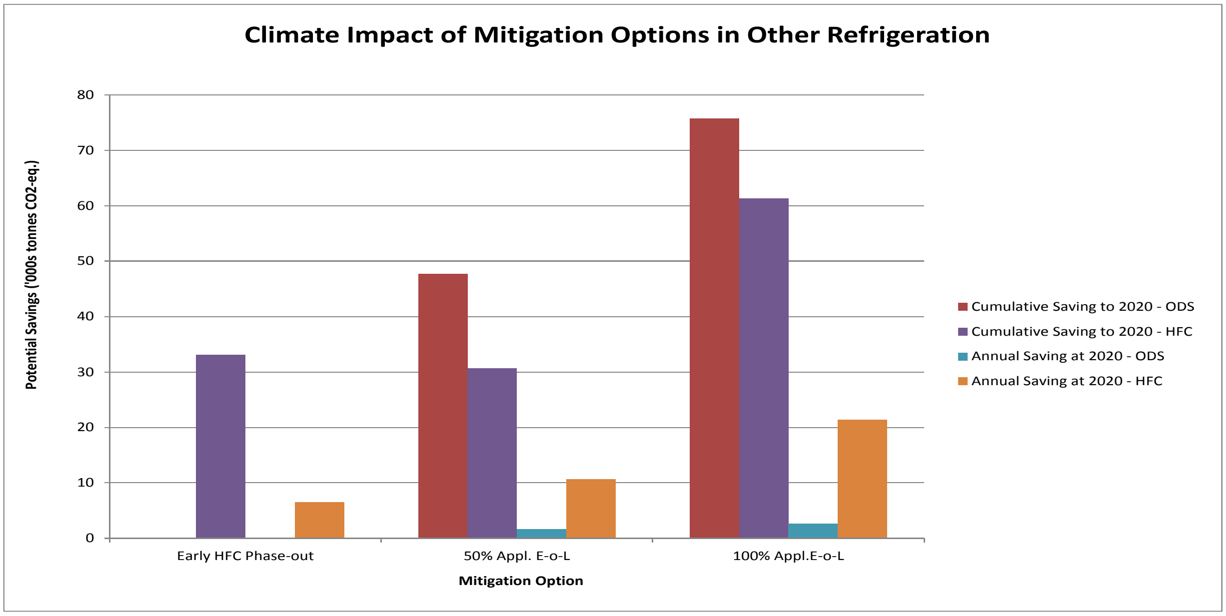


Figure 3-30 CLIMATE IMPACT OF MITIGATION OPTIONS IN OTHER REFRIGERATION

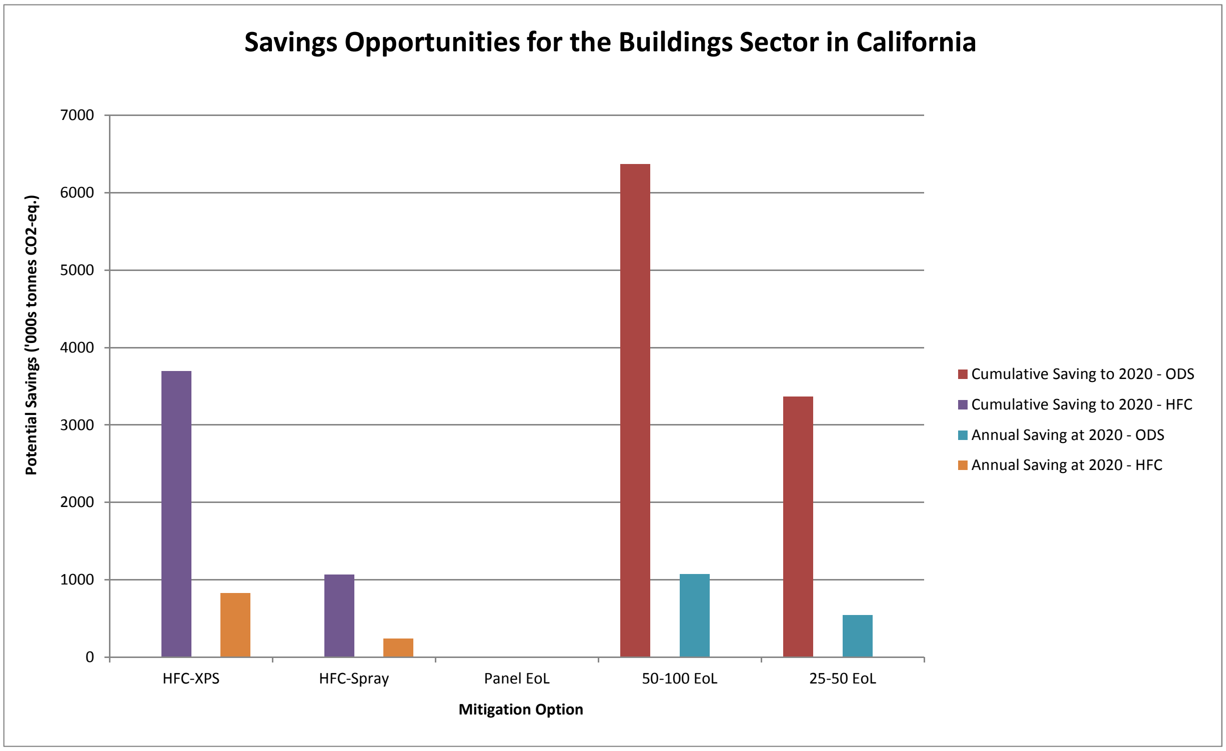


Although these graphs appear similar in scale, it should be noted that each measure in the appliance sector delivers a cumulative saving in excess of 1 million tCO_2-eq. by 2020 while no measure in the Other Refrigeration sector delivers more than 0.14 million tCO_2-eq. in the same period. That said, it would be unusual to enact a policy for appliances that would not spill over into the 'Other Refrigeration' sector, so it is probably reasonable to take these emissions savings as additive for the same policy instrument.

3.9.4. Buildings

One of the interesting outcomes of the analysis involving PU Panels is that there are no significant savings from end-of-life action on PU Panels alone. This arises from the fact that most of the uptake in the use of steel-faced PU Panels has taken place since 1990, with the exception of structural cold stores, which are a very small and specialist use. The consequence is shown in Figure 3-31:

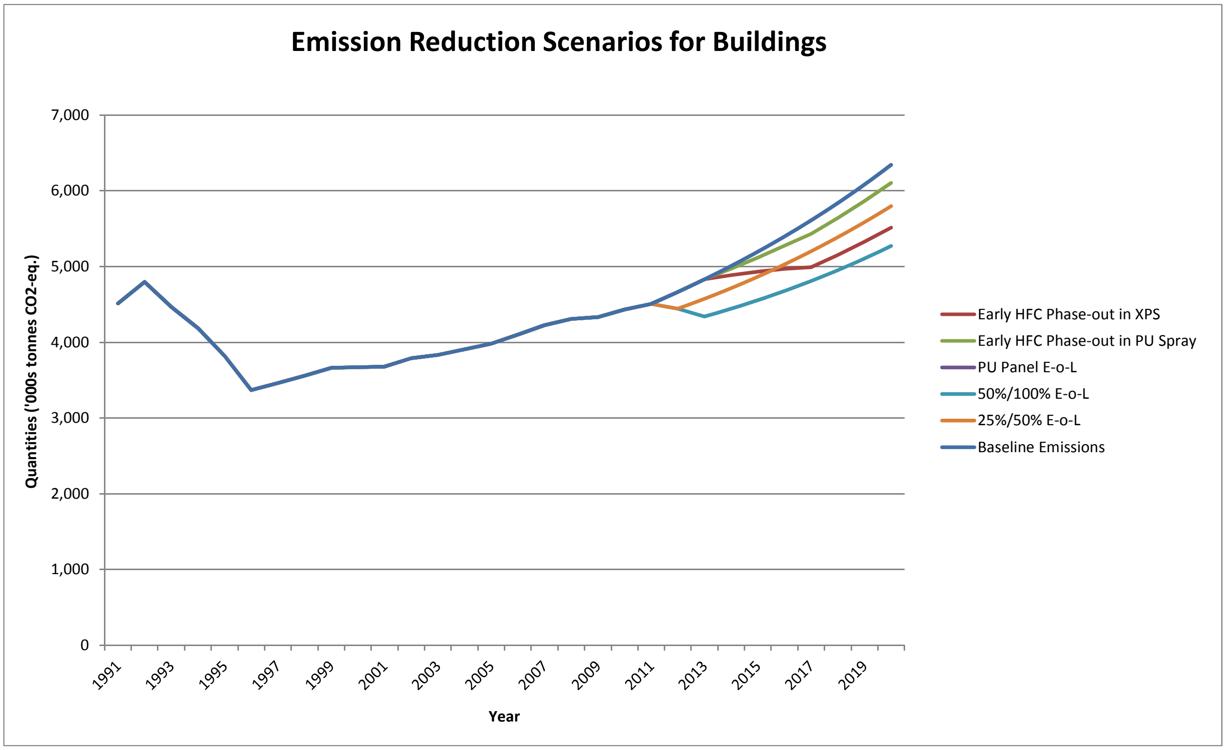
Figure 3-31 SAVINGS OPPORTUNITIES IN THE BUILDING SECTOR FOR CALIFORNIA



This fact also extends into the scenarios on other end-of-life measures, but despite this, the potential cumulative emissions savings range from 4.66 million tCO_2-eq. to 8.73 million tCO_2-eq. for all GHGs, and 0.68 to 1.34 million tCO_2-eq for HFCs alone, indicating the potential importance of end-of-life measures in this sector. However, the cost-effectiveness of these measures is still in question and is discussed further in Section 4.

The impact of early HFC phase-out measures in the XPS sector could reach 3.7 million tCO_2-eq. in reductions by 2020, with the PU Spray sector potentially contributing a further reduction of 1 million tCO_2-eq. This relates to the fact that both are fairly emissive processes in the manufacturing stage. The scheduled phase-outs are very similar in both cases, but the differentiation of the two scenarios is relatively easy in Figure 3-32 as projection based solely on XPS emissions reductions quickly exceeds that for PU Spray Foam.

Figure 3-32 EMISSION REDUCTION SCENARIOS FOR BUILDINGS
-

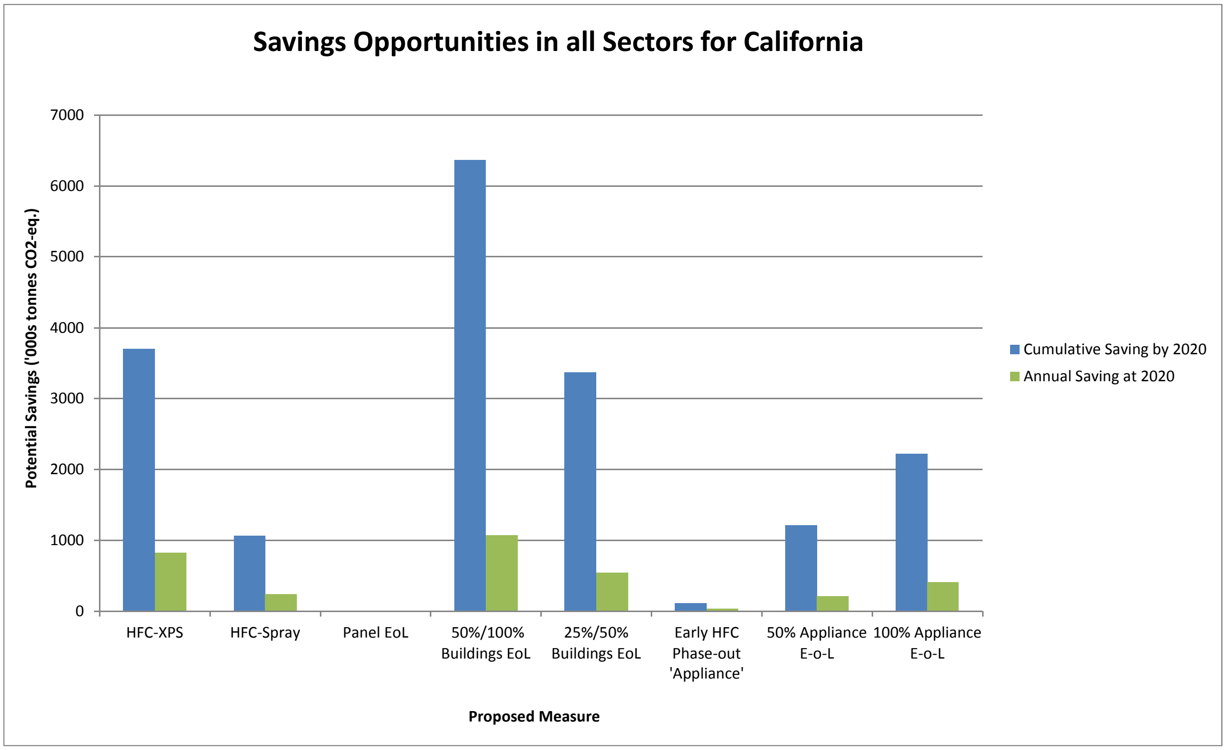


In this graph the impact of the 'PU Panel E-o-L' is plotted, but is so small in relation to the others, that the line is not visible behind the baseline projection.

Summary of Mitigation Options

The analysis shows that cumulative emissions savings of between 10.22 and 14.29 million tCO_2-eq. could be achieved by a suite of measures in the period to 2020, with annual savings at that stage ranging from 2.01-2.76 million tCO_2-eq. Figure 3.33 illustrates the range of savings:

Figure 3-33 SAVINGS OPPORTUNITIES IN ALL SECTORS FOR CALIFORNIA



.

When considering HFC savings in isolation, Figure 3-34 provides the relevant analysis. No HFC savings are realized by 2020 from panel and building EOL.

Figure 3-34 HFC SAVINGS OPPORTUNITIES IN ALL SECTORS FOR CALIFORNIA

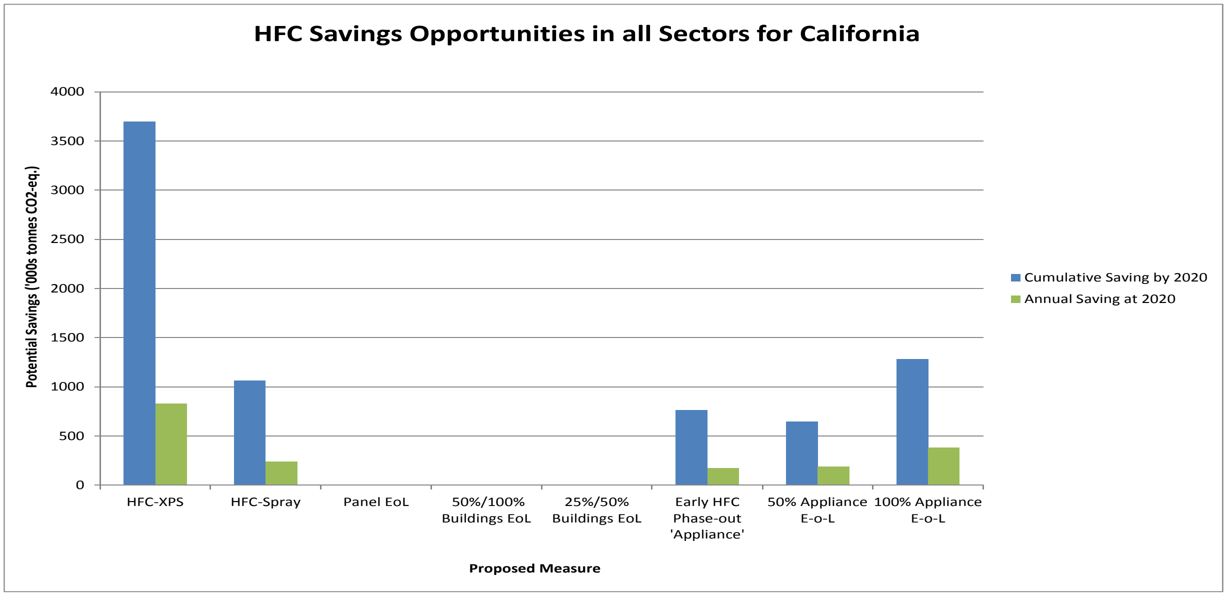


Figure 3-35 and Figure 3-36 show the distributions of these cumulative and annual savings for both HFC and ODS based on the maximum achievable technical potential.

Figure 3-35 MAXIMUM CUMULATIVE MITIGATION POTENTIAL FOR HIGH GWP GASES IN 2020

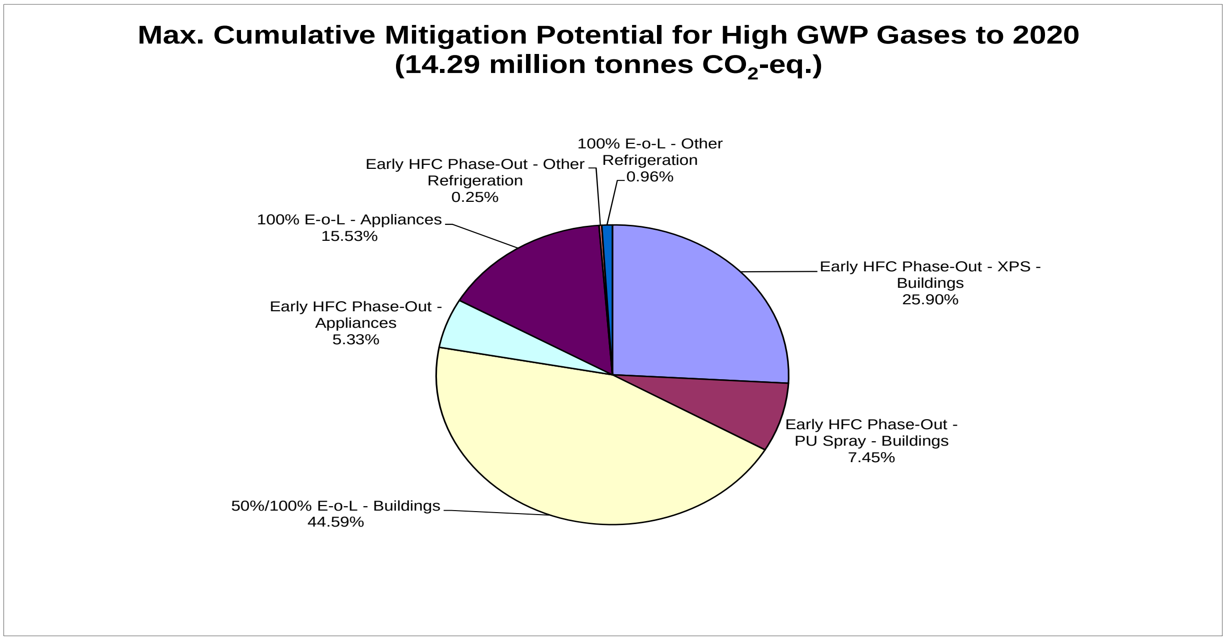
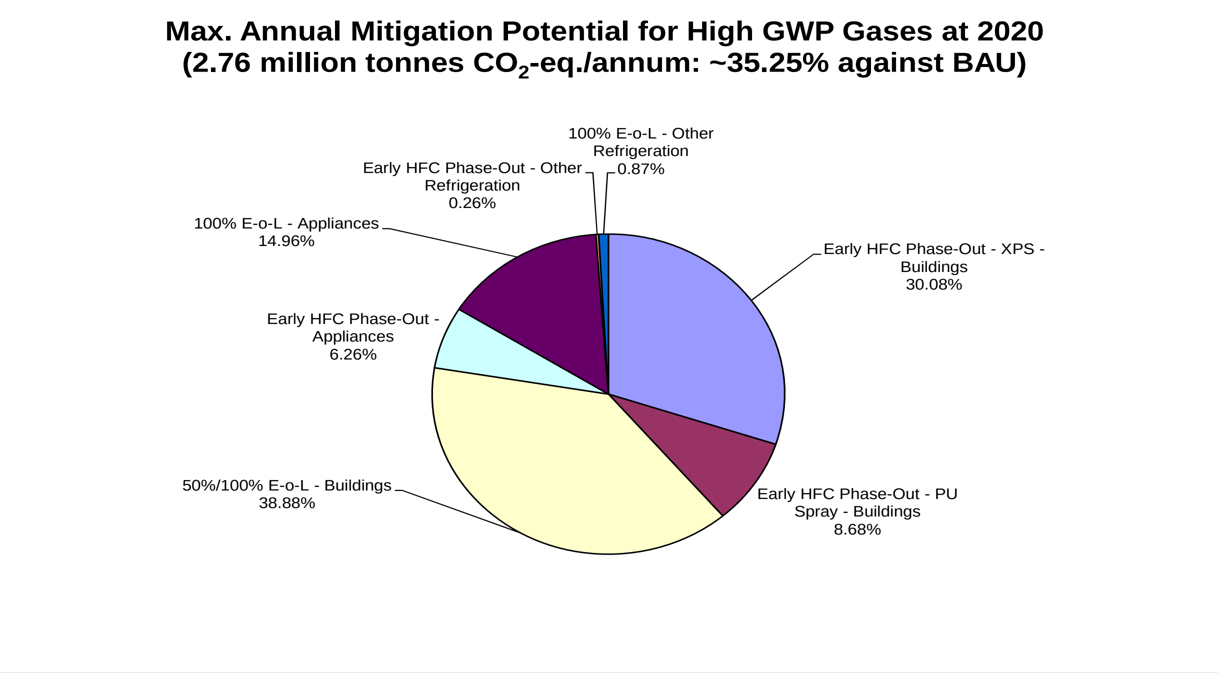


Figure 3-36 MAXIMUM ANNUAL MITIGATION POTENTIAL FOR HIGH GWP GASES AT 2020



4. Discussion

4.1. Review of the Central Proposition

Section 1.3 sets out a paraphrase of the objectives of this project in the form of a Central Proposition. This is set out again below in italics.

