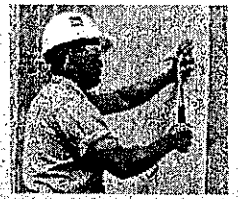
Foam Recovery and Destruction



Glenn Gallagher

ARB Workshop on Stationary High-GWP Early Action Items

February 15, 2008

Outline

- Background
- Greenhouse Gases in Insulating Foam
- Data Sources and Inventory Development
- Emissions and Trends
- Current Recovery & Destruction Programs
- Potential Control Strategies & Costs
- Key Questions and Issues
- Working Group Formation
- Timeline & Contact Information

Background

- Foam Recovery & Destruction Program Recommended as Early Action Measure:
  - High-Global Warming Potential (GWP) Greenhouse Gas (GHG) insulating poly foams are potentially in every building, refrigerator, and freezer
  - Foams are a large source of gases that are greenhouse gases and ozone-depleting substances
  - Reduction of emissions from foam will benefit efforts to mitigate climate change and stratospheric ozone depletion

Background (continued)

- **Foams Included in Early Action**
  - Rigid poly insulating foams with High-GWP GHGs:
    - Polyurethane (closed cell, non-flexible)
    - Polyisocyanurate
    - Phenolic Foam
    - Spray-in Foam
    - XPS (Extruded Polystyrene) Boardstock & Panels
- **Foams Not Included in Early Action**
  - Materials with minimal to no GHGs:
    - Polystyrene (Styrofoam®) packaging material
    - Open cell foams (flexible polyurethane, etc.)

Banks of High-GWP GHGs in Foam

- **Banks of High-GWP GHGs in Foam:**
  - Banks are sources of gases within existing foam that is still being used as insulation in appliances, buildings, and transport refrigerated units
  - Largest source of current and future emissions are from the banks of foam
  - Banks of existing foam will continue to be an emissions source for 50-70 years

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Sources of High-GWP GHG Foam Banks

- Sources of High-GWP GHG Foam Banks:
  - Building insulation (rigid poly foams) – 64%
  - Appliances (refrigerators, freezers) – 29%
  - Commercial refrigeration units – 4%
  - Transport refrigerated units – 2%
  - Miscellaneous (water heaters, picnic coolers, dashboards, surfboards) – <1%

Source: UNEP 2006 Report of the Rigid and Flexible Foams Technical Options Committee

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Greenhouse Gases in Insulating Foam

Transition of High-GWP GHGs used in Foam

Foam Gas	Dates Used	ODS	GWP
CFC-11	1930s-1995	Yes	4,600
HCFC-141b	1996 – now (from stockpiles)	Yes	700
HFC-134a	2000 – now	No	1,300
HFC-245fa	2005 - now	No	950

Source: IPCC/TEAP, 2002. Safeguarding the Ozone Layer and the Global Climate System

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Foam Emission Pathways

Process/Location	Loss of Gas	Note
Manufacture	4—100%	Each foam type unique
During Life of Insulation	0—2.5% per year	Average loss 1% per year
Recycling/Disposal	Up to 25%	Shredding/ breakage
Landfilled	0.5—2.5% per year	Average loss 1% per year

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

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Data Sources and Inventory Development

- **US EPA Vintaging Model Used to Calculate Emissions and Banks**
  - Designed specifically for ODS & High-GWP GHG stationary sources
  - Uses top-down and bottom-up data, but not 100% complete
  - National estimates scaled to California population
- Caleb Management Services
  - Will conduct a complete Foam Inventory & Emissions Study (specific to California)
  - Data available by June 2009
- Lifecycle Analysis of High-GWP GHGs to be contracted Spring 2008, completed late 2009

