PLASTICS' ENERGY AND GREENHOUSE GAS SAVINGS USING REFRIGERATOR AND FREEZER INSULATION AS A CASE STUDY

Final Report

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PLASTICS' ENERGY AND GREENHOUSE GAS SAVINGS USING REFRIGERATOR AND FREEZER INSULATION AS A CASE STUDY

EXECUTIVE SUMMARY

This analysis is a case study that examines the greenhouse gas emissions implications of using plastic foam insulation in refrigerators and freezers. The specific plastic foam used in this analysis is polyurethane. To give these results perspective, they need to be placed in context with a baseline where polyurethane foam is not used. At this time, only polyurethane foam is used as insulation in household refrigerators and freezers in the U.S., so there is no alternative with which to compare. One possible context is to show the emissions that would be incurred if no insulation were used in refrigerators. However, we have selected fiberglass insulation as a baseline, because historically it was the insulation replaced by polyurethane foam. For comparison purposes, we have assumed a refrigerator and a freezer with physical dimensions identical to one using polyurethane foam, but which instead have used the same thickness of fiberglass. This is used only to establish a baseline for comparison. In actual fact, if fiberglass were used, the dimensions and design of the refrigerator or freezer would be different to allow substantially greater thickness of insulation, thus creating appliances that would not be equivalent to the ones studied here.

The results of this analysis are based on a comparison of the cradle-to-manufacture energy requirements and greenhouse gas emissions for each type of insulation, as well as those for the operation of refrigerators or freezers using each type of insulation. The energy required to manufacture the refrigerator or freezer and all equivalent materials in the appliances is not included because they are identical for each, and so the results will not differ.

In Figure ES-1, the total energy requirements for both the refrigerator and the freezer with polyurethane insulation are 61 percent that of the appliances with fiberglass insulation. The energy required during the use phase for the appliances dominates the results. One percent or less of the energy requirements come from the manufacture of either of the insulation materials. A consumer saves 8,815 kwh of electricity, or 98 million Btu, over the lifetime of the refrigerator by using the polyurethane-insulated refrigerator. A consumer saves 5,400 kwh of electricity, or 60 million Btu, over the lifetime of the freezer with the use of polyurethane insulation. Using a U.S. average electricity cost of 6.97 cents/kwh (October, 1997), this translates to a savings of approximately $600 for refrigerators and $375 for freezers.

Greenhouse gas production using carbon dioxide equivalents is shown in Figure ES-2. The total greenhouse gases for both the refrigerator and the freezer with polyurethane insulation are 62-64 percent that of the appliances with fiberglass insulation. As with the energy requirements, the greenhouse gases produced during the use phase for the appliances dominate the results. The reason this coincides with the difference in the amount of the energy used is because most of these emissions are from