The central proposition behind this project is that it could make environmental sense from a climate policy perspective to mitigate emissions by either reducing current reliance on high-GWP blowing agents or by separating and diverting ODS and HFC containing foams out of the waste stream to be processed in ways that avoid ozone depletion and GHG emissions and that it is practicable to do so. The inventory and assessment of potential mitigation strategies are designed to help confirm or dismiss this proposition prior to a more in depth assessment of policy options which, in itself, is outside of the scope of this project.

This proposition is then used in the subsequent sub-sections to assess the value of the findings of this work in context. However, before doing so, it is appropriate to reflect for a moment on the proposition itself.

Following the passing of Assembly Bill 32 in 2006, CARB published a Staff Report in November 2007[12] quantifying the baseline emissions in 1990 and, thereby, establishing the target for emissions from the State in 2020. The total agreed was 427 million tCO_2-eq. That target was seen to be a 25% reduction against the levels existing in 2006 when AB 32 was passed, but is now seen as a 15% reduction in 2010 – indicating the impact of the recession on emissions in the interim. The Business-as-Usual projections contained in the Staff Report suggested that emissions would reach 600 million tCO_2-eq. per annum in 2020, making a reduction of 40% necessary. Clearly, per capita targets would depend on changes in population in the intervening period.

With real savings of 173 million tCO_2-eq. required annually by 2020, it was clear that a number of measures would be required. These have been set out in California's Climate Action Plan which is being continually updated as new policy initiatives are evaluated and agreed upon. High Global Warming Potential Gases are already part of that Plan, particularly where HFCs have been replacements for ODS. However, there has been more debate about the inclusion of ODSs themselves. These were not included in the baseline plotted in the Staff Report of 2007, but it was acknowledged

---

[12] California Air Resources Board – Staff Report 'California 1990 Greenhouse Gas Emissions Level and 2020 Emissions Limit' – November 16, 2007 (CARB, 2007b)

that HFC use in 1990 was at its very early stages because the transition away from ODSs had only just begun at that point.

Irrespective of the ultimate policy treatment, it is meaningful to evaluate the potential avoided emissions from ODS/HFC recovery and destructive in the light of the 173 million tCO_2-eq. annual target in 2020.

The mitigation scenarios selected during this project have already been outlined in Section 3.9. However, it is worth reviewing the global context for the selection of these specific measures.

4.1.1. End-of-Life Measures

The Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol has been actively quantifying and locating banks of ODS in a series of studies responding to decisions of the Parties. The latest of these was Decision XX/7 which initiated the most comprehensive review of banks and potential mitigation options yet.

The Task Force convened by the TEAP to complete this work reported in two separate reports: Phase 1 in June 2009 and Phase 2 in October 2009. The second of these reports focused particularly on the quantification of savings that could be achieved, the timing at which recovery and destruction would be required and the cost of so doing. As had been the case in earlier studies, the TEAP Task Force divided the ODS Banks into three major categories of ‘effort’: low, medium and high. Although ‘effort’ is partially a synonym for ‘cost’, this is not completely the case, since there is some adjustment for the fact that the relative costs of some sectors, such as foams, will always be higher than other sectors, such as refrigeration. Rather than having all refrigerant recovery in the ‘low’ category and all foam in the ‘high’ category, there is some offsetting to allow a level of differentiation within each sector. Note that although the emphasis of the research was on reducing ODS emissions, most of the conclusions could also apply to reducing HFC emissions as well.

The TEAP analysis also recognized that recovery from densely populated (urban) areas would be easier than from sparsely populated (rural) areas. Its full analysis is summarized in the following Table 4-1:

Table 4-1 LEVELS OF EFFORT REQUIRED TO MANAGE ODS BANKS

Sector	***Low Effort***	***Medium Effort***	***High Effort***
Domestic Refrigeration - Refrigerant	DP	SP	
Domestic Refrigeration – Blowing Agent	DP	SP	
Commercial Refrigeration - Refrigerant	DP	SP	
Commercial Refrigeration – Blowing Agent	DP	SP	
Transport Refrigeration - Refrigerant	DP/SP		
Transport Refrigeration – Blowing Agent	DP/SP		
Industrial Refrigeration - Refrigerant	DP/SP		
Stationary Air Conditioning - Refrigerant	DP	SP	
Other Stationary Air Conditioning - Refrigerant	DP	SP	
Mobile Air Conditioning - Refrigerant	SP	SP	
Steel Faced Panels – Blowing Agent		DP	SP
XPS Foams – Blowing Agent			DP/SP*
PU Boardstock – Blowing Agent			DP/SP*
PU Spray – Blowing Agent			DP*/SP*
PU Block - Pipe		DP	SP
PU Block - Slab		DP	SP
Other PU Foams – Blowing Agent			DP/SP*
Halon – Fire Suppression	DP	SP	

DP = Densely Populated Areas SP = Sparsely Populated Areas * = Still technically unproven

This table underlined the fact that, even when cost elements were not explicitly addressed, the management of existing ODS banks, in foams, was seen as representing the most significant challenge (largely high effort). Indeed, in some instances (e.g., PU Spray Foams) it was acknowledged that recovery and destruction of blowing agents from those sources was still globally unproven technically. This reflects the fact that flows of ODS into building demolition waste streams are still in their infancy and there is little global experience as yet in managing such materials. Even in Japan, where the regulation of demolition processes attracts high levels of compliance, a study on ODS Bank Management in the built environment conducted by the Japan Technical Committee on Construction Materials (JTCCM) in the period 2002-2005 concluded that it was not possible to mandate the recovery and destruction of ODS in buildings because of continuing uncertainties about technical feasibility and economic impacts. Of course, this is not to rule out the likelihood that experience will spawn innovation and technological development in this area. However, the Japanese view was that this is best achieved by voluntary action, often supported by incentives, rather than unenforceable legislation.

Against this background, the TEAP analysis decided to exclude those ODS banks in the high effort category from further consideration, since neither technical feasibility nor economic viability could be established from the available data. However, there were a few foam sectors which fell into the medium effort category, at least in the densely populated urban areas, and these were identified as follows:

- Appliances
- Commercial Refrigeration
- Steel-faced Panels
- Block Pipe Section and Slab

In practice, the quantity of block (bun[13]) manufactured and used globally is relatively small as a proportion of the total. Where pipe section is produced from block (or, indeed, extruded from thermoplastic foams), there is a potential for recovery during decommissioning. This may also be the case for block (bun) foam prefabricated for use in composite panels. Cost estimates were therefore produced only for these areas of foam use. Table 4-2 shows the outcome of the TEAP analysis on costs of recovery and destruction based per kilogram of blowing agent destroyed.

For steel-faced panels there is also some relevant experience, since these products tend to be used on buildings in Europe with shorter average life-times than traditional constructions (typically 30 years). Although these are only now reaching the waste stream in any number, the potential to use existing refrigerator de-manufacturing equipment or even direct incineration exists. In most cases, the presence of the steel facings also adds to the economic case since these can be recovered and recycled. Nevertheless, across the European Union's 27 member states (EU-27) there is a large range of demolition waste practice. Only where waste segregation is already highly advanced (e.g., Austria) does the economics of recovery and destruction stack-up. There is therefore some reticence within some Member States to see any move towards a mandated recovery and destruction requirement for ODS in steel-faced panels. However, the potential of an incentive-led approach, perhaps based on carbon valuation, may prove a more mutually acceptable way forward.

In contrast to the challenges of the building sector, there is considerably more experience in managing foams from appliances and commercial refrigeration equipment. In several regions of the world, including Europe and Japan the recovery of blowing agents from domestic refrigerators and freezers has been required. This has been extended over time to cover other types of appliance. In the case of Europe this has been driven by product lifecycle legislation such as the WEEE[14] Regulation

---

[13] Often called 'bun' foam in North America.

[14] WEEE – 'Waste Electrical and Electronic Equipment'

rather than the ozone regulations per se, although efforts have been made to ensure that both regulatory strands are complementary to one another.

This said, there have been on-going concerns in Europe about the percentage of end-of-life appliances being de-manufactured in line with the legislative requirements as well as the maintenance of adequate standards for recovery and destruction within those operations designated to manage the process. Even in Germany, a recent study uncovered a number of failures to uphold the existing standards. Further investigation revealed that the most likely cause of these malpractices has been the over-capacity in the sector, with prices for the de-manufacture of domestic refrigerators dropping from their initial levels in excess of $25/unit to values as low as $8/unit.

Table 4-2 TEAP ANALYSIS ON COST OF ODS RECOVERY & DESTRUCTION

Effort Level	Sector	Population Density	ODS Recovered	Segregation/ Collection Costs	Transport Costs (Recovery)	Recovery Processing Costs	Transport Costs (Destruction)	Destruction Costs	Total Cost
				(US$ per kg)	*(US$ per kg)*	*(US$ per kg)*	*(US$ per kg)*	*(US$ per kg)*	*(US$ per kg)*
Low Effort	Domestic Refrigerators	Dense	Refr.	6-10*	6-8	10-20	0.01-1.0**	5-7	27-46
	Domestic Refrigerators	Dense	BA			20-30			37-56
	Commercial Refrigerators	Dense	Refr.	8-12*	8-10	8-15	0.01-1.0**	5-7	29-45
	Commercial Refrigerators	Dense	BA			25-35		5-7	46-65
	Transport Refrigeration+	Dense/ Sparse	Refr.	------	------	15-20	0.01-1.0**	5-7	20-28
	Industrial Refrigeration	Dense/ Sparse	Refr.	------	------	4-6	0.01-1.0**	5-7	9-14
	Stationary A/C ^	Dense	Refr.	1-2^^	------	4-25	0.01-1.0**	5-7	10-35
	Mobile A/C	Dense	Refr.	------	------	4-6	0.01-1.0**	5-7	9-14
	Fire Protection	Dense	Fire Supp.	1-2^^	------	4-25	0.01-1.0**	6-8	11-36
Medium Effort	Domestic Refrigerators	Sparse	Refr	10-15*	30-40^^^	10-20	0.01-1.0**	5-7	55-83
	Domestic Refrigerators	Sparse	BA			20-30			65-93
	Commercial Refrigerators	Sparse	Refr	15-20*	40-50^^^	8-15	0.01-1.0**	5-7	68-93
	Commercial Refrigerators	Sparse	BA			25-35		5-7	85-113
	Stationary A/C	Sparse	Refr	1-2^^	------	10-35	0.01-1.0**	5-7	16-45
	Mobile A/C	Sparse	Refr	1-2^^	------	4-6	0.01-1.0**	5-7	10-16

Effort Level	Sector	Population Density	ODS Recovered	Segregation/ Collection Costs	Transport Costs (Recovery)	Recovery Processing Costs	Transport Costs (Destruction)	Destruction Costs	Total Cost
Medium Effort	Steel-faced Panels	Dense	BA	75-90	5-10	30-40	0.01-1.0**	5-7	115-148
	Block - Pipe	Dense	BA	10-15	15-20	30-40	0.01-1.0**	5-7	60-83
	Block - Slab	Dense	BA	80-100	5-10	30-40	0.01-1.0**	5-7	120-158
	Fire Protection	Sparse	Fire Supp.	1-2^^	------	10-35	0.01-1.0**	6-8	17-46

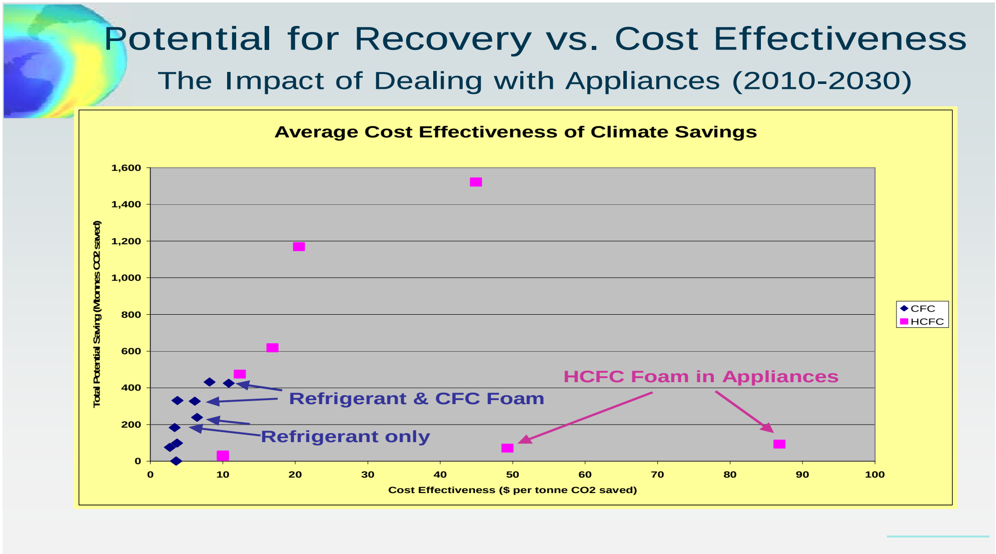
Key: Refr. = Refrigeration
BA = Blowing Agent

Fire Supp. = Fire Suppression

* = Very dependent on local collection strategy
** = Covering shipment distance of 200 – 1000 km for destruction
\+ = Refrigerant only
^ = Assumed on-site recovery
^^ = Awareness raising for recovery schemes
^^^ = Shipping complete units

Another factor to consider here is that voluntary carbon finance cannot be leveraged in the region, even though the relevant methodologies (Voluntary Carbon Standard (VCS) and Climate Action Reserve (CAR)) apply to these recovery and destruction operations. This is because the market sees no 'additionality' from ODS recovery and destruction in regions where the measure is already mandated. Even if such funding were to be available, its contribution would be less substantial for HCFC recovery and destruction than for CFC recovery and destruction. This observation arises from the lower GWP of HCFCs in comparison with CFCs. An additional piece of analysis of the TEAP data for developing countries, as presented at the July 2010 Geneva Workshop on ODS Bank Management, illustrated that even the recovery of foam from appliances can be costly in climate terms as Figure 4-1 shows:

Figure 4-1 POTENTIAL FOR RECOVERY VS COST EFFECTIVENESS



Potential for Recovery vs. Cost Effectiveness

The Impact of Dealing with Appliances (2010-2030)

Depending on location (urban or rural) the cost of recovery and destruction of HCFCs in appliance foam can range from $115-$150 per tCO$_2$-eq. saved. This compares to a figure of $10 per tCO$_2$-eq. saved for CFCs when recovered from both the refrigerant and foam at the same time. The analysis doesn't take into account the recovery of HFC-134a refrigerant in the appliance, which can, of course, provide additional climate benefit for a given investment under appropriate circumstances.

Even at these relatively inflated costs for ODS bank management, the recovery and destruction of appliance foam is more cost effective in climate terms on a per kilogram basis than building foams, but not on a per MTCO$_2$E reduction basis (due to the relatively lower greenhouse gas potential in HCFC and HFC-containing appliance foams compared to CFC-containing building foams). The Milieu Study in 2007 initiated by the European Commission ahead of its review of the existing Ozone Regulation was assisted by Caleb in identifying costs for recovery and destruction of blowing agents from steel-faced panels, when compared with appliance foams (Milieu, 2007). Table 4-3 illustrates this information in $ per kg of blowing agent recovered and managed, from dismantling through destruction.

Table 4-3 COST ANALYSIS FOR RECOVERY & DESTRUCTION OF STEEL-FACED PANELS

Cost is shown in $/kilogram of insulating foam unless otherwise stated.

Foam Recovery Activity	**Domestic Appliance (for baseline cost comparison)**	**Steel-Faced Panels JTCCM (Japan)** [a]	**Steel-Faced Panels - Kingspan Panels (U.K. Trial Projects)** [b]	**Steel-Faced Panels Austria Study** [c]
Dismantling	--------------- [d]	$70 - $83	$83 - $115	N/A - Discounted
Sorting	--------------- [d]	$4 - $5	$5 - $8	N/A - Discounted
Transport	$32 - $45	$26 - $32	$6 - $13	$32 - $38 both transport and Destruction
Destruction	$51 - $64	$26 - $32	$32 - $45	
Total Cost ($/kg foam blowing agent)	$83 - $109	$126 - $152	$126 - $181	$32 - $38 (discounted)
Total cost converted to $/MTCO$_2$E [e]	$115 - $150	$41 - $50	$41 - $59	$12 - $14 (discounted)

Table Notes:

a) According to the United Nations Environment Programme's 2006 Report of the Rigid and Flexible Foams Technical Options Committee, "In Japan, the JTCCM (Japan Technical Committee on Construction Materials) project has made comparisons between direct foam incineration and blowing agent recovery/destruction options for building insulation. In the latter case, the efficiency of recovery is highly dependent on the particle size of the foams at demolition. The study concludes that the costs of the two routes are relatively similar, but that, at best, these are around 4-5 times higher than the cost of recovering refrigerant (i.e., around $150 per kg of blowing agent recovered). In situations where there is less retained blowing agent, the costs can be ten times higher. With these cost considerations in mind, the Japanese Government has decided to adopt a strategy of promoting voluntary action on blowing agent recovery from buildings via its Construction Material Recycling Law. This is in contrast to earlier thinking which suggested that a mandatory approach could be applied. In parallel, the Government is also keenly promoting non-HFC policies to avoid future recovery burdens of this nature."

b). United Kingdom trial projects to determine feasibility of foam recovery from building panels. Additional information in "Kingspan Panels Sustainability Report – Harnessing an Ability for Positive Change" Kingspan Insulating Panels, 2006. (Kingspan, 2006b).

c) The Steel-Faced Panels Austria Study costs were heavily discounted, should not be used to estimate costs in California, and are shown only for reference.

d) Dismantling and sorting costs not included here because these activities were already being conducted to remove refrigerant, metals, and other materials from appliances. However, in California, appliance recyclers who recover and manage insulating foam from the appliance do incur higher costs for dismantling and sorting. These higher costs are not reflected in the studies summarized in this table.

e). The cost assumes a mix of foam blowing agents recovered and destroyed. Estimated mix for recycled appliances in 2010 is 2% HFC-134a and 98% HCFC-141b. Estimated mix for building panel foam recycled in 2010 is 90% CFC-11, 7% HCFC-141b, and 3% HFC-245fa. Cost of foam recovery and destruction expressed in $/MTCO_2E destroyed (reduced) is highly dependent upon the type of high-GWP greenhouse gas within the foam. Unlike the cost per kilogram destroyed, which is constant, the GWP of the foam blowing agent is responsible for a high or low cost per $MTCO_2E$ reduction. Foams containing higher-GWP agents such as CFC-11 (GWP of 4680) are less expensive to manage per $MTCO_2E$ because they have more $MTCO_2Es$ per kilogram recovered than a lower GWP agent such as HCFC-141b (GWP of 713). Thus, each kilogram of CFC-11 recovered contains 6.6 times more GHG "content" than HCFC-141b (GWP of 4680 divided by GWP of 713 equals 6.6.). As GWP of the foam blowing agent decreases, less $MTCO_2E$ per kilogram is contained in the recovered foam, increasing the unit cost of recovery in terms of \$/$MTCO_2E$ reduction. For example, at a current estimated cost of \$83-\$109 to recover and destroy each kilogram of appliance foam, then the cost for appliances containing only CFC-11 is \$18-\$23/ $MTCO_2E$; while the cost would be \$116-\$153/ $MTCO_2E$ for appliances containing only HCFC-141b, and \$88-\$115/ $MTCO_2E$ for appliances containing only HFC-245fa.

The information suggests that kilo-for-kilo; blowing agent from insulation in steel-faced panels would be approximately twice as expensive to recovery and destroy as blowing agent from appliances, with a large proportion of the additional cost being associated with dismantling and segregation.

In the most recent study completed by the Building Research Establishment (BRE) in the United Kingdom, the assessment of cost associated with the management of ODS in buildings was in the order of £200 ($300) per tCO_2-eq. saved (BRE, 2010). It should be stressed that the prime purpose of this study was not to review costs in detail, but it is interesting to note that this assessment supports the view that average recovery costs from the wider building sector would be proportionately higher than those associated with steel-faced panels.

4.1.2. Early Phase-out of HFCs

The three main areas of HFC use identified in this study are those associated with the manufacture of PU foams in appliances, PU Spray Foam and extruded polystyrene (XPS).

Again, taking a global perspective to the challenge of early HFC phase-out, it is self-evident that a large proportion of the world's appliances are already being manufactured with hydrocarbons, both in their cooling circuits (where present) and their foams. Although the US appliance industry has reached a level of 25% hydrocarbon use (AHAM, 2010), it has staunchly defended its need for HFCs and, in particular, HFC-245fa on the basis of ever-tightening energy regulations and also on the basis of the particularity of US domestic refrigerator design. There is some evidence that manufacturers are awaiting the commercial introduction of unsaturated HFCs (also referred to as hydro fluoro-olefins or HFOs) which are showing particular promised in respect of thermal performance.

The PU Spray Foam industry globally is in a much more difficult situation, with current hydrocarbons ruled out on safety grounds due to their flammability or combustibility. Efforts are being deployed to evaluate alternatives such as super-critical CO_2 and methyl formate, to name but two. However, there is no obvious alternative at this stage.

For the XPS sector, world production is split between the use of liquid CO_2 (albeit with high capital cost and some product limitations), hydrocarbon (particularly in the Far East where flammability seems to be a less significant issue) and HFCs – particularly for the smaller producers. The role of HFCs in the field is universally recognized and there are no immediate alternatives. Some European manufacturers are experimenting with lower-GWP blends containing di-methyl ether, but these are not yet in commercial use.

The North American XPS industry was able to mount a powerful argument in the early part of the decade, to make the case that the use of XPS for sheathing was unique and that the product requirements were totally different than for other parts of the globe. This led to the extension of the period for use of HCFC-142b/22 blends until 1st January 2010. Therefore, transition to HFC-134a and related blowing agents has been relatively recent.