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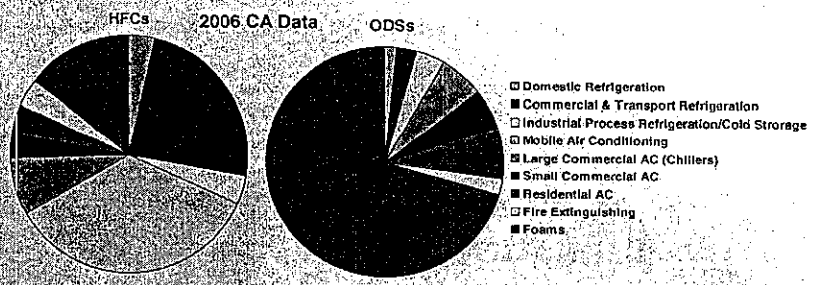
Banks of High-GWP GHGs in Foam (Compared to all High-GWP GHG Sources)

- Major CA Bank Sources (all High-GWP GHGs) in 2006 CA proportion of est. banks from USEPA, IPCC/TEAP
- HFCs ~ 80 $MMTCO_2E$; ODSs ~ 700 $MMTCO_2E$



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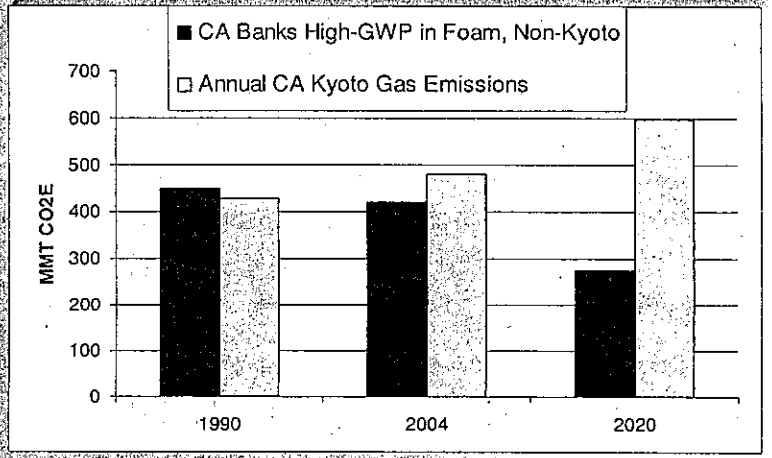
Banks of High-GWP GHGs in Foam



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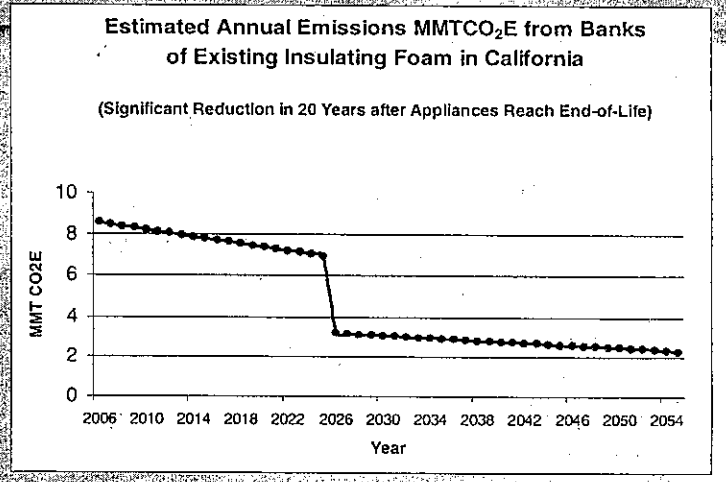
Emissions and Trends - Annual



Source: US EPA Vintaging Model and 50-year extrapolation

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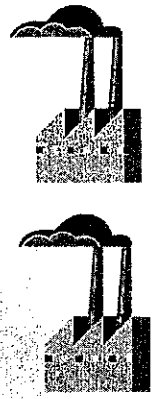
Foam Emission Equivalents

Reducing foam GHG emissions (9 $MMTCO_2E$) for just one year is equivalent to any one of the following:

- Removing 1.6 million cars and light-duty trucks from road for a year
- Saving 1 billion gallons of gasoline
- Eliminating CO_2 emissions from 1.9 coal-fired power plants for a year



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Current Recovery & Destruction Programs

- All current programs are voluntary
- U.S. EPA sponsors the Responsible Appliance Disposal (RAD) Program
- RAD Program does not require foam recovery & destruction, but it is a potential option
- Building insulation is not currently recovered in North America or Europe (small-scale program in Japan)

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Responsible Alliance Disposal (RAD) Program

- **RAD Program:**
  - RAD partners include Sears and 4 major utility companies in California
  - Three recycling facilities in California with total refrigerant + foam recovery
  - Consumers receive $35 "bounty" for recycling old freezers and refrigerators still in operating condition
  - Appliance recyclers receive funding from utilities to take inefficient appliances off the electrical grid; and a modest premium for additional foam recovery and destruction

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Potential Control Strategies

- Voluntary
  - Continue existing appliance foam recovery program
  - Expand appliance foam recovery through incentives
  - Building foam insulation recovery prior to demolition, or post-demolition separation
  - Other sources of foam - options require additional research

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Potential Control Strategies (continued)

- Regulatory
  - Landfill ban on foam containing High-GWP GHGs
  - Recovery & Destruction required for end-of-life foam
  - Enforcement mechanisms not yet determined

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Costs

- **Recovery & Destruction from Appliances** (estimates from US EPA Vintaging Model):
  - Automated Recovery: Approximately $6.50/MTCO$_2$E ($7.60/appliance)
  - Manual Recovery is very labor intensive; seven times greater cost than automated system, at approximately $48/MTCO$_2$E ($56/appliance)
- **Recovery & Destruction from Building Insulation:**
  - No cost data
  - Cost will be researched and included in Life Cycle Analysis (LCA) study in 2009

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Key Questions and Issues

- Emissions, Banks, and Cost
- Foam gases in landfills: how much degradation, recovery and combustion efficiencies, toxic by-products
- Additional research underway
- Foam emissions & banks
- Cost of various recovery systems
- Literature review of High-GWP GHGs in landfill gas

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Working Group Formation

- **Stakeholders Include:**
  - Appliance & scrap metal recyclers, construction & demolition contractors, waste management industry, local government, landfill & transfer station operators
- Form Group and meet in Spring 2008
- If Interested, Please Provide Your Contact Information

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Timeline (Estimated)

Spring 2008	1st Working Group/Stakeholder Consultation Meeting
Fall 2008	1st Public Workshop to Discuss Control Strategies and Options
Spring 2009	2nd Working Group/Stakeholder Consultation Meeting
Summer 2009	2nd Public Workshop on Proposed Regulation
Winter 2009	Board Meeting on Action

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Contact Information

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More Information

- Visit: http://www.arb.ca.gov/cc/foam/foam.htm
- Join list serve at: http://www.arb.ca.gov/listserv/listserv.php

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Questions?

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ARB – Draft Concept Paper
Foam Recovery and Destruction Program[1]

I. Overview

Plastic insulating foams containing high-Global Warming Potential (GWP) Greenhouse Gas (GHG) blowing agents are used in refrigerators, freezers, buildings, commercial refrigeration units, and transport refrigerated units. After the appliance or insulating material has reached the end of its useful life, the waste foam is landfilled, and the high-GWP gases within the foam are emitted into the atmosphere (they are also emitted during the products' useful lifetime).[2] Blowing agents include CFC-11, HCFC-141b, HFC-134a, and HFC-245fa, with GWPs of 4600, 700, 1300, and 950, respectively.[3]

A foam recovery and destruction program could reduce GHG emissions in California by about 9 $MMTCO_2E$ annually.[4]