Figure ES-1
Total Energy for Each of the Insulated Refrigerators and Freezers

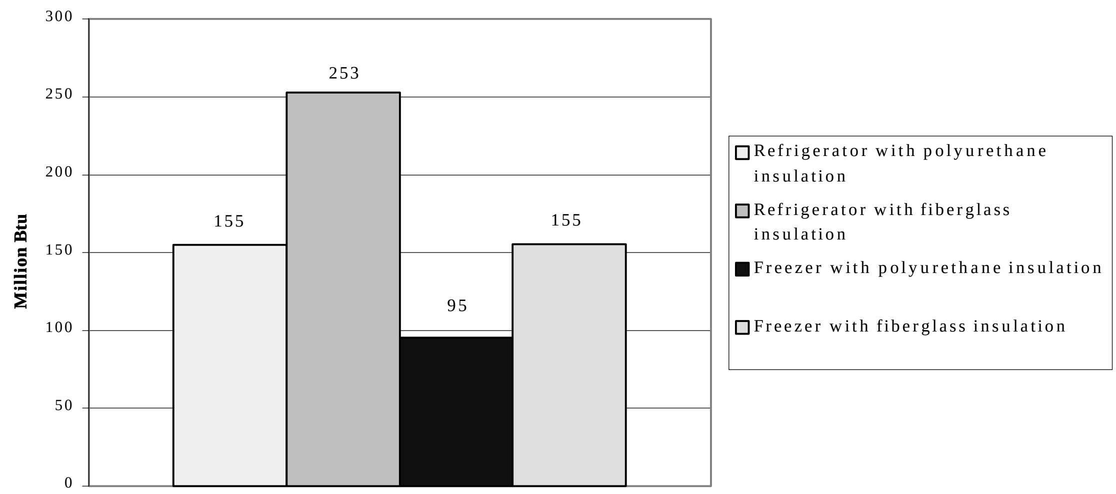
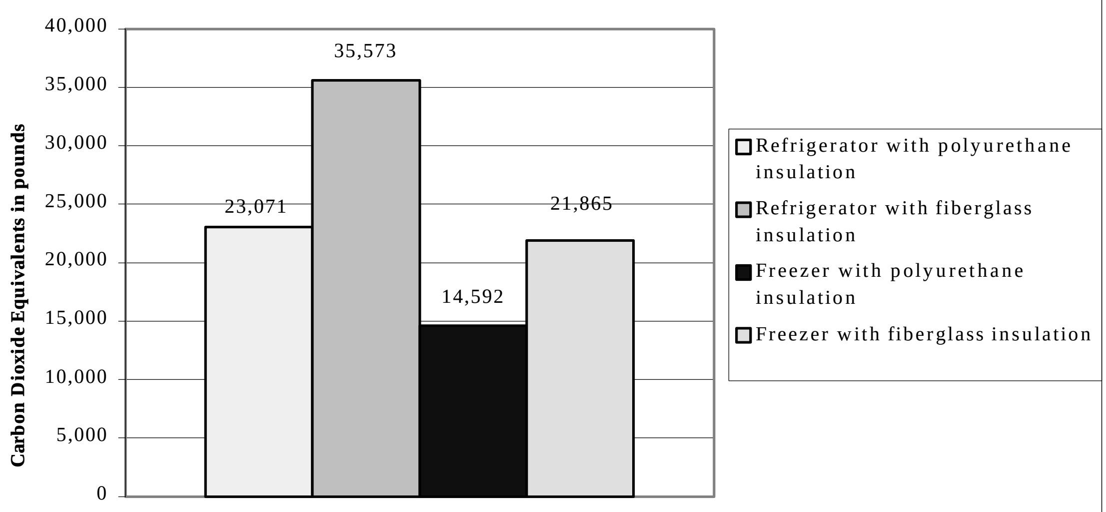


Figure ES-2
Total Greenhouse Gases for Each of the Insulated Refrigerators and Freezers



fuel production and combustion for the use of the appliances. The blowing agent HCFC-141b from the polyurethane-insulated refrigerator makes up only one percent of the greenhouse gas emissions, while the carbon dioxide is 94 to 95 percent of the total.

It takes approximately 1.5 months of use of a polyurethane-insulated refrigerator before the energy savings exceed the energy it takes to manufacture the insulation. For the polyurethane-insulated freezer, it takes approximately 2.2 months of use before the energy savings exceed the energy it takes to manufacture the insulation.

Clearly, at a time when energy use and greenhouse gases releases are major concerns, the benefits of polyurethane insulation are very significant. With 106 million refrigerators and 33.4 million freezers in use, the greenhouse gas benefit is 34.9 million tons and 6.4 million tons of carbon dioxide equivalents per year, respectively. To put this data in perspective, 34.9 million tons of carbon dioxide is equivalent to the amount of carbon dioxide emitted by the gasoline produced and combusted to use 4.8 million cars per year. This same type of equivalent for the 6.4 million tons of carbon dioxide equivalents per year is 0.88 million cars per year.

PLASTICS' ENERGY AND GREENHOUSE GAS SAVINGS USING REFRIGERATOR AND FREEZER INSULATION AS A CASE STUDY

INTRODUCTION

This analysis is a case study that examines the greenhouse gas emissions implications of using plastic foam insulation in refrigerators and freezers. The specific plastic foam used in this analysis is polyurethane. To give these results perspective, they need to be placed in context with a baseline where polyurethane foam is not used. At this time, only polyurethane foam is used as insulation in household refrigerators and freezers in the U.S., so there is no alternative with which to compare. One possible context is to show the emissions that would be incurred if no insulation were used in refrigerators. However, we have selected fiberglass insulation as a baseline, because historically it was the insulation replaced by polyurethane foam. For comparison purposes, we have assumed a refrigerator and a freezer with physical dimensions identical to one using polyurethane foam, but which instead have used the same thickness of fiberglass. This is used only to establish a baseline for comparison. In actual fact, if fiberglass were used, the dimensions and design of the refrigerator or freezer would be different to allow substantially greater thickness of insulation, thus creating appliances that would not be equivalent to the ones studied here.