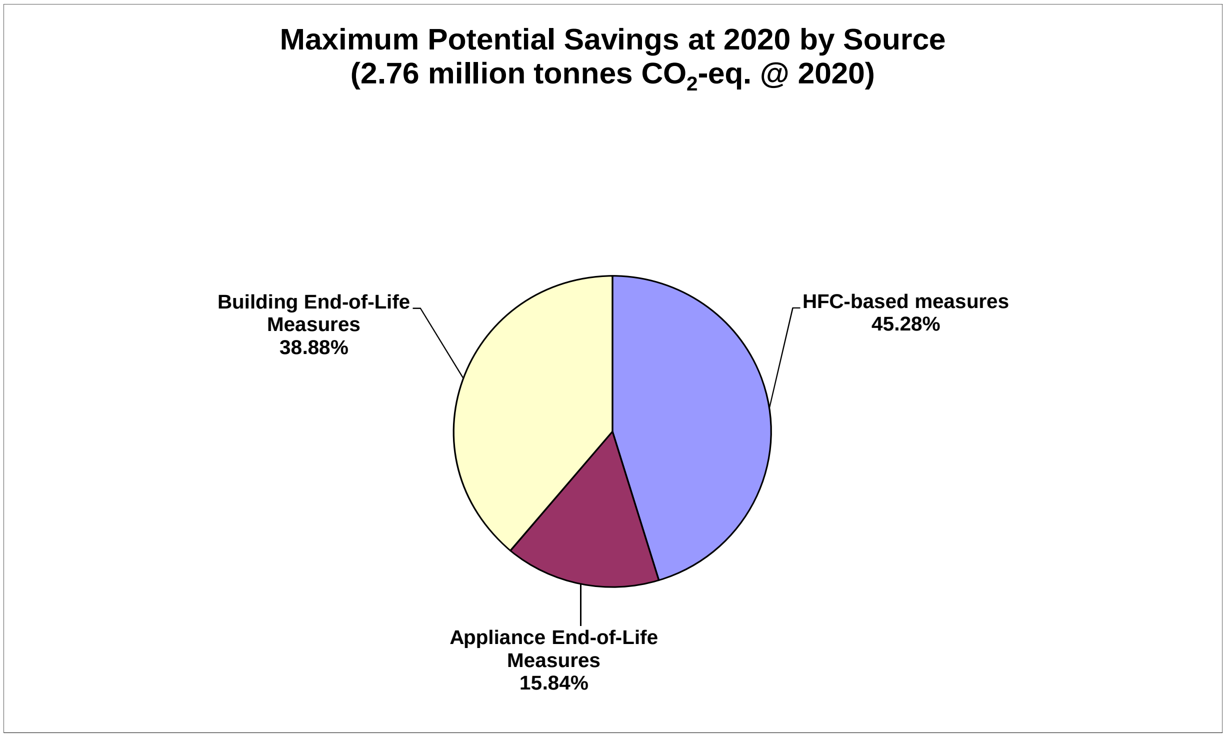
In all three sectors, it is clear that there are still gaps in the available alternatives. Much hope is therefore placed on a new generation of unsaturated HFCs. These typically have GWPs below 10. If the cost structure can be pitched correctly, these could play a large role in the XPS and PU Spray sectors, in particular, and potentially as a means of maintaining and/or improving energy performance in the appliance sector. Since the United States is well placed to take early advantage of these potential blowing agents (because they are being developed there), there is a legitimate prospect that early HFC phase-out can become a reality. This will be even more the case if transitions from high GWP HFCs to these new low GWP unsaturated HFCs can be incentivized through monetization of the carbon emission saving. Bearing in mind the uncertainties remaining, the modeled phase-out has been scheduled from 2014 with completion in 2017.

Costs associated with such transitions are not yet established. However, an, as yet, unpublished report for the Department of Environment, Farming and Rural Affairs (DEFRA) in the UK suggests that the capital costs for a transition to unsaturated HFCs (HFOs) could be modest, although the operating cost increments could be significant.

4.2. Implications on the relevance of Project Findings

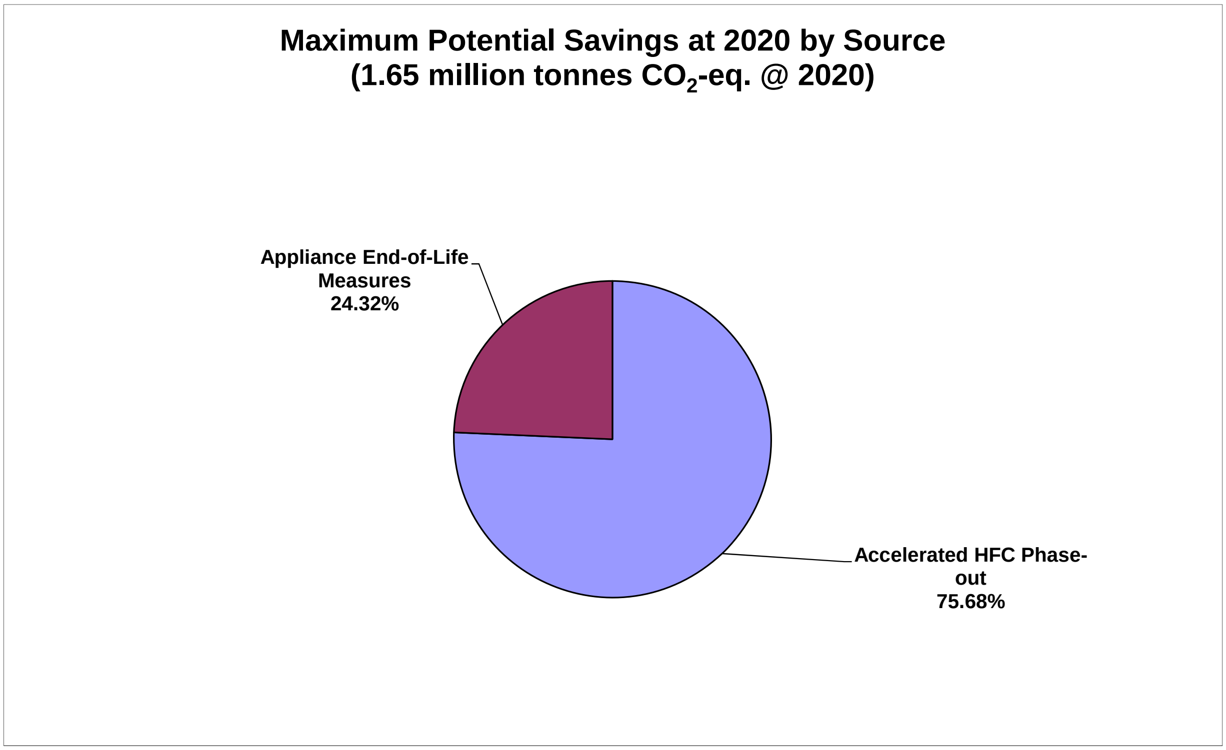
The assessment of mitigation options set out in Section 3.10 indicates that savings up to 2.76 million tCO_2-eq. per annum can be achieved by 2020 (1.65 million tCO_2-eq from HFC, and 1.11 million tCO_2-eq from ODS). Against the AB 32 total target of 173 million tCO_2-eq. per annum reduction goal, the HFC savings represents a small (0.95%), but still a significant, potential saving. The breakdown of the annual saving by source is as follows:

Figure 4-2 MAXIMUM POTENTIAL SAVINGS AT 2020 BY SOURCE



It can be seen that end-of-life savings are slightly in the majority overall but that these are split between two very different sectors, buildings and appliances. However, this is not the case when HFC measures are considered in isolation. Figure 4-3 shows the HFC-portion only of potential savings by source.

Figure 4-3 MAXIMUM POTENTIAL SAVINGS AT 2020 FROM HFC-BASED MEASURES



One of the challenges of assessing the end-of-life benefits arising from measures in the building sector is that those benefits often occur well into the future and can be spread over many years. Since this study is limited to evaluations up to 2020, many of the end-of-life measures are only just taking effect in the latter part of the next decade. Even then, end-of-life measures in buildings could account for over 35% of the annual savings by 2020, highlighting the significance of the sector – a significance that will only grow further in the following decade.

This assessment is also based on the assumption of a 30 year average lifetime for all buildings in California. If that average is, in fact, significantly longer than assumed, the impact of building end-of-life measures will become smaller when measured at 2020, although the savings will still be potentially equivalent in the post-2020 era on a cumulative basis, assuming that measures are deployed to manage building foams at end-of-life over that period.

As explained in Section 4.1, the opportunities for appliance de-manufacture at end-of-life are better understood and established globally. However, even at their maximum potential, they would only deliver around 15.8% of the savings that are believed to be available. One of the challenges that would need to be addressed is achieving widespread uptake of end-of-life appliance schemes. The authors believe that California is in a better position than other regions of the world in this regard, since it has not legislated on the matter so far. This leaves the way open for the leverage of carbon finance in an area in which such finance has already been shown to sway behavior. This is likely to be less likely the case for building end-of-life, where indicative costs suggest that carbon finance will have little impact in the short-term. However, since there is little direct information on the cost structure of activities to manage foams at end-of-life in the buildings structure in California, it is not known whether the early indications of cost from the United Kingdom and elsewhere will play out in the Californian environment.

The contribution to savings in 2020 arising from the potential early phase-out of HFCs in foam-based products is both realizable and economically attractive as a mitigation option. Although all foam manufacturing sectors using HFCs would be potential targets for this activity, it is clear that XPS is the most lucrative sector from a mitigation perspective. The challenge for California is now that all XPS used in the State is manufactured outside of its borders.

This implies that any steps taken to curb the use of HFC-containing XPS foam would need to be applied at the product level rather than the process level. A progressive product ban would be one option, although the use of a progressive taxation might be another. Either way, the regulators would need to be sure that they had a reliable means of distinguishing between HFC and non-HFC containing foams. They would also need to give due consideration to ensuring that unsaturated HFCs (HFOs) were either completely excluded from such a provision or were only taxed at a level commensurate with their respective GWPs.

5. Summary and Conclusions

5.1. Purpose of the Project

The central proposition behind this project is that it could make environmental sense from a climate policy perspective to mitigate emissions by either reducing current reliance on high-GWP blowing agents or by separating and diverting ODS and HFC containing foams out of the waste stream to be processed in ways that avoid ozone depletion and GHG emissions and that it is practicable to do so. The inventory and assessment of potential mitigation strategies are designed to help confirm or dismiss this proposition prior to a more in depth assessment of policy options which, in itself, is outside of the scope of this project. The outputs from this project will assist the California Air Resources Board in developing and implementing strategies that contribute to the State of California reaching its goal of CO_2-eq greenhouse gas (GHG) emission reductions to 1990 levels by 2020.

The specific project purpose was as follows:

- Characterize foams blowing agent banks according to product/application
- Characterize current foam production, use and end-of-life fate according to the main foam using sectors
- Characterize ODS phase-out, replacement and not-in-kind technology trends according to product/application
- Develop a emissions model based on collected blowing agent, foam and phase-out data to indicate emissions now and in 2020 under BAU and other scenarios

5.2. Project Method

The project involved the surveying of 302 organizations responsible for the production, installation, use, and end-of-life management of foams that contain ODS or HFC. Based on the survey findings, a foam Banks and emissions model was developed. The model characterized the distribution of foams and their greenhouse gas containing blowing agents across different end-use sectors and the foam life-cycle. The model also helped identify potential greenhouse gas mitigation options and their climate impact in 2020. The project methodology involved the study of the existing literature, the development of a research plan, the development of tools and materials to be used in the survey process, the analysis of results and the development of the spreadsheet based blowing agent Banks and emissions model.

5.3. Project Findings

5.3.1. Summary of the ODS/HFC Bank

The ODS/HFC Bank peaked in 1996 at nearly 364 million tCO$_2$-eq. and has been gradually reducing since then. In 2005 it was around 316 million tCO$_2$-eq.The buildings end-use accounted for 85% and the appliances end-use accounted for 9% of the 2005 Bank. Other applications – Transport Refrigerated Units and Marine buoyancy accounted for the remaining 6%. By 2020, the Bank is estimated to be 227 million tCO$_2$-eq. Although the total Bank is decreasing due to the continuing phase-out of ODSs, the HFC bank continues to increase, with an estimated 31.6 million tCO$_2$eq in 2010; growing to 98.8 million tCO$_2$eq by 2020. The majority of HFC banks growth between 2010 and 2020 will be in the buildings the sector.

Table 5-1 SUMMARY 0F ALL BLOWING AGENT BANKS (1996-2020)

Banks per Application/End-Use Category (million tCO$_2$-eq) - All						
Year	Buildings	Appliances	Other Refrigeration	TRUs	Marine & Other	**Totals**
1996	286.31	41.28	6.08	15.01	15.01	**363.69**
2005	267.72	28.89	2.82	7.81	7.81	**315.05**
2010	244.97	25.15	1.59	3.65	3.65	**279.01**
2020	182.73	37.92	2.01	2.49	2.49	**227.64**

Table 5-2 SUMMARY 0F HFC BLOWING AGENT BANKS (1996-2020)

Banks per Application/End-Use Category (million tCO$_2$-eq) - HFCs only						
Year	Buildings	Appliances	Other Refrigeration	TRUs	Marine & Other	**Totals**
1996	0.00	0.04	0.00	0.00	0.00	**0.04**
2005	2.93	5.79	0.25	0.69	0.69	**10.35**
2010	9.99	17.27	0.89	1.72	1.72	**31.59**
2020	53.98	37.88	2.00	2.47	2.47	**98.80**

5.3.2. Summary of the ODS/HFC Emissions

Greenhouse Gas emissions from the 2005 Bank were just over 6 million tCO_2-eq. – with 66% arising from the buildings end-use and 20% from the appliances end-use. By 2020, annual emissions are estimated to be approaching 8 million tCO_2-eq. Emissions are expected to increase between 2010 and 2020, due to continuing ODS emissions from buildings, and also due to HFC emissions increasing from 0.8 million tCO_2eq in 2010; to 2.43 million tCO_2eq in 2020. Under a business-as-usual scenario, HFC emissions will continue to increase past 2020 as well.

Indeed the majority of HFC emissions in the period from 2010 to 2020 emanate from the building sector, despite the fact that some relevant appliances will reach end-of-life before 2020. The main reason for this is the relatively emissive nature of the XPS and PU Spray Foam activities.

Table 5-3 SUMMARY OF BLOWING AGENT EMISSIONS (1996-2020)

Emissions per Application/End-Use Category (million tCO_2-eq) - All						
Year	Buildings	Appliances	Other Refrigeration	TRUs	Marine & Other	**Totals**
1996	3.37	0.83	0.16	0.30	0.30	**4.96**
2005	3.98	1.21	0.16	0.33	0.33	**6.01**
2010	4.43	0.66	0.07	0.27	0.27	**5.70**
2020	6.34	1.10	0.08	0.15	0.15	**7.82**

Table 5-4 SUMMARY OF HFC BLOWING AGENT EMISSIONS (1996-2020)

Emissions per Application/End-Use Category (million tCO_2-eq) - HFCs only						
Year	Buildings	Appliances	Other Refrigeration	TRUs	Marine & Other	**Totals**
1996	0.00	0.00	0.00	0.00	0.00	**0.00**
2005	0.11	0.13	0.01	0.02	0.02	**0.29**
2010	0.60	0.17	0.01	0.01	0.01	**0.80**
2020	1.41	0.84	0.04	0.07	0.07	**2.43**

5.3.3. Summary of Emission Mitigation Scenarios

Taking due account of the size and dynamics of banks and emissions, the project team identified six mitigation scenarios for high GWP gases in California. These fell into the two key categories of end-of-life management and early phase-out of HFC use. In the mitigation scenarios developed, it is assumed that end-of-life measures require the shortest lead-times and can be initiated as early as 2012, with full implementation in place by 2014.

The products and equipment targeted in the end-of-life scenarios are as follows:

- All appliances (domestic refrigerators, freezers and water heaters)
- Vending machines and commercial refrigeration equipment
- PU Steel-Faced Panels
- Other insulating foams used in buildings.

For the appliances, vending machines and commercial refrigeration sectors, two scenarios have been assumed, one in which 100% of units are successfully managed (the technical potential) and one in which 50% of appliances are successfully managed. The latter is seen as the more realistic worst-case scenario, although something between the two should be achievable based on European and Japanese experience.

For building insulation, the PU Steel-Faced Panel scenario evaluates 100% recovery and destruction (the technical potential) in isolation. This is then combined with 50% recovery from other insulating foams used in buildings. Finally, a more realistic worst-case is modeled where 25% of general building insulation and 50% of panels are assumed to be managed at end-of-life.

Since there is no current federal constraint on the continued manufacture of products containing HFCs, it would be expected that any decision to introduce a phase-down or phase-out in HFC use, even at State level, would need substantial consultation. It has therefore been assumed that any such measure could only commence in 2014 and would not be fully achieved before 2017. The phase-out should apply to all domestic and commercial appliances, extruded polystyrene insulation foam and polyurethane spray foam.

The four sectors identified for HFC phase-out analysis were:

- All appliances (domestic refrigerators, freezers and water heaters)
- Vending machines and commercial refrigeration equipment

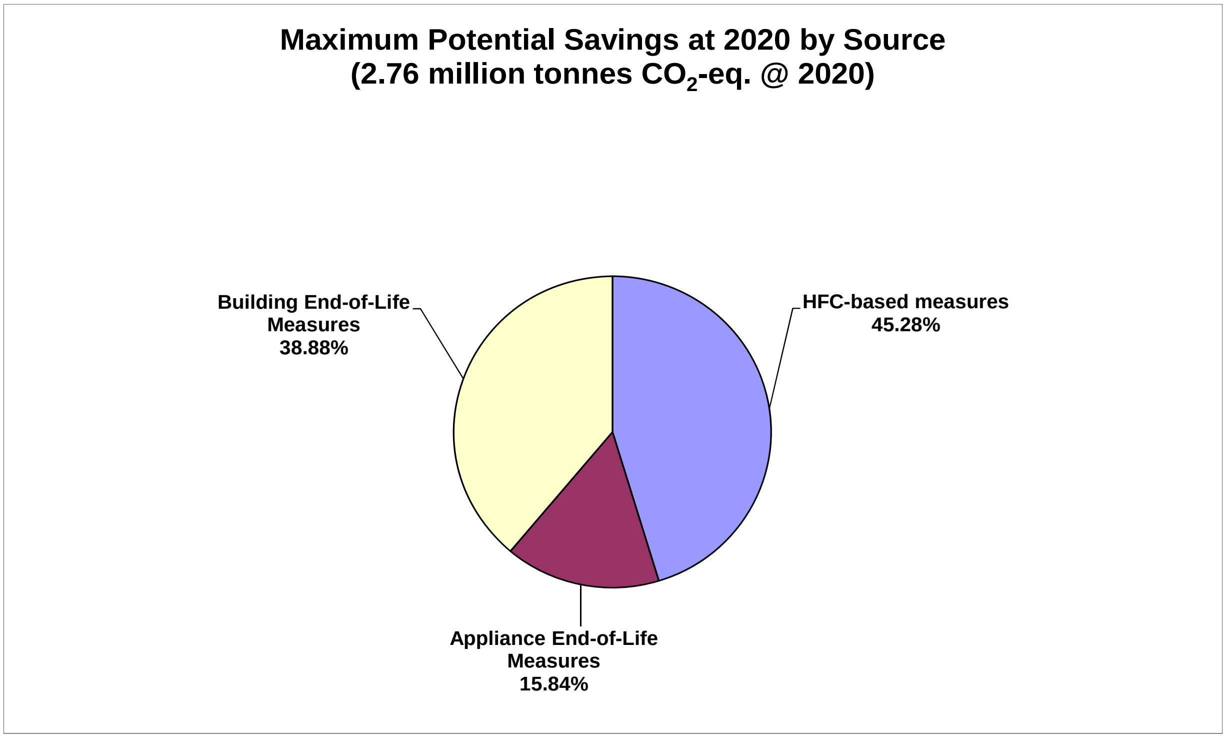
- Extruded polystyrene foam (XPS)
- PU Spray Foam

The following section describes the impacts of these mitigation scenarios by product type.

5.3.4. Impact of Mitigation Scenarios

Caleb's assessment of mitigation options shows that savings up to 2.76 million tCO_2-eq. per annum can be achieved by 2020, with 1.65 million tCO_2-eq. savings from HFCs, and 1.11 million tCO_2-eq. from ODSs. Against the total reduction target of 173 million tCO_2-eq. per annum contained in the Climate Action Plan, published by the California Air Resources Board, the HFC savings portion represents a small (0.95%), but still a significant, potential saving. The breakdown of the annual saving by source is as follows:

Figure 5-1 MAXIMUM POTENTIAL SAVINGS AT 2020 BY SOURCE

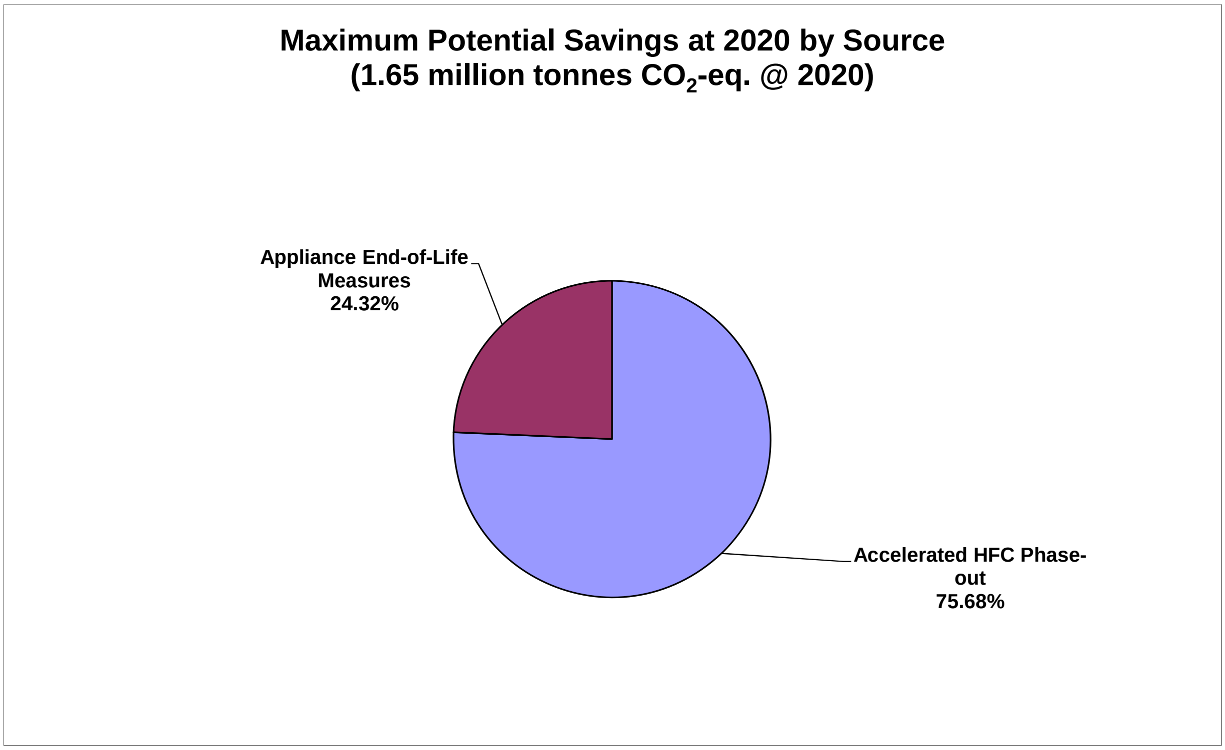


It can be seen that end-of-life savings are slightly in the majority overall but that these are split between two very different sectors, buildings and appliances.