Plastic insulating foams containing high-GWP gases are rigid poly foams manufactured from polyurethane, polyisocyanurate, phenolic resins, and extruded polystyrene (board stock and panels). Non-insulating foams used in bedding, furniture, packaging, and safety applications contain relatively low amounts of high-GWP GHGs compared to rigid poly foam insulation, and are not part of this reduction strategy. Also not included is fiberglass insulation, which contains no GHGs.[5]

II. Background

Need for Regulations:

The California Global Warming Solutions Act of 2006 (AB 32) requires the Air Resources Board (ARB) to adopt a statewide greenhouse gas emissions limit equivalent to the statewide greenhouse gas emissions levels in 1990 to be achieved by 2020. ARB staff identified insulating poly foam as a source of emissions of high-GWP GHGs that include chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC), and hydrofluorocarbons (HFC).

Although CFCs and HCFCs are ozone-depleting substances (ODS) that are not listed as GHGs under the Kyoto Protocol nor explicitly listed in AB 32, they

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[1] This Foam Recovery and Destruction Concept Paper will be discussed as part of the Foam Recovery and Destruction Working Group to be established Spring 2008.

[2] IPCC/TEAP, IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System, Issues related to Hydrofluorocarbons and Perfluorocarbons, 2005.

[3] IPCC, Climate Change 1995: The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (Global Warming Potentials (GWP) cited are from this report).

[4] USEPA, Vintaging Model for ODS and High-GWP GHG Emissions, 2006.

[5] UNEP (United Nations Environment Programme) Montreal Protocol on Substances that Deplete the Ozone Layer, 2006 Report of the Rigid and Flexible Foams Technical Options Committee 2006 Assessment, March 2007.

represent a significant volume of banked high-GWP GHGs that are a potential source of continued emissions for several more decades, due to the long lifespan of appliances and insulating foam used in buildings.[6] Further, non-Kyoto GHGs (e.g., ODS) were anticipated under AB 32 and should be addressed as part of a suite of GHG mitigation strategies.

Overview of Sector (Current Practices):
Currently, all waste insulating foam is landfilled, with the exception of small amounts recovered from some appliances. In 2006, the U.S EPA formed the 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.[7]

History of Sector:
Insulating foams using CFC-11 as the foam blowing agent were first produced shortly after the development of Freon by DuPont in 1931. CFC-11 is an ozone-depleting substance (ODS) and a greenhouse gas with a GWP of 4,600. Due to Montreal Protocol restrictions, the use of Class I ODS including CFC-11 used in foam was phased out by 1995.

CFC-11 as a foam blowing agent was replaced by a less destructive Class II ODS, HCFC-141b, with a GWP of 700. When the Montreal Protocol restrictions called for the phase-out of Class II ODS, the HCFC-141b was generally replaced by a non-ODS hydrofluorocarbon, HFC-245fa (however, the GWP of HFC-245fa is 950, higher than the HCFC it replaced). Additionally, many spray-in foams use HFC-134a as the blowing agent, with a GWP of 1,300.[8,9]

Current Regulatory Requirements (State/Federal):
No state or federal laws require that foams containing ODS or high-GWP-blowing agents in the foam be recovered and destroyed.

III. Emissions Inventory

Estimates of the magnitudes of foam banks in California obtained from US EPA's Vintaging Model indicate that high-GWP GHG blowing agents banked in foams account for a significant proportion (roughly 60%, or about 400 $MMTCO_2E$) of the total potential 660 $MMTCO_2E$ banked ODSs in California in 2007.

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[6] IPCC/TEAP, IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System, Issues related to Hydrofluorocarbons and Perfluorocarbons, 2005.

[7] USEPA, RAD (Responsible Appliance Disposal) Program website: http://www.epa.gov/Ozone/partnerships/rad/ (accessed January 2008).

[8] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.

[9] IPCC/TEAP, IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System, Issues related to Hydrofluorocarbons and Perfluorocarbons, 2005.

The average age of a disposed refrigerator or freezer is 20 years[10], and the average age of building waste from renovation/remodeling or demolition is roughly estimated at 50 years.[11,12] Therefore, the banked foams still in use can be expected to contribute to GHG emissions for many more decades.