The use of polyurethane foam as refrigerator insulation began in the mid- to late 1960s. By the 1970s, most refrigerator manufacturing companies were using polyurethane insulation to a degree. The last of the fiberglass insulation in refrigerator doors was phased out in 1992. This change from fiberglass to polyurethane took so much time because of the capital needed to change the tooling for polyurethane. Some of the reasons that manufacturers changed to polyurethane insulation include:

- It eliminated dermatitis problems from the fiberglass for plant workers.
- It allowed more inside volume for the refrigerator or freezer, for a given exterior dimension, because the thickness of the insulation decreased from 3 - 3½ inches of fiberglass to 1½ inches of polyurethane.
- The polyurethane foam helped to hold the shape of the refrigerator, which allowed down-sizing of the metal exterior and plastic interior skins. This down-sizing of metal and plastic is not included in this analysis, but would likely lead to a slight increase in the benefit of the polyurethane.

The results of this analysis are based on a comparison of the cradle-to-manufacture energy requirements and greenhouse gas emissions for each type of insulation, as well as those for the operation of refrigerators or freezers using each type of insulation. The energy required to manufacture the refrigerator or freezer and all equivalent materials in the appliances is not included because they are identical for each, and so the results will not differ.

The main blowing agent currently used in the polyurethane foam insulation in refrigerators and freezers, and therefore in this report, is HCFC-141b. This blowing agent is viewed by the EPA as a transition material which must be replaced by December 31, 2002. No definite replacement has been found as of yet. Europe is currently using hydrocarbons, such as cyclopentane, but these have higher thermal conductivities than HCFC-141b and so would increase energy requirements for the appliance's use. There are also flammability risks during processing and environmental concerns, as they are VOCs. According to a study done by the Appliance Industry/Government CFC Replacement Consortium[1], HFCs are a likely replacement for HCFC-141b. HFCs have a zero ozone depletion potential. According to the study mentioned previously, the thermal conductivity of certain HFCs is less than 10 percent higher than the HCFC-141b used today. HFC-134a is being used currently in some appliance polyurethane foam. It is the only commercially available HFC at this time. Using HFC-134a as a blowing agent requires approximately 13 percent more energy to perform as well as HCFC-141b does.

End of life scenarios have not been included in this study. If the appliances with polyurethane insulation are shredded, then it is likely that all of the blowing agent will eventually escape to the atmosphere. If the appliances are landfilled, the blowing agent would continue to diffuse somewhat over some period of time, but it is unknown where it would end up. It could possibly react with other gases or liquids in the landfill or it could diffuse through the appliance and the landfill cover into the atmosphere. This would happen very slowly over an unknown period of time. According to the Steel Recycling Institute, 81 percent of major appliances are being recycled; for those appliances recycled, any insulation would probably be shredded. In this study, all of the blowing agent is assumed to eventually reach the atmosphere, and so is shown in the results tables.

RESULTS

Refrigerator Comparison

The total energy requirements and greenhouse gas emissions are compared in Table 1 for polyurethane-insulated and fiberglass-insulated average refrigerators. These results include the production of the insulation and the use of the refrigerator over its average lifetime of 19 years. The emissions also include the release of all blowing agent at the appliances' end-of-life.

The refrigerator with the polyurethane insulation uses 39 percent less total energy through its production and use phase than the refrigerator with fiberglass insulation. More than half of the energy used to operate each of the refrigerators is from coal. This is because more than half of the electricity used during the use phase of the refrigerator comes from coal in the national electricity grid.

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[1] Haworth, G. J. Next Generation Insulation Foam Blowing Agents for Refrigerators /Freezers. The Appliance Industry/Government CFC Replacement Consortium, AHAM - Appliance Research Consortium. 1996.