One of the challenges of assessing the end-of-life benefits arising from measures in the building sector is that those benefits often occur well into the future and can be spread over many years. Since this study is limited to evaluations up to 2020, many of the end-of-life measures are only just taking effect in the latter part of the next decade. Even then, end-of-life measures in buildings could account for over 35% of the annual savings by 2020, highlighting the significance of the sector – a significance that will only grow further in the following decade.

Figure 5-2 shows the HFC-portion only of potential savings by source.

Figure 5-2: MAXIMUM POTENTIAL SAVINGS AT 2020 FROM HFC-BASED MEASURES



5.3.5. Uncertainties and Sensitivity Analysis

Although a detailed uncertainty and sensitivity analysis of data is beyond the scope of this research project, a basic analysis was undertaken to identify the data inputs and assumptions that would lead to the highest sensitivity in result outcomes.

Emission factors based on material input (building insulation inventory and types, number of appliances, types of foam blowing agents used, quantities of foam blowing agents manufactured and disposed of annually, etc.) are extremely robust due to the depth of research into the entire life-cycle analysis of foam manufacturing, use, and disposal at end-of-life. Owing to over-lapping data sources and cross-checking, any uncertainties in material input are estimated to change emission estimates less than plus or minus 10-15 percent.

Other factors and assumptions have a lower confidence level in their absolute values, which result in emission estimates and potential reductions being more sensitive to these inputs. The following describes two assumption factors that could potentially contribute to a higher level of uncertainty than optimal.

As previously identified, emissions of ODS and HFC from land-filled foam are highly uncertain owing to the lack of baseline emissions data from landfills that contain waste insulating foam. Additional research to measure actual high-GWP greenhouse gas emissions from California landfills would be useful. Several studies indicate that, under laboratory conditions, CFCs used as foam blowing agents can be attenuated, or biologically degraded, by the anaerobic bacteria which occur in landfills, reducing the foam blowing agents to lower-GWP compounds (HCFCs are also attenuated, but at much slower rates than CFCs, while HFCs are apparently not attenuated in landfills) (Scheutz 2003; and Scheutz 2007).

Therefore, estimates of CFC and HCFC baseline emissions from landfilled building foam are highly sensitive to the actual attenuation (if any) that occurs within California landfills, since typically half of the foam blowing agent remains at the time of disposal. Although 10% of the remaining blowing agent might be lost as a result of breakage and compaction, the on-going emissions may take place over several further decades, making the impact on annual emissions of attenuation potentially quite low when assessed on an annual basis, even though the cumulative impact can be significant.

Emissions from appliances have a similar sensitivity, although it is assumed that about 60 percent of the original foam blowing agent remains in appliance foam when it is landfilled (virtually no in-use losses, 25 percent loss at the time of appliance shredding, and another 15 percent loss within several weeks after landfilling due to compaction and off-gassing that occurs before the foam resides in appropriate anaerobic conditions for biological attenuation). The appliance emission sensitivity to landfill attenuation becomes less pronounced as HFC-containing appliance foam begins to enter landfills in disposal year 2015, and accounts for more than 80 percent of disposed appliances by 2020 (the HFCs are not currently biologically attenuated in landfills).

A second uncertainty lies in the projected emission reductions available through an HFC phase-down schedule. The estimated reductions from using non-HFC foam blowing agents can be achieved with the timeline presented in this analysis, a phase-down beginning in 2014 and fully achieved by 2017. The reductions from an HFC phase-down represent 45 percent of estimated emission reductions from the foam sector. However, it is possible that no HFC phase-down occurs until after 2020 (the last year of emission projections in this research), which means that the achievable reductions would only be about half of the projected reductions estimated in this analysis.

5.4. Conclusions

When comparing the text of the Central Proposition in Section 5.1 with Caleb's analysis, the following conclusions can be drawn:

I. There is technical potential to reduce 1.45-1.65 million tCO_2-eq of the HFC baseline annual emissions from the foam sector in 2020, equating to 0.95% of the overall target of the Climate Action Plan. If we include ODS emissions as well, the reduction potential increases to emission savings of 25-35% of the baseline annual emissions of high GWP gas emissions from the foam sector in 2020, equating to up to 2.76 million tCO_2-eq.

II. The absolute potential will be influenced by the average life-cycles of the products and equipment involved, many of which will be contained in buildings and therefore influenced by the variation in age profiles and lifecycles of the buildings themselves.

III. The major short-term and medium-term opportunities exist in the accelerated phase-out of HFCs in the foam sector and the potential for end-of-life management of appliances.

IV. Although the management of building foams at end-of-life provides a significant opportunity (>35%) for mitigation even at 2020, the cost may be prohibitive when compared with other options available to the Climate Action Plan.

V. Some uncertainties remain over actual high-GWP greenhouse gas emission rates from California landfill locations and the possible impact of potential anaerobic attenuation processes.

6. Recommendations

6.1. Recommendations for further Research

I. To commission further research into the actual variation of building life-cycles by use and construction type.

II. To stimulate research into the development of innovative end-of-life treatment options for foams emanating from buildings taking due account of any additional information emerging on actual baseline emissions.

III. To maintain a watching brief on the approach of other regions and jurisdictions to the management of building foams at end-of-life and to monitor the cost structure of any activities being taken in California for comparison.

6.2. Recommendations for Regulatory changes

I. To seek early dialogue with those foam sectors continuing to rely on HFC use for their products in order to agree a schedule for the phase-out of products containing high-GWP HFCs

II. To further evaluate the potential for leveraging voluntary carbon finance for ODS Bank management with particular focus on the underpinning of the climate value of these savings and promotion of the sound practices specified by the current Climate Action Reserve (CAR) protocol.

6.3. References

ACC, 2006. 2006 End-Use Market Survey of Polyurethanes Industry in the US, Canada & Mexico; American Chemistry Council.

AFEAS, 2000. Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) 2000. Production, sales and atmospheric release of fluorocarbons through 1998, published at www.afeas.org by AFEAS. Paul Ashford of Caleb Management Services contributed “Development of a Global Emission Function for Blowing Agents Used in Closed Cell Foam” (1999 Final Report) that was incorporated into the AFEAS 2000 findings.

AHAM, 2010. Association of Home Appliance Manufacturers, personal communication from Kevin Messner of AHAM to ICF International, June 2010, and forwarded to Caleb Management Services, Ltd, July 2010

BCAP, 2010. Building Codes Assistance Project (BCAP) – http://bcap-energy.org (last accessed 7/26/10).

BRE, 2010. Assessment of building foams containing ozone – depleting substances in the UK Building Stock; Building Research Establishment (BRE), 2010.

CARB, 2007a. Draft Concept Paper – Foam Recovery & Destruction Program; California Air Resources Board 2007. (Based on extrapolations from the U.S. EPA Vintaging Model.).

CARB, 2007b. California Air Resources Board – Staff Report ‘California 1990 Greenhouse Gas Emissions Level and 2020 Emissions Limit’ – November 16, 2007.

CARB, 2008. Foam Recovery & Destruction: California Air Resources Board AB 32 Climate Change Early Action Measure – Background for the Working Group Pre-Meeting; May 2008.

CARB, 2009. Defining & Determining Emissions for Refrigerated Shipping Containers and the Total Re-generation process in the Vicinity of Shipping Ports; CARB White Paper, 2009.

CEC, 1998, 2005, and 2008. Building Energy Efficiency Standards for Residential and Non-Residential Buildings; California Energy Commission, 1998, 2005, 2008.

CEC, 2000. 2001 California Non-Residential Energy Standards, Task 1 Report: Measure Identification of Analysis Plan; California Energy Commission; 2000.

CEC, 2005. 2005 Building Energy Efficiency Standards, Non-Residential Compliance Manual; California Energy Commission; 2005.

CEC, 2006. California Energy Commission; California State-Wide Residential Appliance Saturation Study, 2006; http://websafe.kemainc.com/RASSWEB/DesktopDefault.aspx (accessed July 16, 2010; last report updated June 30, 2006).

CEC, 2009. California Energy Commission 2009 Forecast Floor Space Data.

CIWMB, 1993. Metallic Discards Management Plan, California Integrated Waste Management Board, Publication No. 500-93-001, August 1993. Note that CIWMB has been re-named CalRecycle.

CIWMB, 1994. Metallic Discards Management Local Enforcement Agency (LEA) Advisory Letter No 11 (LEA Advisory # 11), March 24, 1994.

CIWMB, 2009a. California 2008 State-wide Waste Characterization Study; California Integrated Waste Management Board (CIWMB)/ Cascadia Consulting Group, August 2009.

CIWMB, 2009b. Interview with Greg Dick of the California Integrated Waste Management Board (CIWMB). Construction and demolition (C & D) waste volumes and practices discussed.

DTSC, 2002. DRAFT REPORT California's Automobile Shredder Waste Initiative. Department of Toxic Substances Control, November 2002. Note: The DTSC Draft Report was used for scrap metal recycling informational purposes only, and no regulatory considerations are cited or quoted from this Draft Report. http://www.dtsc.ca.gov/HazardousWaste/upload/HWMP_REP_ASW_draft.pdf (accessed September 2, 2010).

DTSC, 2007. AB 1447 (2007) Changes to the Appliance Recycling Program, Fact Sheet 2007, from California Department of Toxic Substances Control. Additional information on the Certified Appliance Recycling Program at: http://www.dtsc.ca.gov/HazardousWaste/Mercury/Certified_Appliance_Recycler.cfm (accessed September 2, 2010).

Environment Canada, 1999. Cianciarelli, D. Characterization of Emissions from a 812 kWe Reciprocating Engine Fired with Landfill Gas. Meloche Landfill, Kirkland, Québec. Report ERMD 99-05. December 1999.

Environment Canada, 2000a. Cianciarelli, D. Characterization of Emissions from a Power Boiler Fired with Landfill Gas. Report ERMD 99-07. March 2000.

Environment Canada, 2000b. Cianciarelli, D., and Mann, J. Characterization of Emissions from an Enclosed Flare. Trail Road Landfill, Ottawa-Carleton, Ontario. Report ERMD 2000-02. August 2000.

Environment Canada, 2000c. Cianciarelli, D., and Mann, J. Characterization of Emissions from a 925 kWe Reciprocating Engine Fired with Landfill Gas. Waterloo Regional Landfill, Waterloo, Ontario. Report ERMD 2000-04. December 2000.

Environment Canada, 2002. Cianciarelli, D. and Bourgeau, S. Characterization of Emissions from a 1 MWe Reciprocating Engine Fired with Landfill Gas. BFI Usine de Triage Lachenaie Ltée Lachenaie, Québec. Report ERMD 2001-03. January 2002.

Environment Canada, 2005. Greer, A., and Cianciarelli, D. Characterization of Emissions from a 26 kWe Micro Turbine Fired with Landfill Gas. Shepard Landfill, Calgary, Alberta. Report ERMD 2004-02. January 2005.

Godwin, 2003. Godwin, D., Van Pelt, M.M., and Peterson, K. Modeling Emissions of High Global Warming Potential Gases from Ozone Depleting Substance Substitutes. Proceedings from 12th International Emission Inventory Conference, San Diego, California, April 29 – May 1, 2003. Accessed August 27, 2010 at <http://www.epa.gov/ttn/chief/conference/ei12/green/godwin.pdf>.

ICF International, 2008. Study on the Collection and Treatment of Unwanted Ozone-Depleting Substances in Article 5 and Non-Article 5 Countries. ICF International, Final Report May 2008.

IPCC/TEAP, 2005. Intergovernmental Panel on Climate Change and Technology and Economic Assessment Panel (IPCC/TEAP) Special Report: Safeguarding the Ozone Layer and the Global Climate System, 2005.

Kingspan, 2006a. End of Life Options for Steel based Building Envelope Systems; Kingspan Insulated Panels, 2006.

Kingspan, 2006b. Kingspan Panels Sustainability Report – Harnessing an Ability for Positive Change" Kingspan Insulating Panels, 2006.

Martin Labbe LLB, 2005. Analysis of Impact of California Truck Refrigeration Unit (TRU) Regulation; Martin Labbe LLB, 2005.

Milieu, 2007. Review of the implementation of Regulation (EC) No 2037/2000 on substances that deplete the Ozone Layer: Regulatory Options; Milieu Environmental Law & Policy; 2007.

NMMA, 2006. 2006 Recreational Boating: Statistical Abstract; National Marine Manufacturers Association (NMMA).

O’Connor, 2004. Survey on actual service lives for North American buildings; J. O’Connor, Forintek Canada Corp., 2004. Presented at Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, October 2004.

PURRC, 2005. Polyurethane Recycling; Polyurethane Recycle & Recovery Council (PURRC), 2005.

SBI Energy, 2008. Polystyrene and Polyurethane Foam Insulation Products in U.S. Building and Construction; SBI Energy, 2008.

Scheutz, 2003. Scheutz, C., Fredenslund, A.M., and Kjeldsen, P. Attenuation of Alternative Blowing Agents in Landfills. Environment and Resources, DTU, Technical University of Denmark; August 2003.

Scheutz, 2007. Attenuation of Fluorocarbons Released from Foam Insulation in Landfills; C. Scheutz, Y. Dote, A.M. Fredenslund, H. Mosbek, P. Kjeldsen; Technical University of Denmark, Environmental Science &Technology Vol. 41, No. 22, 2007.

Scheutz, C.; and Kjeldsen, P, 2002. Determination of the Fraction of Blowing Agent Released from Refrigerator/Freezer Foam after Decommissioning the Product. Report, Association of Home Appliance Manufacturers, 2002.

Skeist Inc., 2004. “Blowing Agents for Polyurethane Rigid Foam”; Skeist Inc., 2004. Docket ID EPA-HQ-OAR-2004-0507-002, www.regulations.gov.

TEAP, 2009. United Nations Environment Programme (UNEP) Technology and Assessment Panel (TEAP) Task Force Decision XX/7 – Phase 2 Report “Environmentally Sound Management of Banks of Ozone-Depleting Substances”, October 2009.

U.S. Bureau of the Census, 1997. Construction Statistics Data User’s Conference; US Bureau of the Census; 1997.

U.S. Department of Commerce, 2010. National Income & Product Accounts Database: US Department of Commerce; Bureau of Economic Analysis; Table 1.1.1 Percent Change from Preceding Period in Real GDP (1960-2008). http://www.bea.gov/national/nipaweb/TableView.asp?SelectedTable=1&ViewSeries=NO&Java=no&Request3Place=N&3Place=N&FromView=YES&Freq=Year&FirstYear=1960&LastYear=2008&3Place=N&Update=Update&JavaBox=no (last accessed 07/25/10).

US EPA, 2001a. U.S. High GWP Gas Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions. EPA 000-F-97-000. June 2001.

US EPA, 2001b. Municipal Solid Waste in The United States: 2001 Facts and Figures. EPA/530-R-03-011. October 2003.

US EPA, 2004. Analysis of Costs to Abate International Ozone-Depleting Substance Substitute Emissions. EPA 430-R-04-006., June 2004.

US EPA, 2005. U.S. EPA Vintaging Model data for CFC, HCFC, and HFC banks from high-global warming potential greenhouse gas and ODS sectors, 2005.

US EPA, 2010. United States Environmental Protection Agency, Responsible Appliance Disposal (RAD) Program website. Overview and requirements of the voluntary RAD program at: http://www.epa.gov/ozone/partnerships/rad/index.html (accessed August 31, 2010).

Westberg, 2007. How Electric Customers Dispose of Used Refrigerators and Why They Choose a Utility Program; S. Westberg, et al.; 2007 Energy Program Evaluation Conference, Chicago; (also see for paper http://www.cee1.org/eval/db_pdf/652.pdf).

Wethje, 2005. Disposal of Refrigerators-Freezers in the US: State of the Practice; L.R. Wethje, P/E.; Appliance Research Consortium, 2005.

7. List of Inventions Reported and Publications Produced

7.1. *Task 1 Report: Literature Review*

7.2. *Task 2 Report: Revised Research Plan*

7.3. *Task 3 Report: Compendium Report: Data, Interview Database & Questionnaires*

7.4. *Tasks 4 & 5 Report: Screening & Technical Interview Report*

7.5. *Preliminary Blowing Agent Banks & Emissions Model*

7.6. *Advanced Blowing Agent Banks & Emissions Model*

8. Glossary of Terms, Abbreviations, and Symbols

A	AB	Assembly Bill
	AB 32	Assembly Bill 32 The bill establishes a timetable to bring California into near compliance with the provisions of the Kyoto Protocol
	AB 970	AB 970 (Ducheny, 2000; Electrical Energy: thermal powerplants: permits) requires the California Public Utilities Commission to identify constraints in California's transmission and distribution system and to take actions to remove them.
	AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
	AHRI	Air Conditioning, Heating & Refrigeration Institute
	Anaerobic	requiring the absence of or not dependent on the presence of oxygen
	ARCA	Appliance Recycling Centers of America
	ASHRAE	American Society of Heating, Refrigeration & Air Conditioning Engineers
	ASR	Assorted Shredder Residues
	Armines	ARMINES is the research branch of the Ecole des Mines, one of the "grandes écoles" (great engineering schools) of France (part of project delivery team)
B	B.A.	Blowing Agents
	BAU	Business As Usual
	BRE	Building Research Establishment
	Btu	British thermal unit
C	(C) CAT	(California) Climate Action Team
	CAR	Certified Appliance Recycler
	CAR	Climate Action Reserve
	CARB	California Air Resources Board
	C & D	Construction & Demolition (Waste)
	CEC	California Energy Commission
	CFC	Chlorofluorocarbon
	CIWMB	California Integrated Waste Management Board (name changed in 2009 to CalRecycle)
	Composite Panel	a.k.a. Sandwich Panels or PU Panels: Insulating panels with steel or aluminum facings and a polyurethane foam core
D	DEFRA	Department of Environment, Farming & Rural Affairs
	DTSC	California Department of Toxic Substances Control
E	EOL	End-of-Life
	EU-27	European Union 27 member states. Also known as the European Union (EU), it is an economic and political union of 27 member states, located primarily in Europe.
F	FRP	Fiber Reinforced Plastic
G	GDP	Gross Domestic Product
	GHG	Greenhouse Gas
	GRP	Glass Reinforced Plastic
	GWP	Global Warming Potential
H	HC	Hydrocarbon
	HCFC	Hydrochlorofluorocarbon
	HFC	Hydrofluorocarbon
	HFO	Hydrofluoroolefins
	HVAC	Heating, Ventilation & Air Conditioning
I	IECC	International Energy Conservation Code

	IPCC	Intergovernmental Panel on Climate Change
	ISOR	Initial Statement of Reasons. The California Air Resources Board writes an ISOR for each newly proposed regulation. The ISOR will typically contain information on the current process or source of air emissions, an inventory of current and projected emissions, discussion of mitigation approaches, and an estimate on the potential reduction of air emissions as a result of the proposed regulation.
J	JTCCM	Japan Technical Committee on Construction Materials
K		
L	LCA	Life Cycle Assessment
	LCCP	Life Cycle Carbon Performance
M	Methanogenic	A process whereby micro-organisms give off methane gas as a by-product of their metabolism. Methanogenesis is the final step in the decay of organic matter
	MOCLA-FOAM	Spreadsheet model showing distribution and fate of foam based organic chemicals in land-fills; created by Kjeldsen P. & Christensen T.H., 2001
	MRF	Materials Recovery Facility
	MRSH	Materials that Require Special Handling
	MSW(I)	Municipal Solid Waste (Incineration)
N	NAMA	National Automated Merchandising Association
	NIK	Not-In-Kind
	NMMA	National Marine Manufacturers Association
O	ODS	Ozone Depleting Substance
P	PCPs	Polychlorinated biphenyls
	PIP	Pour-In-Place (Foam)
	PIR	Polyisocyanurate (Foam)
	PUR	Polyurethane (Foam)
	PURRC	Polyurethane Recycle & Recovery Council
	PU Panel	a.k.a. Composite or sandwich Panel: Insulating panels with steel or aluminum facings and a polyurethane foam core
Q		
R	RAD	Responsible Appliances Disposal: The US-EPA's Responsible Appliance Disposal (RAD) Program is a voluntary partnership program that began in 2006 to help protect the ozone layer and reduce emissions of greenhouse gases
	Redox Potentials	Reduction potential (also known as redox potential, oxidation / reduction potential or ORP) is a measure of the tendency of a chemical species to acquire electrons and thereby be reduced.
	RFP	Request for Proposals
	RPE	Robert Penny Enterprises (part of project delivery team)
S	Sandwich Panel	a.k.a. Composite or PU Panel: Insulating panels with steel or aluminum facings and a polyurethane foam core
	SEG equipment	Appliances de-manufacturing/recycling equipment made in Germany by SEG Umwelt Service GmbH
	SNAP	Significant New Alternatives Policy: The Significant New Alternatives Policy (SNAP) Program is a US-EPA's program to evaluate and regulate substitutes for the ozone-depleting chemicals that are being phased out under the stratospheric ozone protection provisions of the Clean Air Act (CAA)
	SPF	Spray Polyurethane Foam
	SRC	Survey Research Center, University of California, Berkeley (part of project delivery team)
T	TEAP	Technical & Economic Assessment Panel: The Technology and Economic Assessment Panel (TEAP) provides, at the request of Parties to the Montreal Protocol, technical information related to the alternative technologies that have been investigated and employed to make it possible to virtually eliminate use of Ozone Depleting Substances (CFCs, Halons etc.), that harm the ozone layer.
	Title 24	California's Building Standards Code