Approximately one million refrigerators and freezers are disposed of annually in California and recycled. Waste foams from appliances are concentrated at the point of appliance recycling locations.[13]

Approximately 6,000 tons of waste foam is landfilled each year in California from building construction and demolition debris.[14] Waste foam from building construction and demolition could potentially be generated from every building undergoing renovation/remodeling or demolition (number of buildings affected yet to be determined).

Current Emissions and Trends:
Emissions of high-GWP GHGs (CFCs and HCFCs) from foam in California are estimated to be about 9 $MMTCO_2E$ annually. Emission estimates are based on national emission estimates from the US EPA Vintaging Model, and scaled down to California's percentage of the national population.

Emissions are expected to decline slightly each year as older appliances and building insulation with CFC-11 reaches end-of-life and is replaced by foams with HFCs that have lower global warming potentials (with future reductions possible only because the banks of existing foam gas have already been released into the atmosphere). Emissions over the next twenty years should decrease to an average emissions rate of approximately 8 $MMTCO_2E$ annually. After 20 years, almost all existing appliances will have reached the end-of-life recycling stage, eliminating older banks of foam in appliances, but leaving remaining large banks of high-GWP GHGs in building insulation foam. The building insulation with CFC-11 will continue to be disposed of for at least another 30 years (which is 21 to 50 years from the current time), at an average emissions rate of 2.7 $MMTCO_2E$ annually.

After 50 years under a business as usual scenario (and assuming no increase in insulation usage), the annual emissions should eventually decline and stabilize at approximately 2.1 $MMTCO_2E$, or 25 percent of the current emission levels, because foams containing CFCs and HCFCs were replaced by foams containing

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[10] AHAM (American Home Appliance Manufacturers) Appliance Recycling & Accelerated Replacement, David B. Calabrese, October 2004: http://www.energystar.gov/ia/partners/downloads/Plenary_C_David_Calabrese.pdf.

[11] Athena Institute, Minnesota Demolition Survey: Phase 2 Report, February 2004, prepared for Forintek Canada Corporation, February 2004.

[12] California Air Resources Board (ARB) Research Division Staff Working Estimates and Calculations for Insulating Foam Recovery/ Destruction Climate Change Early Action Measure, January 2008.

[13] David Godwin (USEPA), Marian Martin Van Pelt and Katrin Peterson (ICF Consulting), Modeling Emissions of High Global Warming Potential Gases from Ozone Depleting Substance Substitutes, 2003.

[14] California Integrated Waste Management Board (CIWMB), Targeted Statewide Waste Characterization Study: Detailed Characterization of Construction and Demolition Waste, June 2006.

HFCs with about 25 percent the global warming potential of previously used blowing agents. The cumulative emissions from 50 years of existing foam banks (not including foam that will be manufactured in the future) are estimated to be about 236 $MMTCO_2E$.[15]

The use of hydrocarbons as non-ODS, lower-GWP foam blowing agents is beginning to gain acceptance in most regions of the world, except in the USA, where existing VOC-emission regulations and stringent fire safety codes inhibits the use of the hydrocarbon alternatives to fluorocarbons.[16]

Outstanding Questions/Uncertainties:
The estimates for annual emissions and banks of foam previously described are the best available estimates as of January 2008. These estimates are based on national figures, scaled down to California's percentage of the national population, and may not reflect conditions specific to California.

ARB will fund research to inventory banks and annual emissions of high-GWP GHG from insulation foam used in appliances, buildings, commercial refrigeration units, transport refrigerated units, and other miscellaneous sources in California (the foam inventory and emissions study was approved by ARB in January 2008, and the results will be made available 2009).