Table 1

TOTAL ENERGY REQUIREMENTS AND GREENHOUSE GAS EMISSIONS FOR THE PRODUCTION OF INSULATION AND REFRIGERATOR USE OVER THE LIFETIME OF AN AVERAGE REFRIGERATOR

	Average Refrigerator Using Polyurethane Insulation	Average Refrigerator Using Fiberglass Insulation
Energy Profile (Million Btu)		
Natural gas	26.8	43.7
Petroleum	6.1	9.9
Coal	81.8	133.3
Hydropower	5.0	8.2
Nuclear	31.0	50.5
Other	4.2	6.8
Total Energy	155	253
Energy by Category (Million Btu)		
Energy of Material Resource (1)	0.19	0.0109
Process (2)	155	253
Transportation (3)	0.0009 *	0.0015
Total Energy	155	253
Greenhouse Gas Emissions (CO2 equivalents in pounds)		
Carbon Dioxide	20,807	33,915
Methane	967	1,576
Nitrous Oxide	50	82
HCFC 141b	1,247	0
Total CO2 Equivalents	23,071	35,573

(1) The energy of material resource is the energy taken out of the pool of common energy sources, such as natural gas or petroleum. These materials would have been used as fuel but were used for plastics manufacture instead.
(2) The process energy is all energy used to manufacture all materials or use the product.
(3) The transportation energy is any energy used to transport materials between processes.
* The polyurethane precursors data provided by APC did not separate transportation energy from process energy. Consequently, some transportation energy is included in the process energy category.

Source: Franklin Associates

The refrigerator with the polyurethane insulation emits 35 percent less total carbon dioxide equivalents of greenhouse gases than the refrigerator with fiberglass insulation. The reason this coincides with the difference in the amount of the energy used is because most of these emissions are from fuel production and combustion for the use phase of the appliances. Carbon dioxide itself makes up 90 and 95 percent of the greenhouse gas emissions on a carbon dioxide equivalents basis for the polyurethane insulation and fiberglass insulation refrigerators respectively. Nitrous oxide makes up less than one percent of the greenhouse gas emissions for both systems on a carbon equivalent basis. The blowing agent HCFC-141b makes up five percent of the greenhouse gas emissions from the polyurethane-insulated refrigerator. Blowing agent emissions are released during the polyurethane foam curing, but the blowing agent continues to be released in small amounts over the lifetime of the refrigerator. This study

Table 2

ENERGY REQUIREMENTS AND GREENHOUSE GAS EMISSIONS BY LIFE CYCLE STAGE FOR THE PRODUCTION OF INSULATION AND REFRIGERATOR USE OVER THE LIFETIME OF A 19 CUBIC FOOT REFRIGERATOR

		Greenhouse Gases							
	Energy (Million Btu)	Carbon Dioxide (lb)	Methane (lb)	Methane (CO2 equiv)	Nitrous Oxide (lb)	Nitrous Oxide (CO2 equiv)	HCFC 141b (lb)	HCFC 141b (CO2 equiv)
Average refrigerator (polyurethane insulation)								
Polyurethane insulation production	0.62 (1)	46.9	0.50	10.4	0.0026	0.79	0.090	56.7
Refrigerator use	154	20,760	45.5	956	0.16	49.7	1.89	1,191
Total	155	20,807	46.0	967	0.16	50.5	1.98	1,247
Average refrigerator (fiberglass insulation)								
Fiberglass insulation production	0.11	20.1	0.029	0.61	7.8E-05	0.024	0	0
Refrigerator use	253	33,895	74.9	1,575	0.26	82	0	0
Total	253	33,915	75.0	1,576	0.26	82	0	0

(1) This total production energy includes 0.19 million Btu of energy of material resource (feedstock energy)

Source: Franklin Associates

assumes that eventually, after the refrigerator's lifetime has ended, all blowing agent will leak from the refrigerator.

The energy requirements and greenhouse gas emissions by life cycle stage are given in Table 2. One percent or less of the energy requirements, carbon dioxide, and methane come from the manufacture of either of the insulation materials. The amount of nitrous oxide for the manufacture of either type of insulation is less than 2 percent of the total. Only the polyurethane insulation emits the HCFC-141b, the primary currently used blowing agent for the production of the polyurethane foam. The major portion of the energy requirements and greenhouse gases is from the use phase of the refrigerator over its lifetime. The ratio of the thermal conductivities of the fiberglass and polyurethane (using the HCFC-141b blowing agent) was used to calculate the amount of energy needed for the use of a fiberglass-insulated refrigerator. In short, it is the energy efficiency of the polyurethane foam insulation in refrigerators that dominates.

The HCFC-141b emission is shown from both the polyurethane insulation production and the refrigerator use. The amount lost from polyurethane insulation production is approximately 5 percent of the blowing agent before the foam insulation has cured. The amount emitted under the heading "Refrigerator use" is the remaining blowing agent in the refrigerator. This will actually not happen until the refrigerator is shredded or landfilled after an unknown period of time.