	TRU	Transport Refrigerated Unit
	TS or T/S	Transfer Station: A waste collection and temporary storage location for solid waste before the waste is ultimately sent to a landfill or other waste management facility
	T-8 Lamp	The T8 fluorescent lamp is the standard for new construction in the USA and is a popular replacement for 34-watt T12 lamps (*National Lighting Product Information Program – NLPIP*)
U	UNEP	United Nations Environment Programme
V	Vintaging Model	Published by US-EPA in 2005 – provides a dynamic inventory of US ODS banks and emissions
	VCS	Voluntary Carbon Standard
W	WTE	Waste To Energy (Combustion/Incineration Facility)
	WEEE	Waste Electrical & Electronic Equipment
X	XPS	Extruded Polystyrene (Foam)
Y		
Z		

9. Appendices

Appendix 1 for a list of respondents

SCREENING INTERVIEWS

BUILDINGS

REF	ORGANIZATION	TYPE	STAGE
1	BKI	BUILDINGS	INSTALLATION
2	Home Furnishing & Thermal Insulation Institute	BUILDINGS	INSTALLATION
3	California Building Industry Association	BUILDINGS	INSTALLATION
4	Chitwood Energy	BUILDINGS	INSTALLATION
5	Palacios Architects	BUILDINGS	INSTALLATION
6	Peikert Group Architects	BUILDINGS	INSTALLATION
7	Perkowitz & Ruth Architects	BUILDINGS	INSTALLATION
8	Peruzzi Architects	BUILDINGS	INSTALLATION
9	Peteris Architects	BUILDINGS	INSTALLATION
10	Pleskow & Rael	BUILDINGS	INSTALLATION
11	Pizzulli Associates Inc	BUILDINGS	INSTALLATION
12	The Practice Architects	BUILDINGS	INSTALLATION
13	RLB Architecture	BUILDINGS	INSTALLATION
14	RNL Design	BUILDINGS	INSTALLATION
15	RRM Design Group	BUILDINGS	INSTALLATION
16	Reed & Reed Associates	BUILDINGS	INSTALLATION
17	Reveal Studio Inc	BUILDINGS	INSTALLATION
18	Rivers & Christian	BUILDINGS	INSTALLATION
19	Rockefeller Architecture Inc	BUILDINGS	INSTALLATION
20	Roschen VanCleve Architects	BUILDINGS	INSTALLATION
21	Rossetti Architects	BUILDINGS	INSTALLATION
22	Saito Design Group	BUILDINGS	INSTALLATION
23	Milano Group	BUILDINGS	INSTALLATION
24	Salerno Livingston Architects	BUILDINGS	INSTALLATION
25	Schucard Associates	BUILDINGS	INSTALLATION
26	Signature Architects	BUILDINGS	INSTALLATION
27	Sprotte & Watson Architecture & Planning	BUILDINGS	INSTALLATION
28	Studio E Architects Inc	BUILDINGS	INSTALLATION
29	Two Corporation Architects & Builders	BUILDINGS	INSTALLATION
30	Ware-Malcomb	BUILDINGS	INSTALLATION
31	Westberg & White Inc	BUILDINGS	INSTALLATION
32	Saunders & Wiant Architects	BUILDINGS	INSTALLATION
33	Sky View Design	BUILDINGS	INSTALLATION
34	Solberg & Associates Architects	BUILDINGS	INSTALLATION
35	South West Concepts	BUILDINGS	INSTALLATION
36	Stearns Architecture	BUILDINGS	INSTALLATION
37	TR Design Group Architecture	BUILDINGS	INSTALLATION
38	Tarlos & Associates Inc	BUILDINGS	INSTALLATION
39	Jerry Tucker & Associates Inc	BUILDINGS	INSTALLATION
40	Vanderhoek Architects Inc	BUILDINGS	INSTALLATION
41	WD Partners Inc	BUILDINGS	INSTALLATION

42	The Woodley Group	BUILDINGS	INSTALLATION
43	Jonathan L Zane Architecture	BUILDINGS	INSTALLATION
44	T-Square Consulting Gp	BUILDINGS	INSTALLATION
45	Paulett Taggard Architects	BUILDINGS	INSTALLATION
46	Tannerhecht Architecture	BUILDINGS	INSTALLATION
47	Team Seven International	BUILDINGS	INSTALLATION
48	Thatcher & Thompson	BUILDINGS	INSTALLATION
49	360 Architecture	BUILDINGS	INSTALLATION
50	Transpacific Architects	BUILDINGS	INSTALLATION
51	Tsao Design Group	BUILDINGS	INSTALLATION
52	Tulloch Construction Inc	BUILDINGS	INSTALLATION
53	Upwall Architects	BUILDINGS	INSTALLATION
54	VBN Architects	BUILDINGS	INSTALLATION
55	Watry Design Inc	BUILDINGS	INSTALLATION
56	Weir Andrewson & Associates	BUILDINGS	INSTALLATION
57	Paul Welschmeyer Architects	BUILDINGS	INSTALLATION
58	Lawson Willard Architects	BUILDINGS	INSTALLATION
59	Woodring & Associates	BUILDINGS	INSTALLATION
60	Michael Zucker & Associates	BUILDINGS	INSTALLATION
61	Zwick Architects	BUILDINGS	INSTALLATION
62	Shlemmer, Kamus & Algaze	BUILDINGS	INSTALLATION
63	Stern Architects Inc	BUILDINGS	INSTALLATION
64	Sumich Design Inc	BUILDINGS	INSTALLATION
65	Teale Architecture	BUILDINGS	INSTALLATION
66	Thirtieth Street Architecture	BUILDINGS	INSTALLATION
67	AEC Services	BUILDINGS	INSTALLATION
68	Carlson Architecture Inc	BUILDINGS	INSTALLATION
69	Lex Coffroth & Associates	BUILDINGS	INSTALLATION
70	Glenn County Resource Planning and Development Department	BUILDINGS	INSTALLATION
71	Humboldt County Planning and Building Department	BUILDINGS	INSTALLATION
72	Imperial County Planning and Building Department	BUILDINGS	INSTALLATION
73	Inyo County Planning Department	BUILDINGS	INSTALLATION
74	Kern County Planning Department	BUILDINGS	INSTALLATION
75	Kings County Planning Agency	BUILDINGS	INSTALLATION
76	Lake County Community Development Department, Planning Division	BUILDINGS	INSTALLATION
77	Lassen County Department of Community Development	BUILDINGS	INSTALLATION
78	Los Angeles County Department of Regional Planning	BUILDINGS	INSTALLATION
79	Madera County Planning Department	BUILDINGS	INSTALLATION
80	Marin County Community Development Agency, Planning Division	BUILDINGS	INSTALLATION
81	Mariposa County Planning and Building Department	BUILDINGS	INSTALLATION
82	Mendocino County Planning & Building Services Department	BUILDINGS	INSTALLATION
83	Merced County Planning and Community Development Department	BUILDINGS	INSTALLATION
84	Modoc County Planning	BUILDINGS	INSTALLATION
85	Mono County Planning Department	BUILDINGS	INSTALLATION
86	Monterey County Planning & Building, Inspection Department	BUILDINGS	INSTALLATION
87	Napa County Conservation Development and Planning Department	BUILDINGS	INSTALLATION
88	Nevada County Planning Department	BUILDINGS	INSTALLATION

89	Orange County Planning and Development Services Department	BUILDINGS	INSTALLATION
90	Placer County Planning Department	BUILDINGS	INSTALLATION
91	Plumas County Planning Department	BUILDINGS	INSTALLATION
92	Riverside County Transportation and Land Management Agency/Planning Department	BUILDINGS	INSTALLATION
93	Sacramento County Planning and Community Development Department	BUILDINGS	INSTALLATION
94	San Benito County Planning Department	BUILDINGS	INSTALLATION
95	San Bernardino Land Use Services Department	BUILDINGS	INSTALLATION
96	San Diego County Department of Planning and Land Use	BUILDINGS	INSTALLATION
97	San Francisco Planning Department	BUILDINGS	INSTALLATION
98	San Joaquin County Community Development Department	BUILDINGS	INSTALLATION
99	San Luis Obispo County Department of Planning and Building	BUILDINGS	INSTALLATION
100	San Mateo County Environmental Services Agency, Planning and Building Division	BUILDINGS	INSTALLATION
101	Santa Barbara County Planning and Development	BUILDINGS	INSTALLATION
102	JVB Construction Management Inc	BUILDINGS	INSTALLATION
103	Lincolne-Scott Inc	BUILDINGS	INSTALLATION
104	Waler & Opsal Consulting	BUILDINGS	INSTALLATION
105	ANOVA Architects Inc	BUILDINGS	INSTALLATION
106	AP Architects	BUILDINGS	INSTALLATION
107	Akiyama Architects Inc	BUILDINGS	INSTALLATION
109	Architectural Design West	BUILDINGS	INSTALLATION
110	Arktegraf Inc	BUILDINGS	INSTALLATION
111	BFGS Architects & Planners Inc	BUILDINGS	INSTALLATION
112	BJY Bethseda Inc	BUILDINGS	INSTALLATION
113	C. Douglas Barnes	BUILDINGS	INSTALLATION
114	Beals Alliance	BUILDINGS	INSTALLATION
115	Berteaux Architecture Collaborative	BUILDINGS	INSTALLATION
116	Blackbird Associates	BUILDINGS	INSTALLATION
117	Blue Design Group	BUILDINGS	INSTALLATION
118	Borges Architectural Group	BUILDINGS	INSTALLATION
119	Carillo Architects Group	BUILDINGS	INSTALLATION
120	Christiansen Group	BUILDINGS	INSTALLATION
121	Commercial Architecture	BUILDINGS	INSTALLATION
122	DC Architects	BUILDINGS	INSTALLATION
123	DLP Associates	BUILDINGS	INSTALLATION
124	Darden Architects Inc	BUILDINGS	INSTALLATION
125	ALB Designs	BUILDINGS	INSTALLATION
126	ATI Architects & Engineers	BUILDINGS	INSTALLATION
127	Selsor Construction & Demolition	BUILDINGS	EOL MANAGEMENT
128	Henningsen Construction Co	BUILDINGS	EOL MANAGEMENT
129	ISRI - Institute of Scrap Recycling Industries	BUILDINGS	EOL MANAGEMENT
130	Snitzer	BUILDINGS	EOL MANAGEMENT
131	Brinkmann Demolition & Recycling	BUILDINGS	EOL MANAGEMENT
132	American Wrecking	BUILDINGS	EOL MANAGEMENT

133	Urban Renovations	BUILDINGS	EOL MANAGEMENT
134	US Demolition Inc	BUILDINGS	EOL MANAGEMENT
135	Heil Demolition	BUILDINGS	EOL MANAGEMENT
136	Gabels Haulage & demolition	BUILDINGS	EOL MANAGEMENT
137	Samson Demolition	BUILDINGS	EOL MANAGEMENT
138	Full Scale Demolition	BUILDINGS	EOL MANAGEMENT
139	Specialized Environmental	BUILDINGS	EOL MANAGEMENT
140	Penhall Company	BUILDINGS	EOL MANAGEMENT
141	Campanella Corp. Building Demolitions	BUILDINGS	EOL MANAGEMENT
142	Demolition Services Inc	BUILDINGS	EOL MANAGEMENT
143	SALINAS DISPOSAL	BUILDINGS	EOL MANAGEMENT
144	WM SOUTH GATE TRANSFER STATION	BUILDINGS	EOL MANAGEMENT
145	SUNSET ENVIRONMENTAL T/S	BUILDINGS	EOL MANAGEMENT
146	UNIVERSAL REFUSE REMOVAL	BUILDINGS	EOL MANAGEMENT
147	RESOURCE RECOVERY SYSTEMS TS	BUILDINGS	EOL MANAGEMENT
148	NORTH VALLEY DISPOSAL T/S	BUILDINGS	EOL MANAGEMENT
149	STOCKTON SCAVENGER ASSOC. T/S	BUILDINGS	EOL MANAGEMENT
150	CENTRAL VALLEY WASTE SERVICES T/S	BUILDINGS	EOL MANAGEMENT
151	HEALTH SANITATION SERVICE T/S	BUILDINGS	EOL MANAGEMENT
152	EAST QUINCY TRANSFER STATION	BUILDINGS	EOL MANAGEMENT
153	CHESTER TRANSFER STATION	BUILDINGS	EOL MANAGEMENT
154	GREENVILLE TRANSFER STATION	BUILDINGS	EOL MANAGEMENT
155	EAST VALLEY DIVERSION	BUILDINGS	EOL MANAGEMENT
156	DOWNTOWN DIVERSION	BUILDINGS	EOL MANAGEMENT
157	Smart and Final	GENERIC	EOL MANAGEMENT
158	Loyalton Landfill	GENERIC	EOL MANAGEMENT
159	Yreka Solid Waste Landfill	GENERIC	EOL MANAGEMENT

160	Hay Road Landfill, Inc. (B + J Landfill)	GENERIC	EOL MANAGEMENT
161	Potrero Hills Landfill	GENERIC	EOL MANAGEMENT
162	Central Disposal Site	GENERIC	EOL MANAGEMENT
163	Drilling Mud Disposal Facility	GENERIC	EOL MANAGEMENT
164	Santa Rosa Geothermal Co. L.P.	GENERIC	EOL MANAGEMENT
165	Korbel Maintenance Disposal Site	GENERIC	EOL MANAGEMENT
166	Fink Road Landfill	GENERIC	EOL MANAGEMENT
167	Bonzi Sanitary Landfill	GENERIC	EOL MANAGEMENT
168	Tehama County/Red Bluff Landfill	GENERIC	EOL MANAGEMENT
169	Weaverville Solid Waste TS & Landfill	GENERIC	EOL MANAGEMENT
170	Teapot Dome Disposal Site	GENERIC	EOL MANAGEMENT
171	Woodville Disposal Site	GENERIC	EOL MANAGEMENT
172	Visalia Disposal Site	GENERIC	EOL MANAGEMENT
173	Blue Mountain Minerals	GENERIC	EOL MANAGEMENT
174	Toland Road Landfill	GENERIC	EOL MANAGEMENT
175	Simi Valley Landfill & Recycling Center	GENERIC	EOL MANAGEMENT
176	Yolo County Central Landfill	GENERIC	EOL MANAGEMENT
177	Univ Of Calif Davis Sanitary Landfill	GENERIC	EOL MANAGEMENT
178	Recology (Norcal) Ostrom Road LF Inc.	GENERIC	EOL MANAGEMENT
179	All American Asphalt Inert Fill Operation	GENERIC	EOL MANAGEMENT
180	Sam Jones Landfill (and Mine)	GENERIC	EOL MANAGEMENT
181	Sacramento County Landfill (Kiefer)	GENERIC	EOL MANAGEMENT
182	L and D Landfill Co	GENERIC	EOL MANAGEMENT
183	John Smith Road Class III Landfill	GENERIC	EOL MANAGEMENT
184	California Street Landfill	GENERIC	EOL MANAGEMENT
185	California Street Landfill	GENERIC	EOL MANAGEMENT
186	Agua Mansa Landfill	GENERIC	EOL MANAGEMENT

187	Oro Grande Kiln Waste Dust Dump	GENERIC	EOL MANAGEMENT
188	Victorville Sanitary Landfill	GENERIC	EOL MANAGEMENT
189	Barstow Sanitary Landfill	GENERIC	EOL MANAGEMENT
190	Colton Sanitary Landfill	GENERIC	EOL MANAGEMENT
191	Mid-Valley Sanitary Landfill	GENERIC	EOL MANAGEMENT
192	Landers Sanitary Landfill	GENERIC	EOL MANAGEMENT
193	Holliday Inertwaste Site	GENERIC	EOL MANAGEMENT
194	USMC - 29 Palms Disposal Facility	GENERIC	EOL MANAGEMENT
195	Fort Irwin Sanitary Landfill	GENERIC	EOL MANAGEMENT
196	Mitsubishi Cement Plant Cushenbury L.F.	GENERIC	EOL MANAGEMENT
197	San Timoteo Sanitary Landfill	GENERIC	EOL MANAGEMENT
198	City Of Upland Street Sweeping Debris	GENERIC	EOL MANAGEMENT
199	Ramona Landfill	GENERIC	EOL MANAGEMENT
200	Borrego Landfill	GENERIC	EOL MANAGEMENT
201	Otay Landfill	GENERIC	EOL MANAGEMENT
202	West Miramar Sanitary Landfill	GENERIC	EOL MANAGEMENT
203	Sycamore Sanitary Landfill	GENERIC	EOL MANAGEMENT
204	San Onofre Landfill (Area 52)	GENERIC	EOL MANAGEMENT
205	Las Pulgas Landfill (Area 43)	GENERIC	EOL MANAGEMENT
206	Vulcan Materials Company Carrol Cyn. Sit	GENERIC	EOL MANAGEMENT
207	Foothill Sanitary Landfill	GENERIC	EOL MANAGEMENT
208	Forward Landfill, Inc.	GENERIC	EOL MANAGEMENT
209	North County Landfill	GENERIC	EOL MANAGEMENT
210	City Of Paso Robles Landfill	GENERIC	EOL MANAGEMENT
211	Cold Canyon Landfill Solid Waste DS	GENERIC	EOL MANAGEMENT
212	Chicago Grade Landfill	GENERIC	EOL MANAGEMENT
213	Ox Mountain Sanitary Landfill	GENERIC	EOL MANAGEMENT

214	Vandenberg AFB Landfill	GENERIC	EOL MANAGEMENT
215	Tajiguas Sanitary Landfill	GENERIC	EOL MANAGEMENT
216	Santa Maria Landfill	GENERIC	EOL MANAGEMENT
217	City Of Lompoc Sanitary Landfill	GENERIC	EOL MANAGEMENT
218	Pacheco Pass Landfill Recology (Norcal)	GENERIC	EOL MANAGEMENT
219	City Of Sunnyvale Landfill	GENERIC	EOL MANAGEMENT
220	City of Palo Alto Refuse Disposal Site	GENERIC	EOL MANAGEMENT
221	Zanker Material Processing Facility	GENERIC	EOL MANAGEMENT
222	Newby Island Sanitary Landfill	GENERIC	EOL MANAGEMENT
223	Zanker Road Class III Landfill	GENERIC	EOL MANAGEMENT
224	Kirby Canyon Recycl.& Disp. Facility	GENERIC	EOL MANAGEMENT
225	Guadalupe Sanitary Landfill	GENERIC	EOL MANAGEMENT
226	City Of Santa Cruz Sanitary Landfill	GENERIC	EOL MANAGEMENT
227	City Of Watsonville Landfill	GENERIC	EOL MANAGEMENT
228	Buena Vista Drive Sanitary Landfill	GENERIC	EOL MANAGEMENT
229	Gercon Construction Inc	BUILDINGS	USE
230	Gracier Construction Group	BUILDINGS	USE
	APPLIANCES		
231	Department of Toxic Substances Control	APPLIANCES	INSTALLATION
232	Refrigeration and thermal Test	APPLIANCES	INSTALLATION
233	Sanden Vendo America Inc.	APPLIANCES	INSTALLATION
234	Appliance Magazine	APPLIANCES	INSTALLATION
235	AHAM/ US Bureau of Mines	APPLIANCES	INSTALLATION
236	DTU	APPLIANCES	INSTALLATION
237	AHAM 2	APPLIANCES	INSTALLATION
238	ACC Centre for the Polyurethane Industry	APPLIANCES	INSTALLATION
239	Rainbow Grocery	APPLIANCES	USE
240	California Energy Commission	APPLIANCES	USE
241	Institute of Scrap Recycling Industries (ISRI)	APPLIANCES	EOL MANAGEMENT
242	Sacramento Municipal Utility District (SMUD)	APPLIANCES	EOL MANAGEMENT
243	Southern California Edison	APPLIANCES	EOL MANAGEMENT