IV. Availability and Technological Feasibility

No control measures currently exist on emissions of high-GWP GHG from foam insulation, in California, with the exception of an appliance recycling facility operated by JACO Environmental, and two facilities operated by Appliance Recycling Centers of America (ARCA). Automated recycling systems capture all greenhouse gases from foam from recycled refrigerators and freezers. The collected gases are condensed and sent to a permitted facility where they are destroyed through high-temperature incineration.

Under the standard recycling processes used by all other appliance recyclers, and all construction and demolition practices, up to 25% of all gases within foam are emitted at the time of appliance recycling (through shredding) and building demolition or renovation (through insulation panel breakage). Additional off-gassing from the foam occurs when it is landfilled.[17]

V. Possible Ideas for Reducing GHG Emissions

Possible ideas considered to reduce greenhouse gas emissions include voluntary and regulatory measures.

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[15] California Air Resources Board (ARB) Research Division Staff Working Estimates and Calculations for Insulating Foam Recovery/ Destruction Climate Change Early Action Measure, January 2008.

[16] IPCC/TEAP, IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System, Issues related to Hydrofluorocarbons and Perfluorocarbons, 2005.

[17] David Godwin (USEPA), Marian Martin Van Pelt and Katrin Peterson (ICF Consulting), Modeling Emissions of High Global Warming Potential Gases from Ozone Depleting Substance Substitutes, 2003.

Voluntary Ideas:

1) Appliances: Continue existing appliance foam recovery and destruction programs, and encourage expansion of the program to include additional appliance recyclers. The voluntary program could be coordinated with the US EPA's Responsible Alliance Disposal (RAD) Program.

2) Building and other Insulation: Develop a program to recover and destroy foam from building insulation and other non-appliance sources (commercial refrigeration units, transport refrigeration units, and miscellaneous sources). Below is a partial list of questions to consider regarding potential voluntary mitigation efforts:

Questions regarding both options:

- What are the economic incentives (if any) of a voluntary program?
- Would any economic assistance be available to assist with a voluntary program?
- Would non-participants still be allowed to dispose of foam under a business as usual process?

Questions regarding appliance voluntary option:

- Would non-functioning appliances be included in the RAD Program?

Questions regarding building and other insulation voluntary option:

- How would insulation foam be economically recovered prior to landfilling?
- Which entities would be expected to participate?

Regulatory Ideas:

1) Regulatory measures may include implementation of a program to recover and destroy waste high-GWP insulating foams from appliances, buildings, and other sources. A landfill ban on high-GWP GHG foams from landfills could be part of a regulatory approach, along with a required recovery and destruction program. Below is a partial list of questions to consider regarding potential regulatory mitigation efforts:

Question regarding regulatory option:

- Who is responsible for removing and recovering the foam before it is landfilled?
- What is the cost and who would pay for the program?
- Certified Appliance Recyclers already remove hazardous materials from appliances -- how would any new regulations affect this program?
- Wouldn't more foam waste just be landfilled outside of California?
- Wouldn't transporting the waste foam to a destruction facility result in more greenhouse gas emissions (from fuel usage) than just leaving the foam in landfills?

- Are current destruction facilities available in California, or would new ones have to be built?
- Aren't foam gases transformed to lower-GWP gases in landfills through natural attenuation and degradation?
- Shouldn't a well-operating landfill methane gas capture and combustion system collect and destroy landfilled foam gases before they are emitted to the atmosphere?
- Why not just require foam manufacturers to produce lower-GWP foams?
- The very High-GWP GHGs such as CFCs and HCFCs are no longer used as foam blowing agents, so why not just let the emissions naturally decline over time?
- Which agency would be responsible for enforcement of any required program?

ARB encourages the expertise and input of all stakeholders to help determine answers to outstanding questions and issues. ARB is also pursuing research to determine better estimates on the magnitude of foam banks and emissions, and for a lifecycle analysis to determine the most cost-effective recovery and destruction programs. Findings will be available in 2009 and will help inform the rule-making process.