It is possible that the thermal conductivity of either insulation increases over time–the polyurethane insulation because of some blowing agent diffusion and the fiberglass insulation because of the compaction of the insulation over time. No data were found concerning this effect, but they are considered in the sensitivity analysis at the end of this report.

From the results in Table 2, a comparison can be made of the energy required to produce the two types of insulation, polyurethane and fiberglass. Note that the polyurethane insulation manufacture requires more than five times the amount of energy to produce the fiberglass insulation. Of the polyurethane insulation energy, 0.19 million Btu are from the energy of material resource or feedstock energy, of which fiberglass has only 0.01 million Btu from a small amount of urea-formaldehyde. The remaining energy for the polyurethane comes mainly from the manufacture of the polyol and MDI. The raw materials for the fiberglass come mostly from mining processes, which use very little energy for the amount of material produced. These manufacturing energy requirements are minute compared to the amount of energy needed for the refrigerator's use.

It is often easier to relate to physical quantities rather than energy quantities. Table 3 displays physical units of the fossil fuels required to produce the insulations and operate the refrigerator over its lifetime of 19 years. Using mass or volume, the amounts of natural gas, petroleum, and coal for the polyurethane-insulated refrigerator are approximately half of the amounts of these fuels for the fiberglass-insulated refrigerator.

Table 3

FOSSIL FUEL AMOUNTS FOR THE PRODUCTION OF EACH INSULATION AND REFRIGERATOR USE OVER ITS LIFETIME USING EQUIVALENT MASS OR VOLUME QUANTITIES

	Average Refrigerator Using Polyurethane Insulation	Average Refrigerator Using Fiberglass Insulation	Difference
Fossil Fuels			
Natural gas (cu ft)	25,959	42,313	16,354
Petroleum (barrels of oil)	1.05	1.71	0.66
Coal (pounds)	7,862	12,815	4,953

Source: Franklin Associates

Finally, Table 4 shows the emissions of carbon dioxide avoided by using the polyurethane insulation rather than the fiberglass insulation in refrigerators. The difference in carbon dioxide equivalents is approximately 6.3 tons per refrigerator for its entire lifetime, or about 0.33 tons carbon dioxide equivalents per year per refrigerator. There are approximately 106 million household refrigerators in use in the U.S., so this equates to about 34,900,000 tons of carbon dioxide equivalents avoided per year. This is assuming that all refrigerators in the U.S. are 19 cubic feet with top automatic defrost freezers using polyurethane insulation. If we were considering a different size refrigerator, the results would change but would be proportional because there would be more or less insulation per refrigerator volume used in the different sizes.

Table 4

CARBON DIOXIDE EQUIVALENT AMOUNTS AVOIDED AND LIFE CYCLE ENERGY SAVED BY USING POLYURETHANE INSULATION INSTEAD OF FIBERGLASS INSULATION IN REFRIGERATORS

	Carbon Dioxide Equivalents Avoided		Life Cycle Energy Savings	
	(lb)	(tons)	(Mil Btu)	(kwh)
One refrigerator over its lifetime (19 years)	12,502	6.3	98	8,815
One refrigerator over one year	658	0.33	5.2	468
	(billion lb)	(million tons)	(trillion Btu)	(million kwh)
All refrigerators in U.S. in one year*	70	34.9	551	49,581

* Assuming 106 million refrigerators in the U.S. from 1997 Statistical Abstract, which contains 1995 data. This also assumes the use of average (19 cu ft with top automatic defrost) refrigerators having polyurethane foam insulation in all households.

Source: Franklin Associates

To calculate savings in greenhouse gas emissions, we have assumed that the reduced electricity originated from the average power grid. The alternative, which is favored by some government agencies and other practitioners, is to assume that the savings result from marginal sources of electricity, primarily coal and other fossil fuels. By this we mean that future power plants will use only fossil fuels and not nuclear or hydropower as fuels. If we had chosen that option, the greenhouse gas emission reductions would have been significantly greater (see Sensitivity Analysis section). Both approaches are in common use, and we have selected the option that shows the least savings.