TRU

244	Trailer Body Magazine	TRU - ALL TYPES	INSTALLATION
245	Recycling Today	TRU - ALL TYPES	INSTALLATION
246	FleetSeek	TRU - ALL TYPES	INSTALLATION
247	California Environmental Rights Alliance	TRU - ALL TYPES	INSTALLATION
248	Association of American Railroads	TRU - Rail	INSTALLATION
249	National Association of Trailer Manufacturers	TRU - ALL TYPES	INSTALLATION
250	ACC Centre for the Polyurethane Industry	TRU - ALL TYPES	INSTALLATION
251	California Resources Recovery Association	TRU - ALL TYPES	INSTALLATION
252	Drake Truck Bodies	TRU - TRUCK	INSTALLATION
253	Stoughton Trailer Inc	TRU - TRUCK	INSTALLATION
254	Fruehauf	TRU - TRUCK	INSTALLATION
255	Triple-B Truck Body Company	TRU - TRUCK	INSTALLATION
256	Kidron	TRU - TRUCK	INSTALLATION
257	Johnson Refrigerated Truck Bodies	TRU - TRUCK	INSTALLATION
258	Hercules Manufacturing	TRU - TRUCK	INSTALLATION
259	Wabash National	TRU - TRUCK	INSTALLATION
260	Great Dane	TRU - TRUCK	INSTALLATION
261	ModSpace	TRU - TRUCK	INSTALLATION
262	Utility Trailer Mfg.	TRU - TRUCK	INSTALLATION
263	Thermo King	TRU - TRUCK	INSTALLATION
264	Thermo King of Southern California	TRU - TRUCK	INSTALLATION
265	Allied Container Systems	TRU - TRUCK	INSTALLATION
266	Nucold Inc	TRU - TRUCK	INSTALLATION
267	Hyundai Translead	TRU - TRUCK	INSTALLATION
268	California Trucking Association	TRU - ALL TYPES	INSTALLATION
269	Truck Trailer Manufacturers Association	TRU - TRUCK	INSTALLATION
270	R L Polk & Co	TRU - TRUCK	INSTALLATION
271	Pat Brecht	TRU - TRUCK	INSTALLATION
272	Truckload Carriers Association	TRU - TRUCK	USE
273	Northern refrigerated	TRU - TRUCK	USE
274	Container Outlet	TRU - TRUCK	USE
275	GE Trailer Fleet services	TRU - TRUCK	USE
276	Container Outlet2	TRU - TRUCK	USE
277	National Private Trucking Council	TRU - TRUCK	USE
278	Transportation Logistics Co.	TRU - TRUCK	USE
279	XTRA Lease	TRU - TRUCK	USE
280	XTRA Lease2	TRU - TRUCK	USE
281	PHILLIP'S FREIGHT TRANSPORT	TRU - TRUCK	USE
282	Davis Express	TRU - TRUCK	USE
283	3PL Solutions, LLC	TRU - TRUCK	USE
284	Southwest Truck Service Company	TRU - TRUCK	USE
285	Harbor Services Company	TRU - TRUCK	USE
286	Central Refrigerated Service, Inc	TRU - TRUCK	USE
287	Heitz Trucking Inc	TRU - TRUCK	USE

288	Port of Los Angeles	TRU - RAIL	USE
289	American Association of Port Authorities	TRU - Rail	USE
290	Port of Long Beach	TRU - Rail	USE
291	Institute of Scrap Recycling Industries Inc.	TRU - TRUCK	RECYCLERS
292	ARCA Recycling	TRU - TRUCK	RECYCLERS
293	ARCA Recycling2	TRU - TRUCK	RECYCLERS
294	Refrigerant Exchange	TRU - TRUCK	RECYCLERS
295	Institute of Scrap Recycling Industries Inc.	TRU - TRUCK	RECYCLERS
296	ARCA Recycling	TRU - TRUCK	RECYCLERS
297	P&T METALS, INC.	TRU - TRUCK	RECYCLERS
298	The Sutta Company	TRU - TRUCK	RECYCLERS
299	Rincon Recycling	TRU - TRUCK	RECYCLERS
	MARINE & OTHER		
300	Westport Pacific Boats	MARINE/OTHER	EOL MANAGEMENT
301	Wragg Inc	MARINE/OTHER	EOL MANAGEMENT
302	Vitesse Yachts	MARINE/OTHER	EOL MANAGEMENT

Appendix 2 for a list of interviewees

TECHNICAL INTERVIEWS

TYPE	REF	ORGANIZATION	RESPONDENT	LOCATION	
		Suppliers			
building/supply	1	BASF1	Roy Pask	Wyandotte	MI
building/supply	2	Urethane Technologies	John McNeill	Orange	CA
building/supply	3	Carpenter1	Richard Jehu	Richmond	VA
building/supply	4	Huntsman1	Daniel Rosenvasser	Auburn Hills	MI
building/supply	5	Honeywell1	Ken Gayer	Morristown	NJ
building/supply	6	Foam Supplies (FSI)1	Todd Keske	Earth City	MO
building/supply	7	Owens Corning	Allen Zhang	Tallmadge	OH
building/supply	8	Pactiv Building Products	Daniel Partrich	Lake Forrest	IL
building/supply	9	Dow Roofing Systems	Bill Lion	Holyoke	MA
building/supply	10	R-Max Operating, LLC	John Nerbit	Dallas	TX
building/supply	11	Johns Manville	Steve Hochhauser	Denver	CO
building/supply	12	Firestone Building Product Co.	Mike Gorey	Indianapolis	IN
building/supply	13	Dyplast	Ted Berglund	Atlanta	GA
building/supply	14	Pacific Polymers	Michael Claus	San Jose	CA
building/supply	15	Honeywell2	Steve Bernhardt	Morristown	NJ
building/supply	16	Dupont	Mark Baunschalk	Wilmington	DE
building/supply	17	Honeywell3	David Williams	Buffalo	NJ
building/supply	18	Huntsman polyurethanes2	Rafael Camargo	West Deptford	NJ
building/supply	19	Carpenter Co.2	Jim Hardeman	Richmond	VA
building/supply	20	SWD	Steve Perkins	Mesa	AZ
building/supply	21	BASF2	Dave Elliott	Florham Park	NJ
building/supply	22	Rutherford Chemicals	Laurence Slovin	Bayonne	NJ
building/supply	23	Foam Supplies2	Tim Kalinowski	Earth City	MO
building/supply	24	Stepan	Brad Beauchamp	Northfield	IL
building/supply	25	Resin Technologies	Wil Lorenz	Ontario	CA
building/supply	26	GACO western	System Houses	Tukwila	WA
building/supply	27	Foam Enterprises	Dennis Holbert	Minneapolis	MN
building/supply	28	Kysor Panel Systems	Marian Brown	Ft. Worth	TX
building/supply	29	American Panel	Pam Falanga	Ocala	FL
building/supply	30	Metalspan	Karl Heilscher	Lewisville	TX
building/supply	31	Alumashield	Peter Martin	Daytona Beach	FL
building/supply	32	Centria Arch. Systems	Tom Zombek	Sheridan	PA
building/supply	33	Huntsman3	Jian Huang Wu	Auburn Hills	MI
building/supply	34	BASF3	Ted Smiecinski	Wyandotte	MI
marine/supply	35	Boston Whaler	Chuck Bennett	Edgewater	FL
marine/supply	36	Brunswick Corp.	Brent Dahl	Lake Forest	IL
		Installers			

building/install	37	Pacific Valley Roofing	Ron Reed	Ceres	CA
building/install	38	Quality Foam	James Barrett	Lake Elsinore	CA
building/install	39	Williams Foam	William Ramirez	Sylmar	CA
building/install	40	Atlas Foam products	Jeff Naples	Sylmar	CA
building/install	41	Califoam products	Javeir Juarec	Montclair	CA
building/install	42	Good Works Inc.	Susan Saucedo-King	Redwood Valley	CA
building/install	43	SPFA	Eri Banks	Fairfax	VA
building/install	44	DR Horton	Dan Turpin	Woodland Hills	CA
building/install	45	Lennar Homes	Tanya Parker	Sacramento	CA
building/install	46	Centex Homes	Samantha Fenn	San Diego	CA
building/install	47	Ryland Homes	Donna Revita	Calabasas	CA
building/install	48	William Lyon Homes	Mike Costello	Sacramento	CA
building/install	49	Brookfield Homes	Kelly-Rae Rahm	Contra Costa	CA
building/install	50	California Bldg. Officials	Matt Wheeler	Sacramento	CA
building/install	51	Nat'l Assn. of Home Builders	Gerald Howard	Washington	DC
building/install	52	NAHB Research Center	Vladimir Kochkin	Washington	DC
building/install	53	James Hardie Bldg. Products	Rusty Pittman	Mission Viejo	CA
building/install	54	NAHB	Linda Marceller	Washington	DC
building/install	55	Building Standards Commission	Thomas Morrison	Sacramento	CA
building/install	56	Absolute Urethanes Inc	Eric Plaza	Fresno	CA
building/install	57	Roofco Inc	Jerome Schrader	Rancho Cordova	CA
building/install	58	Zumwalt & Associates	John Zumwalt	Sacramento	CA
building/install	59	Eagle Ridge Roofing	Jim Lance	Carmichael	CA
building/install	60	Elite Roofing Co	Tim Morten	Manteca	CA
tru/install	61	South Coast Air Quality Mgt	Jill Whynot	Diamond Bar	CA
tru/install	62	California Energy Commission	Glen Sharp	Sacramento	CA
tru/install	63	CEC	Robert Hudler	Sacramento	CA
tru/install	64	CARB	Steve Yee	Sacramento	CA
		Users			
tru/users	65	Central Refrigerated Services Inc	Brad Curly	Fontana	CA
tru/users	66	Transport Logistics	Jill Quin	Santa Ana	CA
		EOL			
buildings/eol	67	CIWMB	Gregory Dick	Sacramento	CA
buildings/eol	68	Covanta Energy	Douglas Tomison	Long Beach	CA
buildings/eol	69	WM - Davis Street Transfer Stn.	Rebecca Jewell	San Leandro	CA
buildings/eol	70	Waste Management	Brian Bowen	Sacramento	CA
buildings/eol	71	Sanitation Districts Los Angeles Counties	Matt Eaton	Commerce	CA
buildings/eol	72	Covanta Energy	Jeffrey Hahn	Sacramento	CA
building/eol	73	Reuse People of America	Ted Reiff	Oakland	CA
building/eol	74	CIWMB TWO	Edgar Rojas	Sacramento	CA

appliances/eol	75	JACO Environmental	Michael Dunham	Hayward	CA
appl/eol	76	JACO	Michael Dunham	Fullerton	CA
appl/eol	77	Zanker Road Resource Management Ltd	Michael Gross	San Jose	CA
appl/eol	78	Waste Management	Chuck White	Sacramento	CA
appl/eol	79	ARCA	Rachel Holmes	Minneapolis	MN
appl/eol	80	WM - Davis Street Transfer Stn.	Rebecca Jewell	San Leandro	CA
appl/eol	81	Waste Management	Brian Bowen	Sacramento	CA
tru/eol	82	SA Recycling	George Caamano	Anaheim	CA
tru/eol	83	BW Metals Recycling	James Bandy	Anaheim	CA
marine/eol	84	Surf Board Recycling	Joey Santley	Laguna Niguel	CA

Appendix 3 – Report Figures presented as Data

The following tables show the data which Caleb used to develop the Figures and Graphs used throughout the report. In each case, data are labeled with an Appendix 3 designation (AP3-1, 2, 3, X), followed by a Figure reference in brackets (from Figure 2-1, 2-2, X-Y,) and the title of the relevant Figure (Screening Interviews by Life Cycle Stage) as it is shown in the body of the report.

Table AP3-1: (from Figure 2-1) Screening Interviews by Life Cycle Stage

Stage	**Numbers**	**%**
Suppliers	44	15%
Installers	118	39%
Users	23	8%
EOL	117	39%
	302	

Table AP3-2: (from Figure 2-2) Screening Interviews by Application Type

Type	**Numbers**	**%**
Buildings	230	76%
Appliances	13	4%
TRU	56	19%
Marine & other	3	1%
	302	

Table AP3-3: (from Figure 2-3) Technical Interviews by Life Cycle Stage

Stage	**Numbers**	**%**
Suppliers	36	43
Installers	28	33
Users	2	2
EOL	18	22
	84	

Table AP3-4: (from Figure 2-4) Technical Interviews by Application Type

Type	Numbers	%
Buildings	66	79
Appliances	7	8
TRU	8	10
Marine & other	3	3
	84	

Table AP3-5: (from Figure 3-1) 2007 In-State Polyurethane/Polyisocyanurate Production

Type	Volume - tons	%
Spray Foam	1970	20%
Composite Panels	790	8%
Boardstock; PiP	7080	72%
	9840	

Table AP3-6: (from Figure 3-2) Caleb Estimates of Building Stock Distribution

Type	Total	%
Commercial & Industrial	986,588	6%
Residential - single	9,312,597	56%
Residential - multi-family	6,277,436	38%
	16,576,621	

Table AP3-7: (from Figure 3-3) California Foam Consumption - by Type 1960-2009) – *based on Caleb model estimates*

Foam Type	%
XPS	29%
Polyiso	55%
PU Panel	6%
PU Spray	10%

Table AP3-8: (from Figure 3-4) Bank estimates by Building Type

Year	Single Family	Multi Family	Commercial
1960	0.00	0.00	0.00
1961	1.53	1.44	0.77
1962	3.12	2.92	1.58
1963	4.77	4.46	2.43
1964	6.47	6.06	3.34
1965	8.24	7.72	4.30
1966	10.07	9.44	5.31
1967	11.98	11.24	6.39
1968	13.97	13.11	7.53
1969	16.04	15.05	8.74
1970	18.20	17.08	10.03
1971	20.28	19.06	11.34
1972	22.44	21.13	12.73
1973	24.70	23.31	14.22
1974	27.04	25.59	15.81
1975	29.48	27.99	17.51
1976	32.03	30.51	19.32
1977	34.69	33.16	21.26
1978	37.46	35.96	23.33
1979	40.35	38.90	25.55
1980	43.37	42.00	27.93
1981	46.34	45.10	30.37
1982	49.46	48.37	32.99
1983	52.72	51.84	35.80
1984	56.14	55.51	38.82
1985	59.73	59.40	42.05
1986	63.49	63.52	45.57
1987	67.44	67.88	49.35
1988	71.59	72.51	53.41
1989	75.94	77.41	57.76
1990	80.51	82.62	62.43
1991	85.03	87.92	67.28
1992	88.53	92.40	71.86
1993	92.18	97.21	76.79
1994	94.79	100.88	80.75
1995	96.27	103.26	83.56
1996	96.53	104.19	85.02
1997	95.46	103.48	84.94
1998	94.38	102.80	84.91
1999	93.28	102.15	84.92
2000	92.17	101.53	84.99
2001	90.99	100.92	85.00
2002	89.85	100.37	85.04
2003	88.70	99.88	85.14
2004	87.14	98.84	84.80
2005	85.37	97.53	84.25
2006	83.46	95.97	83.57
2007	81.50	94.38	82.90
2008	79.47	92.76	82.22
2009	77.32	91.01	81.44
2010	74.95	89.02	80.43
2011	72.48	87.02	79.28
2012	70.07	85.11	78.18
2013	67.57	83.13	77.05
2014	64.97	81.10	75.89
2015	62.26	79.00	74.69
2016	59.44	76.82	73.45
2017	56.50	74.58	72.16
2018	53.44	72.25	70.82
2019	50.24	69.83	69.43
2020	46.90	67.32	67.98

Table AP3-9: (from Figure 3-5) Total banks in buildings by blowing agent type

Year	CFCs	HCFCs	HFCs	Other
1960	0.00	0.00	0.00	0.00
1961	3.74	0.00	0.00	0.00
1962	7.63	0.00	0.00	0.00
1963	11.68	0.00	0.00	0.00
1964	15.89	0.00	0.00	0.00
1965	20.28	0.00	0.00	0.00
1966	24.86	0.00	0.00	0.00
1967	29.65	0.00	0.00	0.00
1968	34.65	0.00	0.00	0.00
1969	39.89	0.00	0.00	0.00
1970	45.38	0.00	0.00	0.00
1971	50.75	0.00	0.00	0.00
1972	56.39	0.00	0.00	0.00
1973	62.32	0.00	0.00	0.00
1974	68.54	0.00	0.00	0.00
1975	75.09	0.00	0.00	0.00
1976	81.98	0.00	0.00	0.00
1977	89.24	0.00	0.00	0.00
1978	96.90	0.00	0.00	0.00
1979	104.97	0.00	0.00	0.00
1980	113.48	0.00	0.00	0.00
1981	122.01	0.00	0.00	0.00
1982	131.04	0.00	0.00	0.00
1983	140.60	0.00	0.00	0.00
1984	150.73	0.00	0.00	0.00
1985	161.46	0.00	0.00	0.00
1986	172.88	0.00	0.00	0.00
1987	185.00	0.00	0.00	0.00
1988	197.85	0.00	0.00	0.00
1989	211.49	0.00	0.00	0.00
1990	225.97	0.00	0.00	0.00
1991	240.68	0.00	0.00	0.00
1992	253.27	0.00	0.00	0.00
1993	266.69	0.00	0.00	0.00
1994	276.16	0.80	0.00	0.00
1995	281.17	2.49	0.00	0.00
1996	281.15	5.16	0.00	0.00
1997	275.52	8.94	0.00	0.00
1998	269.73	12.93	0.00	0.00
1999	263.78	17.14	0.00	0.00
2000	257.66	21.60	0.00	0.00
2001	251.35	25.93	0.19	0.00
2002	245.14	30.04	0.63	0.01
2003	238.74	34.03	1.50	0.02
2004	232.12	36.95	2.21	0.08
2005	225.27	39.52	2.77	0.17
2006	218.17	41.54	3.59	0.27
2007	210.81	43.68	4.47	0.39
2008	203.17	45.95	5.40	0.50
2009	195.22	47.67	6.81	0.63
2010	186.95	48.03	9.22	0.76
2011	178.33	47.65	12.46	0.90
2012	169.73	47.28	15.87	1.04
2013	160.73	46.90	19.48	1.19
2014	151.32	46.53	23.30	1.34
2015	141.47	46.17	27.34	1.51
2016	131.14	45.81	31.62	1.69
2017	120.30	45.45	36.15	1.88
2018	108.91	45.09	40.96	2.08
2019	96.95	44.74	46.05	2.29
2020	84.37	44.38	51.46	2.52

Table AP3-10: (from Figure 3-6) Banks in buildings & waste streams by blowing agent type

	Total in buildings			Banks in waste streams		
Year	CFCs	HCFCs	HFCs	CFCs	HCFCs	HFCs
1960	0.00	0.00	0.00	0.00	0.00	0.00
1961	3.74	0.00	0.00	0.00	0.00	0.00
1962	7.63	0.00	0.00	0.00	0.00	0.00
1963	11.68	0.00	0.00	0.00	0.00	0.00
1964	15.89	0.00	0.00	0.00	0.00	0.00
1965	20.28	0.00	0.00	0.00	0.00	0.00
1966	24.86	0.00	0.00	0.00	0.00	0.00
1967	29.65	0.00	0.00	0.00	0.00	0.00
1968	34.65	0.00	0.00	0.00	0.00	0.00
1969	39.89	0.00	0.00	0.00	0.00	0.00
1970	45.38	0.00	0.00	0.00	0.00	0.00
1971	50.75	0.00	0.00	0.00	0.00	0.00
1972	56.39	0.00	0.00	0.00	0.00	0.00
1973	62.32	0.00	0.00	0.00	0.00	0.00
1974	68.54	0.00	0.00	0.00	0.00	0.00
1975	75.09	0.00	0.00	0.00	0.00	0.00
1976	81.98	0.00	0.00	0.00	0.00	0.00
1977	89.24	0.00	0.00	0.00	0.00	0.00
1978	96.90	0.00	0.00	0.00	0.00	0.00
1979	104.97	0.00	0.00	0.00	0.00	0.00
1980	113.48	0.00	0.00	0.00	0.00	0.00
1981	122.01	0.00	0.00	0.00	0.00	0.00
1982	131.04	0.00	0.00	0.00	0.00	0.00
1983	140.60	0.00	0.00	0.00	0.00	0.00
1984	150.73	0.00	0.00	0.00	0.00	0.00
1985	161.46	0.00	0.00	0.00	0.00	0.00
1986	172.88	0.00	0.00	0.00	0.00	0.00
1987	185.00	0.00	0.00	0.00	0.00	0.00
1988	197.85	0.00	0.00	0.00	0.00	0.00
1989	211.49	0.00	0.00	0.00	0.00	0.00
1990	225.97	0.00	0.00	0.00	0.00	0.00
1991	240.68	0.00	0.00	2.35	0.00	0.00
1992	253.27	0.00	0.00	4.73	0.00	0.00
1993	266.69	0.00	0.00	7.15	0.00	0.00
1994	276.16	0.80	0.00	9.61	0.00	0.00
1995	281.17	2.49	0.00	12.12	0.00	0.00
1996	281.15	5.16	0.00	14.69	0.00	0.00
1997	275.52	8.94	0.00	17.32	0.00	0.00
1998	269.73	12.93	0.00	20.02	0.00	0.00
1999	263.78	17.14	0.00	22.81	0.00	0.00
2000	257.66	21.60	0.00	25.68	0.00	0.00
2001	251.35	25.93	0.19	28.41	0.00	0.00
2002	245.14	30.04	0.63	31.24	0.00	0.00
2003	238.74	34.03	1.50	34.18	0.00	0.00
2004	232.12	36.95	2.21	37.25	0.00	0.00
2005	225.27	39.52	2.77	40.44	0.00	0.00
2006	218.17	41.54	3.59	43.77	0.00	0.00
2007	210.81	43.68	4.47	47.25	0.00	0.00
2008	203.17	45.95	5.40	50.90	0.00	0.00
2009	195.22	47.67	6.81	54.72	0.00	0.00
2010	186.95	48.03	9.22	58.74	0.00	0.00
2011	178.33	47.65	12.46	62.66	0.00	0.00
2012	169.73	47.28	15.87	66.79	0.00	0.00
2013	160.73	46.90	19.48	71.15	0.00	0.00
2014	151.32	46.53	23.30	75.75	0.00	0.00
2015	141.47	46.17	27.34	80.61	0.00	0.00
2016	131.14	45.81	31.62	85.76	0.00	0.00
2017	120.30	45.45	36.15	91.22	0.00	0.00
2018	108.91	45.09	40.96	97.01	0.00	0.00
2019	96.95	44.74	46.05	103.15	0.00	0.00
2020	84.37	44.38	51.46	109.66	0.00	0.00

Table AP3-11: (from Figure 3-7) Baseline emission sources in 2010 – buildings

Manufacturing	Polyiso	18.92
	XPS	386.62
	PU Panel	18.91
	PU Spray	111.14
In Use Phase	Single	514.41
	Multi	613.57
	Commercial	543.45
	Cold Store	3.33
Waste Stream	Polyiso	1495.47
	XPS	725.92
	PU Panel	0.00
	PU Spray	0.00
Total		4.43