VI. Emission Reduction Potential

Potential emission reductions of about 9 $MMTCO_2E$ could be achieved annually through a program of foam recovery and destruction (assuming 100 percent recovery of waste foam gases). As older banks of existing foam are replaced by foam with HFCs, the emissions reduction should decline to an average emissions rate of approximately 8 $MMTCO_2E$ annually through the next 20 years.

After 20 years almost all existing appliances will have reached the end of life recycling stage, eliminating older banks of foam in appliances, but leaving remaining large banks of building insulation foam, which will continue to emit approximately 2.7 $MMTCO_2E$ annually from 20 to 50 years from the current year, until all CFC and HCFC-containing foams have reached their end of life. Eventually, emissions from HFC-containing foams should stabilize at approximately 2.1 $MMTCO_2E$ annually.[18]

To put the emission reduction potential into a more everyday perspective, equivalent measures were calculated to show relative magnitude of greenhouse gas emission reductions.[19,20] A reduction of 9 $MMTCO_2E$ per year is comparable to any one of the following actions:

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[18] California Air Resources Board (ARB) Research Division Staff Working Estimates and Calculations for Insulating Foam Recovery/ Destruction Climate Change Early Action Measure, January 2008.

[19] California Air Resources Board (ARB) Climate Change Fact Sheet, Conversion of 1 MMTCO2 to Familiar Equivalents, October 2007.

- Removing 1.6 million cars and light-duty trucks from the road for a year.
- Saving one billion gallons of gasoline.
- Eliminating the energy use from 790,000 homes for a year.
- Eliminating all CO_2 emissions from 1.9 coal-fired power plants for a year.

VII. Cost Information

The US EPA estimates that automated foam recovery at appliance EOL costs approximately \$6.50/MTCO$_2$E (about \$7.60 per appliance), while manual foam recovery at appliance EOL costs approximately \$48/MTCO$_2$E (about \$57 per appliance). Currently, no cost data is available for building foam recovery and destruction, as it is only occurring in small-scale projects in Japan.[21,22]

The Life Cycle Analysis Study to be completed in 2009 will provide better cost estimates.

VIII. Environmental Benefits

By recovering and destroying ODSs from insulating foam, emissions of stratospheric ozone depleters will be mitigated in addition to climate change.

IX. Stakeholders

The following entities are expected to be affected by the mitigation strategies being considered:

Certified Appliance Recyclers; Scrap Metal Recyclers; Construction, Demolition, and Building Contractor Businesses; Waste Management Businesses, Transfer Station and Landfill Owners/Operators; and Owners/Operators of Recycling and Destruction Facilities will be involved in the proposed recovery and destruction of insulating foams from appliances and renovation/demolition waste.

Manufacturers, distributors, and retailers of insulating foam and related equipment. Both positive and negative economic effects are anticipated for foam manufacturers, distributors, and retailers, who may voluntarily try to switch to lower-GWP foams, especially if a deposit and return program is implemented.

Consumers and building owners may have to pay more to dispose of their foam-containing wastes and appliances.

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[20] USEPA, Equivalencies in every-day units for million metric tons of carbon dioxide equivalent emissions from USEPA Greenhouse Gas Equivalencies Calculator, February 2008. http://www.epa.gov/cleanenergy/energy-resources/calculator.html#conversiontable

[21] UNEP (United Nations Environment Programme) Montreal Protocol on Substances that Deplete the Ozone Layer, Report of the Technology and Economic Assessment Panel, Volume 3, Report of the Task Force on Foam End-Of-Life-Issues, May 2005.

[22] IPCC/TEAP, IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System, Issues related to Hydrofluorocarbons and Perfluorocarbons, 2005.

Trade Associations. Many trade associations and other interest groups may be impacted, either positively or negatively by potential programs.

Government Agencies. ARB will coordinate with the California Integrated Waste Management Board (CIWMB), the Department of Toxic Substances Control (DTSC), US EPA, and local air districts on this measure.