Table AP3-12: (from Figure 3-8) Baseline emissions by source for buildings

Year	Manufacturing	In-Use	Waste Stream
1991	2,297.14	1,586.25	630.00
1992	2,437.91	1,670.90	687.85
1993	1,959.32	1,761.12	747.92
1994	1,543.59	1,830.30	810.42
1995	1,067.39	1,875.72	875.58
1996	529.30	1,894.00	943.63
1997	562.29	1,882.39	1014.81
1998	597.47	1,871.32	1089.40
1999	634.97	1,860.81	1167.67
2000	569.25	1,850.89	1249.92
2001	565.68	1,840.81	1271.92
2002	600.38	1,832.10	1356.04
2003	563.25	1,824.22	1444.64
2004	560.04	1,809.64	1538.08
2005	553.30	1,791.85	1636.69
2006	587.69	1,770.87	1740.85
2007	624.38	1,749.79	1850.96
2008	610.87	1,728.59	1967.44
2009	537.49	1,704.61	2090.76
2010	535.59	1,674.76	2221.39
2011	569.00	1,642.42	2294.47
2012	604.66	1,611.47	2447.53
2013	642.73	1,579.72	2607.80
2014	683.39	1,547.09	2776.32
2015	726.81	1,513.53	2954.09
2016	773.19	1,478.98	3144.43
2017	822.74	1,442.55	3345.04
2018	875.67	1,404.92	3557.86
2019	932.24	1,366.02	3783.90
2020	992.70	1,325.76	4024.20

Table AP3-13: (from Figure 3-9) Baseline emissions by blowing agent for buildings

Year	ODS	HFCs
1991	4513.39	0.00
1992	4796.66	0.00
1993	4468.36	0.00
1994	4184.32	0.00
1995	3818.68	0.00
1996	3366.93	0.00
1997	3459.50	0.00
1998	3558.19	0.00
1999	3663.45	0.00
2000	3656.67	13.39
2001	3645.63	32.78
2002	3728.11	60.40
2003	3757.31	74.79
2004	3831.03	76.70
2005	3874.49	107.31
2006	3980.91	118.45
2007	4094.75	130.32
2008	4078.15	228.67
2009	3898.90	433.86
2010	3832.47	599.11
2011	3845.93	659.71
2012	3939.30	724.05
2013	4037.47	792.38
2014	4141.32	864.99
2015	4251.67	942.18
2016	4371.65	1024.26
2017	4497.93	1111.59
2018	4633.01	1204.53
2019	4777.65	1303.48
2020	4932.63	1408.85

Table AP3-14: (from Figure 3-10) Baseline emission sources in 2020 – buildings

Manufacturing	Polyiso	35.06
	XPS	712.91
	PU Panel	37.67
	PU Spray	207.05
In Use Phase	Single	343.06
	Multi	488.21
	Commercial	491.50
	Cold Store	2.98
Waste Stream	Polyiso	2557.15
	XPS	1326.63
	PU Panel	1.86
	PU Spray	138.56
Total		6.34

Table AP3-15: (from Figure 3-11) Climate impact of emissions from the waste stream – buildings

	Major emission sources	Emissions from waste stream
Year	Waste stream	Waste total
1991	2998.82	630.00
1992	3135.21	687.85
1993	3280.66	747.92
1994	3435.78	810.42
1995	3601.25	875.58
1996	3777.78	943.63
1997	3966.13	1014.81
1998	4167.13	1089.40
1999	4381.65	1167.67
2000	4610.61	1249.92
2001	4547.83	1271.92
2002	4789.41	1356.04
2003	5046.67	1444.64
2004	5320.67	1538.08
2005	5612.51	1636.69
2006	5923.41	1740.85
2007	6254.63	1850.96
2008	6607.56	1967.44
2009	6983.65	2090.76
2010	7384.45	2221.39
2011	7431.89	2294.47
2012	7876.39	2447.53
2013	8350.29	2607.80
2014	8855.58	2776.32
2015	9394.38	2954.09
2016	9974.21	3144.43
2017	10587.38	3345.04
2018	11241.39	3557.86
2019	11939.00	3783.90
2020	12683.18	4024.20

Table AP3-16: (from Figure 3-12) Summary of bank development for high GWP gases in California applications

Year	Buildings	Appliances	Other Refrigeration	TRUs	Marine + Other
1975	75.09	0.00	0.00	9.12	9.12
1976	81.98	1.95	0.33	9.41	9.41
1977	89.24	3.98	0.65	9.70	9.70
1978	96.90	6.08	1.04	9.99	9.99
1979	104.97	8.26	1.42	10.30	10.30
1980	113.48	10.53	1.80	10.61	10.61
1981	122.01	12.88	2.18	10.93	10.93
1982	131.04	15.32	2.70	11.26	11.26
1983	140.60	17.84	3.11	11.59	11.59
1984	150.73	20.44	3.66	11.93	11.93
1985	161.46	23.14	4.15	12.28	12.28
1986	172.88	25.92	4.62	12.64	12.64
1987	185.00	28.80	5.00	13.00	13.00
1988	197.85	31.78	5.42	13.38	13.38
1989	211.49	34.86	5.85	13.76	13.76
1990	225.97	38.00	6.29	14.15	14.15
1991	240.68	39.32	6.43	14.38	14.38
1992	253.27	40.60	6.53	14.62	14.62
1993	266.69	42.04	6.58	14.86	14.86
1994	276.95	42.83	6.53	15.10	15.10
1995	283.65	42.93	6.39	15.16	15.16
1996	286.31	41.28	6.08	15.01	15.01
1997	284.46	39.64	5.65	14.26	14.26
1998	282.66	37.97	5.31	13.49	13.49
1999	280.93	36.35	4.87	12.71	12.71
2000	279.26	34.82	4.47	11.91	11.91
2001	277.47	33.32	4.10	11.10	11.10
2002	275.82	32.11	3.81	10.29	10.29
2003	274.29	31.02	3.48	9.50	9.50
2004	271.35	29.90	3.15	8.66	8.66
2005	267.72	28.89	2.82	7.81	7.81
2006	263.58	27.88	2.49	7.00	7.00
2007	259.34	26.88	2.19	6.18	6.18
2008	255.02	25.71	1.90	5.32	5.32
2009	250.33	25.12	1.70	4.42	4.42
2010	244.97	25.15	1.59	3.65	3.65
2011	239.34	26.81	1.65	3.03	3.03
2012	233.91	28.45	1.69	2.98	2.98
2013	228.30	30.07	1.75	2.94	2.94
2014	222.50	31.60	1.78	2.89	2.89
2015	216.49	33.00	1.81	2.84	2.84
2016	210.25	34.34	1.85	2.79	2.79
2017	203.77	35.36	1.90	2.73	2.73
2018	197.03	36.24	1.95	2.63	2.63
2019	190.03	37.12	1.98	2.56	2.56
2020	182.73	37.92	2.01	2.49	2.49

Table AP3-17: (from Figure 3-13) Summary of bank development for high GWP gases in California blowing agent type

Year	ODS	HFC/HC
1975	93.33	0.00
1976	103.09	0.00
1977	113.27	0.00
1978	124.01	0.00
1979	135.25	0.00
1980	147.04	0.00
1981	158.93	0.00
1982	171.57	0.00
1983	184.73	0.00
1984	198.69	0.00
1985	213.31	0.00
1986	228.70	0.00
1987	244.81	0.00
1988	261.80	0.00
1989	279.72	0.00
1990	298.57	0.00
1991	315.19	0.00
1992	329.64	0.00
1993	345.02	0.00
1994	356.52	0.00
1995	363.26	0.02
1996	363.65	0.04
1997	358.19	0.07
1998	352.81	0.11
1999	347.38	0.18
2000	342.10	0.27
2001	336.50	0.60
2002	330.60	1.72
2003	323.69	4.09
2004	314.73	7.00
2005	304.69	10.35
2006	293.84	14.10
2007	282.84	17.94
2008	271.42	21.85
2009	259.75	26.24
2010	247.43	31.58
2011	236.15	37.72
2012	225.92	44.11
2013	215.27	50.73
2014	204.08	57.58
2015	192.31	64.67
2016	179.98	72.05
2017	167.27	79.22
2018	154.53	85.96
2019	141.80	92.44
2020	128.83	98.80

Table AP3-18: (from Figure 3-14) Summary of emissions for high GWP gases in California

Year	Buildings	Appliances	Other Refrigeration	TRUs	Marine + Other
1975	1.54	0.15	0.03	0.20	0.20
1976	1.64	0.16	0.02	0.20	0.20
1977	1.69	0.17	0.03	0.21	0.21
1978	1.81	0.18	0.03	0.22	0.22
1979	1.93	0.19	0.03	0.22	0.22
1980	2.01	0.15	0.02	0.22	0.22
1981	2.14	0.16	0.03	0.22	0.22
1982	2.27	0.17	0.02	0.23	0.23
1983	2.42	0.18	0.03	0.24	0.24
1984	2.58	0.19	0.03	0.24	0.24
1985	2.71	0.20	0.03	0.25	0.25
1986	2.88	0.21	0.03	0.26	0.26
1987	3.07	0.22	0.03	0.27	0.27
1988	3.27	0.24	0.03	0.27	0.27
1989	3.48	0.25	0.03	0.28	0.28
1990	3.65	0.67	0.10	0.31	0.31
1991	4.51	0.72	0.10	0.31	0.31
1992	4.80	0.80	0.13	0.32	0.32
1993	4.47	0.83	0.13	0.33	0.33
1994	4.18	0.84	0.13	0.33	0.33
1995	3.82	0.79	0.12	0.32	0.32
1996	3.37	0.83	0.16	0.30	0.30
1997	3.46	0.87	0.14	0.30	0.30
1998	3.56	0.91	0.17	0.31	0.31
1999	3.66	0.95	0.16	0.31	0.31
2000	3.67	0.99	0.16	0.32	0.32
2001	3.68	1.05	0.14	0.32	0.32
2002	3.79	1.10	0.15	0.33	0.33
2003	3.83	1.14	0.15	0.34	0.34
2004	3.91	1.18	0.16	0.34	0.34
2005	3.98	1.21	0.16	0.33	0.33
2006	4.10	1.24	0.15	0.34	0.34
2007	4.23	1.32	0.16	0.34	0.34
2008	4.31	1.19	0.13	0.35	0.35
2009	4.33	1.06	0.11	0.31	0.31
2010	4.43	0.66	0.07	0.27	0.27
2011	4.51	0.68	0.07	0.15	0.15
2012	4.66	0.70	0.07	0.14	0.14
2013	4.83	0.74	0.08	0.14	0.14
2014	5.01	0.79	0.08	0.14	0.14
2015	5.19	0.82	0.07	0.14	0.14
2016	5.40	0.92	0.07	0.15	0.15
2017	5.61	0.99	0.07	0.15	0.15
2018	5.84	1.02	0.08	0.15	0.15
2019	6.08	1.07	0.08	0.15	0.15
2020	6.34	1.10	0.08	0.14	0.14

Table AP3-19: (from Figure 3-15) Summary of emissions for high GWP gases by blowing agent type

Year	ODS	HFC/HC
1975	2.10	0.00
1976	2.23	0.00
1977	2.31	0.00
1978	2.45	0.00
1979	2.60	0.00
1980	2.60	0.00
1981	2.77	0.00
1982	2.93	0.00
1983	3.11	0.00
1984	3.29	0.00
1985	3.44	0.00
1986	3.64	0.00
1987	3.86	0.00
1988	4.09	0.00
1989	4.33	0.00
1990	5.04	0.00
1991	5.97	0.00
1992	6.37	0.00
1993	6.09	0.00
1994	5.81	0.00
1995	5.38	0.00
1996	4.95	0.00
1997	5.06	0.00
1998	5.25	0.00
1999	5.39	0.01
2000	5.43	0.02
2001	5.44	0.07
2002	5.56	0.14
2003	5.61	0.19
2004	5.70	0.23
2005	5.76	0.27
2006	5.88	0.29
2007	6.07	0.31
2008	5.91	0.41
2009	5.49	0.63
2010	4.89	0.80
2011	4.68	0.87
2012	4.77	0.95
2013	4.89	1.03
2014	5.03	1.12
2015	5.15	1.22
2016	5.24	1.44
2017	5.23	1.74
2018	5.21	2.01
2019	5.25	2.27
2020	5.38	2.43

Table AP3-20: (from Figure 3-16) Total bank estimates for appliances in California

Year	Refrigerators	Freezers	Water Heater (G)	Water Heater (E)
1960	0	0	0	0
1961	0	0	0	0
1962	0	0	0	0
1963	0	0	0	0
1964	0	0	0	0
1965	0	0	0	0
1966	0	0	0	0
1967	0	0	0	0
1968	0	0	0	0
1969	0	0	0	0
1970	0	0	0	0
1971	0	0	0	0
1972	0	0	0	0
1973	0	0	0	0
1974	0	0	0	0
1975	0	0	0	0
1976	0.95	0.59	0.15	0.26
1977	1.95	1.19	0.31	0.52
1978	3.00	1.83	0.46	0.79
1979	4.10	2.48	0.62	1.06
1980	5.26	3.16	0.78	1.32
1981	6.48	3.87	0.94	1.60
1982	7.74	4.61	1.10	1.87
1983	9.07	5.36	1.26	2.14
1984	10.45	6.15	1.42	2.42
1985	11.89	6.95	1.59	2.70
1986	13.39	7.79	1.76	2.98
1987	14.96	8.65	1.92	3.27
1988	16.60	9.54	2.09	3.55
1989	18.30	10.46	2.26	3.84
1990	20.03	11.40	2.44	4.13
1991	20.89	11.82	2.46	4.16
1992	21.73	12.22	2.48	4.18
1993	22.68	12.65	2.51	4.21
1994	23.29	12.85	2.50	4.20
1995	23.53	12.81	2.46	4.12
1996	22.74	12.30	2.33	3.91
1997	21.96	11.78	2.21	3.69
1998	21.20	11.22	2.08	3.48
1999	20.46	10.67	1.96	3.26
2000	19.75	10.16	1.85	3.05
2001	19.10	9.65	1.74	2.84
2002	18.58	9.29	1.62	2.62
2003	18.14	8.98	1.50	2.40
2004	17.72	8.68	1.36	2.14
2005	17.51	8.29	1.21	1.88
2006	17.30	7.92	1.05	1.61
2007	17.09	7.54	0.89	1.35
2008	16.76	7.14	0.72	1.08
2009	16.74	6.95	0.58	0.85
2010	17.05	6.96	0.48	0.67
2011	18.31	7.41	0.46	0.63
2012	19.56	7.87	0.44	0.58
2013	20.77	8.36	0.41	0.54
2014	21.92	8.82	0.38	0.49
2015	23.01	9.22	0.34	0.44
2016	24.04	9.62	0.30	0.38
2017	24.90	9.87	0.26	0.33
2018	25.68	10.05	0.22	0.29
2019	26.42	10.22	0.21	0.27
2020	27.00	10.47	0.20	0.26

Table AP3-21: (from Figure 3-17) Total banks in appliances in California by Blowing Agent

Year	CFCs	HCFCs	HFCs
1960	0	0	0
1961	0	0	0
1962	0	0	0
1963	0	0	0
1964	0	0	0
1965	0	0	0
1966	0	0	0
1967	0	0	0
1968	0	0	0
1969	0	0	0
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0
1974	0	0	0
1975	0	0	0
1976	1.95	0.00	0.00
1977	3.98	0.00	0.00
1978	6.08	0.00	0.00
1979	8.26	0.00	0.00
1980	10.53	0.00	0.00
1981	12.88	0.00	0.00
1982	15.32	0.00	0.00
1983	17.84	0.00	0.00
1984	20.44	0.00	0.00
1985	23.14	0.00	0.00
1986	25.92	0.00	0.00
1987	28.80	0.00	0.00
1988	31.78	0.00	0.00
1989	34.86	0.00	0.00
1990	38.00	0.00	0.00
1991	39.32	0.00	0.00
1992	40.60	0.00	0.00
1993	42.04	0.00	0.00
1994	42.69	0.14	0.00
1995	42.46	0.44	0.02
1996	40.07	1.17	0.04
1997	37.59	1.97	0.07
1998	35.04	2.83	0.11
1999	32.40	3.77	0.18
2000	29.67	4.87	0.27
2001	26.86	6.06	0.40
2002	23.96	7.21	0.94
2003	20.97	8.00	2.05
2004	17.88	8.37	3.64
2005	14.72	8.38	5.76
2006	11.51	8.36	7.97
2007	8.27	8.33	10.21
2008	4.81	8.31	12.50
2009	2.04	8.16	14.82
2010	0.03	7.85	17.15
2011	0.03	7.13	19.51
2012	0.03	6.33	21.92
2013	0.03	5.49	24.35
2014	0.03	4.56	26.80
2015	0.03	3.48	29.24
2016	0.03	2.32	31.72
2017	0.03	1.19	33.84
2018	0.03	0.41	35.47
2019	0.03	0.03	36.71
2020	0.03	0.01	37.52

Table AP3-22: (from Figure 3-18) Total banks in appliances & waste streams

Year	Banks in Waste Streams			Total in Appliances		
	CFCs	HCFCs	HFCs	CFCs	HCFCs	HFCs
1960	0.00	0.00	0.00	0	0	0
1961	0.00	0.00	0.00	0	0	0
1962	0.00	0.00	0.00	0	0	0
1963	0.00	0.00	0.00	0	0	0
1964	0.00	0.00	0.00	0	0	0
1965	0.00	0.00	0.00	0	0	0
1966	0.00	0.00	0.00	0	0	0
1967	0.00	0.00	0.00	0	0	0
1968	0.00	0.00	0.00	0	0	0
1969	0.00	0.00	0.00	0	0	0
1970	0.00	0.00	0.00	0	0	0
1971	0.00	0.00	0.00	0	0	0
1972	0.00	0.00	0.00	0	0	0
1973	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	1.95	0.00	0.00
1977	0.00	0.00	0.00	3.98	0.00	0.00
1978	0.00	0.00	0.00	6.08	0.00	0.00
1979	0.00	0.00	0.00	8.26	0.00	0.00
1980	0.00	0.00	0.00	10.53	0.00	0.00
1981	0.00	0.00	0.00	12.88	0.00	0.00
1982	0.00	0.00	0.00	15.32	0.00	0.00
1983	0.00	0.00	0.00	17.84	0.00	0.00
1984	0.00	0.00	0.00	20.44	0.00	0.00
1985	0.00	0.00	0.00	23.14	0.00	0.00
1986	0.00	0.00	0.00	25.92	0.00	0.00
1987	0.00	0.00	0.00	28.80	0.00	0.00
1988	0.00	0.00	0.00	31.78	0.00	0.00
1989	0.00	0.00	0.00	34.86	0.00	0.00
1990	1.45	0.00	0.00	38.00	0.00	0.00
1991	2.90	0.00	0.00	39.32	0.00	0.00
1992	4.34	0.00	0.00	40.60	0.00	0.00
1993	5.78	0.00	0.00	42.04	0.00	0.00
1994	7.23	0.00	0.00	42.69	0.14	0.00
1995	8.71	0.00	0.00	42.46	0.44	0.02
1996	10.21	0.00	0.00	40.07	1.17	0.04
1997	11.72	0.00	0.00	37.59	1.97	0.07
1998	13.26	0.00	0.00	35.04	2.83	0.11
1999	14.81	0.00	0.00	32.40	3.77	0.18
2000	16.39	0.00	0.00	29.67	4.87	0.27
2001	17.99	0.00	0.00	26.86	6.06	0.40
2002	19.62	0.00	0.00	23.96	7.21	0.94
2003	21.28	0.00	0.00	20.97	8.00	2.05
2004	22.94	0.00	0.00	17.88	8.37	3.64
2005	24.60	0.00	0.00	14.72	8.38	5.76
2006	26.23	0.00	0.00	11.51	8.36	7.97
2007	27.98	0.00	0.00	8.27	8.33	10.21
2008	29.19	0.10	0.00	4.81	8.31	12.50
2009	29.80	0.31	0.01	2.04	8.16	14.82
2010	28.91	0.83	0.03	0.03	7.85	17.15
2011	28.06	1.39	0.05	0.03	7.13	19.51
2012	27.23	1.97	0.08	0.03	6.33	21.92
2013	26.43	2.62	0.13	0.03	5.49	24.35
2014	25.64	3.36	0.20	0.03	4.56	26.80
2015	24.89	4.15	0.29	0.03	3.48	29.24
2016	24.15	4.90	0.67	0.03	2.32	31.72
2017	23.44	5.37	1.47	0.03	1.19	33.84
2018	22.74	5.55	2.61	0.03	0.41	35.47
2019	22.07	5.46	4.12	0.03	0.03	36.71
2020	21.42	5.35	5.68	0.03	0.01	37.52

Table AP3-23: (from Figure 3-19) Baseline GHG emissions for appliances in California 1991 – 2020

Year	ODS	HFC/HC
1991	724.51	0.00
1992	795.24	0.00
1993	831.19	0.00
1994	838.08	1.00
1995	793.28	1.26
1996	829.52	1.46
1997	864.71	2.34
1998	903.17	3.54
1999	944.97	5.24
2000	985.22	7.07
2001	1020.30	27.83
2002	1039.58	58.42
2003	1056.62	85.36
2004	1066.65	116.26
2005	1088.50	126.25
2006	1106.21	133.60
2007	1173.53	142.29
2008	1042.69	149.80
2009	892.64	162.43
2010	484.81	171.31
2011	500.44	181.46
2012	507.17	193.67
2013	527.60	207.46
2014	561.30	223.61
2015	581.65	241.95
2016	571.13	352.42
2017	478.98	510.43
2018	373.63	646.15
2019	276.10	798.16
2020	262.37	841.83

Table AP3-24: (from Figure 3-20) Baseline for appliances related emission sources in 2020

Manu	In Use Phase				Waste Stream
PU Inject	Refrigerator	Freezer	WH (Gas)	WH (Elec)	Waste Stream
152.26	67.49	26.18	0.49	0.64	857.78

Table AP3-25: (from Figure 3-21) Total banks in other refrigeration & waste streams

	Banks in Waste Streams			Total in Other Refrigeration		
Year	CFCs	HCFCs	HFCs	CFCs	HCFCs	HFCs
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0.33	0.00	0.00
1977	0	0	0	0.65	0.00	0.00
1978	0	0	0	1.04	0.00	0.00
1979	0	0	0	1.42	0.00	0.00
1980	0	0	0	1.80	0.00	0.00
1981	0	0	0	2.18	0.00	0.00
1982	0	0	0	2.70	0.00	0.00
1983	0	0	0	3.11	0.00	0.00
1984	0	0	0	3.66	0.00	0.00
1985	0	0	0	4.15	0.00	0.00
1986	0	0	0	4.62	0.00	0.00
1987	0	0	0	5.00	0.00	0.00
1988	0	0	0	5.42	0.00	0.00
1989	0.00	0.00	0.00	5.85	0.00	0.00
1990	0.25	0.00	0.00	6.29	0.00	0.00
1991	0.47	0.00	0.00	6.43	0.00	0.00
1992	0.74	0.00	0.00	6.53	0.00	0.00
1993	0.99	0.00	0.00	6.58	0.00	0.00
1994	1.24	0.00	0.00	6.51	0.02	0.00
1995	1.47	0.00	0.00	6.34	0.05	0.00
1996	1.80	0.00	0.00	5.96	0.12	0.00
1997	2.04	0.00	0.00	5.44	0.21	0.00
1998	2.38	0.00	0.00	5.03	0.28	0.00
1999	2.67	0.00	0.00	4.47	0.39	0.00
2000	2.93	0.00	0.00	3.98	0.49	0.00
2001	3.12	0.00	0.00	3.51	0.59	0.01
2002	3.33	0.00	0.00	3.13	0.65	0.03
2003	3.55	0.00	0.00	2.70	0.71	0.06
2004	3.77	0.00	0.00	2.27	0.74	0.15
2005	3.99	0.00	0.00	1.82	0.75	0.25
2006	4.17	0.00	0.00	1.36	0.75	0.38
2007	4.36	0.00	0.00	0.95	0.74	0.50
2008	4.46	0.01	0.00	0.52	0.74	0.63
2009	4.48	0.03	0.00	0.21	0.72	0.76
2010	4.35	0.08	0.00	0.01	0.69	0.89
2011	4.22	0.15	0.00	0.01	0.63	1.02
2012	4.10	0.20	0.00	0.01	0.54	1.15
2013	3.98	0.27	0.00	0.01	0.46	1.29
2014	3.86	0.34	0.00	0.01	0.35	1.42
2015	3.74	0.40	0.00	0.01	0.25	1.55
2016	3.63	0.44	0.02	0.01	0.16	1.68
2017	3.53	0.47	0.05	0.01	0.10	1.80
2018	3.42	0.48	0.11	0.01	0.04	1.90
2019	3.32	0.48	0.18	0.01	0.01	1.96
2020	3.22	0.47	0.27	0.01	0.00	2.00

Table AP3-26: (from Figure 3-22) Total banks in TRUs & related waste streams

	Banks in Waste Streams			Total in TRUs		
Year	CFCs	HCFCs	HFCs	CFCs	HCFCs	HFCs
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0.00	0.00	0.00	0.15	0.00	0.00
1969	0.00	0.00	0.00	0.31	0.00	0.00
1970	0.00	0.00	0.00	0.47	0.00	0.00
1971	0.00	0.00	0.00	0.64	0.00	0.00
1972	0.00	0.00	0.00	0.80	0.00	0.00
1973	0.00	0.00	0.00	0.97	0.00	0.00
1974	0.00	0.00	0.00	1.15	0.00	0.00
1975	0.00	0.00	0.00	1.32	0.00	0.00
1976	0.00	0.00	0.00	1.50	0.00	0.00
1977	0.00	0.00	0.00	1.69	0.00	0.00
1978	0.00	0.00	0.00	1.87	0.00	0.00
1979	0.00	0.00	0.00	2.07	0.00	0.00
1980	0.00	0.00	0.00	2.26	0.00	0.00
1981	0.00	0.00	0.00	2.46	0.00	0.00
1982	0.12	0.00	0.00	2.66	0.00	0.00
1983	0.25	0.00	0.00	2.73	0.00	0.00
1984	0.37	0.00	0.00	2.80	0.00	0.00
1985	0.50	0.00	0.00	2.86	0.00	0.00
1986	0.63	0.00	0.00	2.94	0.00	0.00
1987	0.75	0.00	0.00	3.01	0.00	0.00
1988	0.88	0.00	0.00	3.09	0.00	0.00
1989	1.01	0.00	0.00	3.17	0.00	0.00
1990	1.14	0.00	0.00	3.26	0.00	0.00
1991	1.27	0.00	0.00	3.35	0.00	0.00
1992	1.40	0.00	0.00	3.45	0.00	0.00
1993	1.52	0.00	0.00	3.56	0.00	0.00
1994	1.65	0.00	0.00	3.67	0.00	0.00
1995	1.78	0.00	0.00	3.72	0.01	0.00
1996	1.91	0.00	0.00	3.71	0.03	0.00
1997	2.04	0.00	0.00	3.50	0.08	0.00
1998	2.17	0.00	0.00	3.28	0.13	0.00
1999	2.31	0.00	0.00	3.05	0.19	0.00
2000	2.45	0.00	0.00	2.82	0.24	0.00
2001	2.59	0.00	0.00	2.59	0.30	0.00
2002	2.74	0.00	0.00	2.34	0.36	0.02
2003	2.89	0.00	0.00	2.09	0.38	0.08
2004	3.04	0.00	0.00	1.84	0.38	0.16
2005	3.19	0.00	0.00	1.58	0.38	0.25
2006	3.35	0.00	0.00	1.31	0.38	0.34
2007	3.52	0.00	0.00	1.03	0.38	0.43
2008	3.69	0.00	0.00	0.74	0.38	0.51
2009	3.81	0.01	0.00	0.44	0.38	0.57
2010	3.89	0.02	0.00	0.19	0.37	0.63
2011	3.82	0.06	0.00	0.00	0.35	0.68
2012	3.75	0.10	0.00	0.00	0.30	0.72
2013	3.68	0.14	0.00	0.00	0.25	0.77
2014	3.61	0.18	0.00	0.00	0.19	0.82
2015	3.54	0.23	0.00	0.00	0.14	0.87
2016	3.48	0.27	0.01	0.00	0.08	0.92
2017	3.42	0.29	0.06	0.00	0.03	0.95
2018	3.36	0.28	0.13	0.00	0.00	0.94
2019	3.30	0.28	0.19	0.00	0.00	0.91
2020	3.24	0.27	0.26	0.00	0.00	0.87

Table AP3-27: (from Figure 3-23) Total banks in marine/other applications & related waste stream

	Banks in Waste Streams			Total in Marine & Other		
Year	CFCs	HCFCs	HFCs	CFCs	HCFCs	HFCs
1960	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.53	0.00	0.00
1962	0.00	0.00	0.00	1.08	0.00	0.00
1963	0.00	0.00	0.00	1.63	0.00	0.00
1964	0.00	0.00	0.00	2.20	0.00	0.00
1965	0.00	0.00	0.00	2.77	0.00	0.00
1966	0.00	0.00	0.00	3.36	0.00	0.00
1967	0.00	0.00	0.00	3.95	0.00	0.00
1968	0.00	0.00	0.00	4.56	0.00	0.00
1969	0.00	0.00	0.00	5.17	0.00	0.00
1970	0.00	0.00	0.00	5.80	0.00	0.00
1971	0.00	0.00	0.00	6.44	0.00	0.00
1972	0.00	0.00	0.00	7.09	0.00	0.00
1973	0.00	0.00	0.00	7.76	0.00	0.00
1974	0.00	0.00	0.00	8.43	0.00	0.00
1975	0.40	0.00	0.00	9.12	0.00	0.00
1976	0.79	0.00	0.00	9.41	0.00	0.00
1977	1.19	0.00	0.00	9.70	0.00	0.00
1978	1.58	0.00	0.00	9.99	0.00	0.00
1979	1.97	0.00	0.00	10.30	0.00	0.00
1980	2.35	0.00	0.00	10.61	0.00	0.00
1981	2.74	0.00	0.00	10.93	0.00	0.00
1982	3.13	0.00	0.00	11.26	0.00	0.00
1983	3.51	0.00	0.00	11.59	0.00	0.00
1984	3.90	0.00	0.00	11.93	0.00	0.00
1985	4.28	0.00	0.00	12.28	0.00	0.00
1986	4.67	0.00	0.00	12.64	0.00	0.00
1987	5.05	0.00	0.00	13.00	0.00	0.00
1988	5.44	0.00	0.00	13.38	0.00	0.00
1989	5.82	0.00	0.00	13.76	0.00	0.00
1990	6.28	0.00	0.00	14.15	0.00	0.00
1991	6.74	0.00	0.00	14.38	0.00	0.00
1992	7.20	0.00	0.00	14.62	0.00	0.00
1993	7.66	0.00	0.00	14.86	0.00	0.00
1994	8.13	0.00	0.00	15.10	0.00	0.00
1995	8.60	0.00	0.00	15.12	0.03	0.00
1996	9.07	0.00	0.00	14.91	0.10	0.00
1997	9.54	0.00	0.00	13.97	0.29	0.00
1998	10.02	0.00	0.00	13.02	0.47	0.00
1999	10.50	0.00	0.00	12.05	0.66	0.00
2000	10.98	0.00	0.00	11.06	0.85	0.00
2001	11.47	0.00	0.00	10.05	1.05	0.00
2002	11.96	0.00	0.00	9.02	1.21	0.06
2003	12.45	0.00	0.00	7.98	1.29	0.22
2004	12.95	0.00	0.00	6.92	1.29	0.45
2005	13.40	0.00	0.00	5.83	1.29	0.69
2006	13.85	0.00	0.00	4.80	1.28	0.92
2007	14.31	0.00	0.00	3.75	1.28	1.15
2008	14.78	0.00	0.00	2.68	1.28	1.36
2009	15.07	0.03	0.00	1.59	1.27	1.55
2010	15.20	0.08	0.00	0.70	1.24	1.70
2011	14.81	0.21	0.00	0.02	1.17	1.82
2012	14.42	0.35	0.00	0.02	0.99	1.95
2013	14.05	0.49	0.00	0.02	0.81	2.08
2014	13.68	0.63	0.00	0.02	0.62	2.21
2015	13.33	0.76	0.00	0.02	0.43	2.35
2016	12.98	0.87	0.04	0.02	0.24	2.49
2017	12.64	0.92	0.17	0.02	0.08	2.57
2018	12.32	0.91	0.34	0.02	0.00	2.55
2019	12.00	0.89	0.52	0.02	0.00	2.48
2020	11.68	0.88	0.69	0.02	0.00	2.40

Table AP3-28: (from Figure 3-24) Baseline emission sources in 2020 – Other refrigeration

Manu	PU Inject	5.88
In Use Phase	VM Ref.	1.38
	VM NR	0.59
	Commercial-New	0.74
	Commerical-Refurb	2.32
Waste Stream	PU Inject	69.94
Total		0.08

Table AP3-29: (from Figure 3-25) Baseline emission sources in 2020 – TRU

Manu	PU Inject	3.34
In Use Phase	TRU-Road	2.02
	TRU-Rail	0.18
	TRU-Sea	0.05
Waste Stream	PU Inject	40.07
Total		0.05

Table AP3-30: (from Figure 3-26) Baseline emission sources in 2020 – Marine & Other

Manu	PU Inject	9.07
In Use Phase	Boats	2.36
	Canoes	0.12
	Other Applications	3.24
	Cold Stores (Non-Stru	0.50
Waste Stream	PU Inject	129.05
Total		0.14

Table AP3-31: (from Figure 3-27) Mitigation options for appliances in California

Year	Baseline	Early HFC Phase-out	50% Appl. E-o-L	100% Appl.E-o-L
1991	724.51	724.51	724.51	724.51
1992	795.24	795.24	795.24	795.24
1993	831.19	831.19	831.19	831.19
1994	839.08	839.08	839.08	839.08
1995	794.54	794.54	794.54	794.54
1996	830.98	830.98	830.98	830.98
1997	867.04	867.04	867.04	867.04
1998	906.72	906.72	906.72	906.72
1999	950.22	950.22	950.22	950.22
2000	992.29	992.29	992.29	992.29
2001	1048.14	1048.14	1048.14	1048.14
2002	1098.02	1098.02	1098.02	1098.02
2003	1142.01	1142.01	1142.01	1142.01
2004	1182.97	1182.97	1182.97	1182.97
2005	1214.85	1214.85	1214.85	1214.85
2006	1239.95	1239.95	1239.95	1239.95
2007	1316.00	1316.00	1316.00	1316.00
2008	1192.72	1192.72	1192.72	1192.72
2009	1055.34	1055.34	1055.34	1055.34
2010	656.43	656.43	656.43	656.43
2011	682.25	682.25	682.25	682.25
2012	701.23	701.23	667.18	667.18
2013	735.49	735.49	656.62	656.62
2014	785.38	785.38	689.20	643.67
2015	824.11	779.97	714.30	611.62
2016	924.11	834.63	781.32	645.52
2017	990.00	848.85	824.53	665.93
2018	1020.39	868.76	842.81	671.97
2019	1074.89	912.51	877.85	687.41
2020	1104.83	932.45	895.41	692.46

Table AP3-32: (from Figure 3-28) Mitigation options for other refrigeration in California

Year	Baseline	Early HFC Phase-out	50% Appl. E-o-L	100% Appl.E-o-L
1991	104.82	104.82	104.82	104.82
1992	129.12	129.12	129.12	129.12
1993	130.57	130.57	130.57	130.57
1994	129.71	129.71	129.71	129.71
1995	122.72	122.72	122.72	122.72
1996	160.85	160.85	160.85	160.85
1997	137.15	137.15	137.15	137.15
1998	174.68	174.68	174.68	174.68
1999	162.08	162.08	162.08	162.08
2000	157.74	157.74	157.74	157.74
2001	137.57	137.57	137.57	137.57
2002	149.31	149.31	149.31	149.31
2003	154.89	154.89	154.89	154.89
2004	158.16	158.16	158.16	158.16
2005	164.62	164.62	164.62	164.62
2006	153.53	153.53	153.53	153.53
2007	159.17	159.17	159.17	159.17
2008	134.81	134.81	134.81	134.81
2009	113.00	113.00	113.00	113.00
2010	68.76	68.76	68.76	68.76
2011	74.00	74.00	74.00	74.00
2012	70.24	70.24	67.29	67.29
2013	77.61	77.61	69.17	69.17
2014	75.25	73.90	67.07	63.23
2015	74.68	71.86	66.23	58.47
2016	72.67	68.28	64.41	56.83
2017	72.47	66.39	63.88	55.95
2018	76.69	70.21	66.42	56.80
2019	77.46	70.57	66.55	56.27
2020	80.85	73.56	68.49	56.76

Table AP3-33: (from Figure 3-29) Climate impact of mitigation options in appliances

	ODS			HFC/HC		
	Early HFC Phase-out	50% Appl. E-o-L	100% Appl.E-o-L	Early HFC Phase-out	50% Appl. E-o-L	100% Appl.E-o-L
Cum. Savings to 2020 ('000 t CO_2 eq)	0.00	563.31	935.66	761.18	647.90	1282.41
Annual Savings @ 2020	0.00	19.65	33.28	172.38	189.77	379.09

Table AP3-34: (from Figure 3-30) Climate impact of mitigation option in other refrigeration

	ODS			HFC/HC		
	Early HFC Phase-out	50% Appl. E-o-L	100% Appl.E-o-L	Early HFC Phase-out	50% Appl. E-o-L	100% Appl.E-o-L
Cum. Savings to 2020 ('000 t CO_2 eq)	0.00	47.72	75.79	33.10	30.67	61.35
Annual Savings @ 2020	0.00	1.65	2.68	6.53	10.71	21.41

Table AP3-35: (from Figure 3-31) Savings opportunities in the building sector for California

	ODS					HFC/HC				
	HFC-XPS	HFC-Spray	Panel EoL	50-100 EoL	25-50 EoL	HFC-XPS	HFC-Spray	Panel EoL	50-100 EoL	25-50 EoL
Cum. Savings to 2020 ('000 t CO_2-eq)	175217.95	175217.95	175214.84	168848.02	171849.52	3698.46	1064.71	0.00	0.00	0.00
Annual Savings @ 2020	0.00	0.00	3.11	6369.92	3368.43	828.56	239.09	0.00	0.00	0.00

Table AP3-36: (from Figure 3-32) Emission reduction scenario for buildings

Year	Baseline	HFC-XPS	HFC-Spray	Panel EoL	50 - 100 EoL	25 - 50 EoL
1991	4513.39	4513.39	4513.39	4513.39	4513.39	4513.39
1992	4796.66	4796.66	4796.66	4796.66	4796.66	4796.66
1993	4468.36	4468.36	4468.36	4468.36	4468.36	4468.36
1994	4184.32	4184.32	4184.32	4184.32	4184.32	4184.32
1995	3818.68	3818.68	3818.68	3818.68	3818.68	3818.68
1996	3366.93	3366.93	3366.93	3366.93	3366.93	3366.93
1997	3459.50	3459.50	3459.50	3459.50	3459.50	3459.50
1998	3558.19	3558.19	3558.19	3558.19	3558.19	3558.19
1999	3663.45	3663.45	3663.45	3663.45	3663.45	3663.45
2000	3670.06	3670.06	3670.06	3670.06	3670.06	3670.06
2001	3678.41	3678.41	3678.41	3678.41	3678.41	3678.41
2002	3788.51	3788.51	3788.51	3788.51	3788.51	3788.51
2003	3832.11	3832.11	3832.11	3832.11	3832.11	3832.11
2004	3907.76	3907.76	3907.76	3907.76	3907.76	3907.76
2005	3981.84	3981.84	3981.84	3981.84	3981.84	3981.84
2006	4099.41	4099.41	4099.41	4099.41	4099.41	4099.41
2007	4225.13	4225.13	4225.13	4225.13	4225.13	4225.13
2008	4306.90	4306.90	4306.90	4306.90	4306.90	4306.90
2009	4332.87	4332.87	4332.87	4332.87	4332.87	4332.87
2010	4431.75	4431.75	4431.75	4431.75	4431.75	4431.75
2011	4505.88	4505.88	4505.88	4505.88	4505.88	4505.88
2012	4663.66	4663.66	4663.66	4663.66	4443.17	4443.17
2013	4830.25	4830.25	4830.25	4830.25	4340.59	4574.40
2014	5006.80	4886.11	4972.20	5006.80	4443.28	4714.68
2015	5194.43	4931.81	5119.07	5194.43	4554.92	4864.90
2016	5396.60	4968.57	5273.66	5396.45	4677.50	5027.79
2017	5610.32	4990.93	5432.23	5609.97	4808.80	5200.76
2018	5838.45	5153.40	5641.28	5837.87	4951.02	5386.36
2019	6082.16	5327.35	5864.69	6081.31	5104.90	5585.54
2020	6342.66	5513.70	6103.57	6341.48	5271.22	5799.30

Table AP3-37: (from Figure 3-33) Savings opportunities in all sectors for California

	HFC-XPS	HFC-Spray	Panel EoL	50%/100% Buildings EoL	25%/50% Buildings EoL	Early HFC Phase-out 'Appliance'	50% Appliance E-o-L	100% Appliance E-o-L
Cum. Savings to 2020 ('000 t CO_2-eq)	3699.55	1064.71	3.11	6369.92	3368.43	109.93	1211.21	2218.06
Annual Savings @ 2020	828.96	239.09	1.18	1071.44	543.36	33.19	209.42	412.37

Table AP3-38: (from Figure 3-34) HFC Savings opportunities in all sectors for California

	HFC-XPS	HFC-Spray	Panel EoL	50%/100% Buildings EoL	25%/50% Buildings EoL	Early HFC Phase-out 'Appliance'	50% Appliance E-o-L	100% Appliance E-o-L
Cum. Savings to 2020 ('000 t CO_2-eq)	3698.46	1064.71	0.00	0.00	0.00	761.18	647.90	1282.41
Annual Savings @ 2020	828.56	239.09	0.00	0.00	0.00	172.38	189.77	379.09

Table AP3-39: (from Figure 3-35) Maximum cumulative mitigation potential for high GWP gases in 2020

	Cumulative to 2020
Early HFC Phase-Out - XPS - Buildings	3.70
Early HFC Phase-Out - PU Spray - Buildings	1.06
50%/100% E-o-L - Buildings	6.37
Early HFC Phase-Out - Appliances	0.76
100% E-o-L - Appliances	2.22
Early HFC Phase-Out - Other Refrigeration	0.04
100% E-o-L - Other Refrigeration	0.14

Table AP3-40: (from Figure 3-36) Maximum annual mitigation potential for high GWP gases at 2020

	Annual Saving @ 2020
Early HFC Phase-Out - XPS - Buildings	0.83
Early HFC Phase-Out - PU Spray - Buildings	0.24
50%/100% E-o-L - Buildings	1.07
Early HFC Phase-Out - Appliances	0.17
100% E-o-L - Appliances	0.41
Early HFC Phase-Out - Other Refrigeration	0.01
100% E-o-L - Other Refrigeration	0.02

Table AP3-41: (from Figure 4-1) Potential for recovery VS cost effectiveness

Figure sourced from TEAP workshop on ODS bank management, held in Geneva in July 2010. No data available for this report

Table AP3-42: (from Figure 4-2) Maximum potential savings at 2020 by source

	Annual Saving @ 2020
HFC-based measures	1.25
Appliance End-of-Life Measures	0.44
Building End-of-Life Measures	1.07

Table AP3-43: (from Figure 4-3) Maximum potential savings at 2020 from HFC-based measures

	Annual Saving @ 2020
HFC-based measures	1.25
Appliance End-of-Life Measures	0.40

Table AP3-44: (from Figure 5-5) Maximum potential savings at 2020 by source

Same as Table AP3-42

Table AP3-45: (from Figure 5-6) Maximum potential savings at 2020 from HFC-based measures

Same as Table AP3-43