X. Related Studies Underway

Research: At the ARB Board Meeting on January 24, 2008, the Board approved a research contract to develop a California inventory for ODS and HFC foam banks and emissions from foam. The research will quantify types and quantities of foams used in appliances and buildings in California, including kinds and amounts of blowing agents utilized. The contractor will deliver a detailed, bottom-up foam inventory for California, along with life-cycle climate performance (LCCP) projections in 2020 for business as usual (BAU) vs. technological advancements (i.e. low-GWP blowing agents, not-in-kind [NIK] technologies, etc.). Results of the research are expected to be available in 2009.

In a separate study that the ARB recently put in place, High-GWP GHG destruction (including foam gases) will be examined in terms of life-cycle analysis (LCA) as part of the high-GWP GHG LCA-modeling contract. The most cost-effective foam recovery and destruction programs will be identified as part of the study, with findings available in 2009.

XI. Citations

The following references were utilized in addition to those already cited within the body of the document:

IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 3, Industrial Processes and Product Use, 2006:
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SEPA (Scottish Environment Protection Agency), Guidance on the Recovery and Disposal of Controlled Substances Contained in Refrigerators and Freezers, 2002:
http://www.sepa.org.uk/pdf/consultation/closed/2003/fridge/fridge_consultation.pdf

USEPA, Draft Proposed Measures Arising from the IPCC/TEAP Special Report & its Supplement, by End-Use, Expert Workshop on IPCC/TEAP Special Report, July 2006.

USEPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005, Office of Atmospheric Programs, EPA 430-R-07-002, April 2007.
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USEPA, U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.
http://www.epa.gov/highgwp/projections.html

Appendix A

Emission Estimate Calculations (US EPA Vintaging Model Estimate)

The US EPA Vintaging Model was used to estimate emissions from insulation foam used in appliances, building panels, and from miscellaneous applications, such as air conditioners and transport refrigerated units. The Vintaging Model is an emissions estimation model for High-GWP GHGs and ODSs that uses a detailed bottom-up method for national inventory and emission estimates. The Vintaging Model results in the best available emission estimates from foam at this time, although not all necessary data has been collected for California to make a more precise estimate. More precise emission estimates will be available after the completion of the ARB-funded foam inventory research in June 2009.

Emissions from appliances:
The following assumptions were used in the Vintaging Model and subsequent emission calculations to estimate emissions from foam in appliances:

1) 20 year lifetime for refrigerators.
2) R-11 use in refrigerators stopped in 1995; from 1995 – 2005 HCFC-141b was used.
3) In 2005, half of disposed refrigerators contain R-11 as the foam blowing agent and the other half contain 141b.
4) 25% of the foam blowing agent is lost into the cabinet (during the lifetime of the refrigerator) and is released into the atmosphere - the remaining 75% is recoverable.
5) 13,000,000 refrigerator/freezers are disposed of annually in the US and 60% go to landfills or transfer stations.
6) The California population fraction of the U.S. was roughly 13% in 2005.
7) 100-year direct GWPs of 4,600 and 700 were used for R-11 and HCFC-141b, respectively.
8) Blowing agent masses of 0.45 kg/appliance and 0.38 kg/appliance for R-11 and HCFC-141b, respectively, as estimated by USEPA (Dave Godwin, USEPA personal conversation 6 July 2007).

Using the assumptions and factors above, annual greenhouse gas emissions in California from appliances are calculated to be 0.9 $MMTCO_2E$.

Emissions from building insulation and miscellaneous foam sources:
The US EPA Vintaging Model uses a similar approach (to the above appliance foam estimates) to estimate an additional 7.7 $MMTCO_2E$ annual emissions in California from building panel insulation foam and non-appliance insulation foam. As of January 2008, several inputs for measuring building foam emissions were considered proprietary information, and these assumptions have not yet been provided to ARB.

The Foam Inventory Research Study will provide the latest foam banks and emission estimates in 2009.