Also, Table 4 displays the amount of energy saved by using the polyurethane-insulated refrigerator instead of the fiberglass-insulated refrigerator. A consumer will have saved 8,815 kwh of electricity, or 98 million Btu, over the lifetime of the refrigerator by using the polyurethane-insulated refrigerator. This equates to a little over $600 per refrigerator using an U.S. average electricity cost of 6.97 cents/kwh (October, 1997).

The carbon dioxide emissions avoided by using polyurethane insulation in refrigerators instead of fiberglass insulation over one year is approximately 6 times the amount of carbon dioxide emitted during the manufacture of the polyurethane insulation. It takes approximately 1.5 months of use of a polyurethane-insulated refrigerator before the energy savings exceeds the energy it takes to manufacture the insulation.

Freezer Comparison

The total energy requirements and greenhouse gas emissions for two average stand alone freezers are given in Table 5. These results include the production of the insulation and the use of the freezer over its average lifetime of 19 years.

The freezer with the polyurethane insulation uses 37 percent less total energy through its production and use phase than the freezer with fiberglass insulation. More than half of the energy used to operate each of the freezers is from coal. This is because more than half of the electricity generation used during the use phase of the freezer comes from coal in the national electricity grid.

The freezer with the polyurethane insulation emits 33 percent less total carbon dioxide equivalents of greenhouse gases than the freezer with fiberglass insulation. The reason this coincides with the difference in the amount of the energy used is because most of these emissions are from fuel production and combustion for the use of the appliances. Carbon dioxide itself makes up 88 and 95 percent of the greenhouse gas emissions on a carbon dioxide equivalents basis for the polyurethane-insulated and fiberglass-insulated freezers respectively. Nitrous oxide makes up less than one percent of the greenhouse gas emissions for both systems on a carbon equivalent basis. The blowing agent HCFC-141b makes up 8 percent of the greenhouse gas emissions from the polyurethane-insulated freezer. Blowing agent emissions are released before the

Table 5

TOTAL ENERGY REQUIREMENTS AND GREENHOUSE GAS EMISSIONS FOR THE PRODUCTION OF INSULATION AND FREEZER USE OVER THE LIFETIME OF AN AVERAGE FREEZER

	Average Freezer Using Polyurethane Insulation	Average Freezer Using Fiberglass Insulation
Energy Profile (Million Btu)		
Natural gas	16.5	26.9
Petroleum	3.8	6.2
Coal	50.2	82.0
Hydropower	3.0	4.9
Nuclear	19.0	31.0
Other	2.6	4.2
Total Energy	95.2	155
Energy by Category (Million Btu)		
Energy of Material Resource	0.18	0.010
Process	95.0	155
Transportation	0.0008 *	0.0069
Total Energy	95.2	155
Greenhouse Gas Emissions (CO2 equivalents in pounds)		
Carbon Dioxide	12,786	20,841
Methane	597	973
Nitrous Oxide	31	51
HCFC 141b	1,178	0
Total CO2 Equivalents	14,592	21,865

(1) The energy of material resource is the energy taken out of the pool of common energy sources, such as natural gas or petroleum. These materials would have been used as fuel but were used for plastics manufacture instead.
(2) The process energy is all energy used to manufacture all materials or use the product.
(3) The transportation energy is any energy used to transport materials between processes.
* The polyurethane precursors data provided by APC did not separate transportation energy from process energy. Consequently, some transportation energy is included in the process energy category.

Source: Franklin Associates

polyurethane foam has cured, over the lifetime of the freezer, and during its end-of-life stage.

The energy requirements and greenhouse gas emissions by life cycle stage are given in Table 6. One percent or less of the energy requirements and carbon dioxide come from the manufacture of either of the insulation materials. The amount of methane and nitrous oxide for the manufacture of either type of insulation is less than 2 percent of the total. Only the polyurethane insulation emits the HCFC-141b, the primary current blowing agent for the production of the polyurethane foam. Table 6 shows that the major portion of the energy requirements and greenhouse gases is from the use phase of the freezer over its lifetime. The ratio of the thermal conductivities of the fiberglass and

Table 6

ENERGY REQUIREMENTS AND GREENHOUSE GAS EMISSIONS BY LIFE CYCLE STAGE FOR THE PRODUCTION OF INSULATION AND FREEZER USE OVER THE LIFETIME OF AN AVERAGE FREEZER

	Energy (Million Btu)	Greenhouse Gases						
		Carbon Dioxide (lb)	Methane (lb)	Methane (CO2 equiv)	Nitrous Oxide (lb)	Nitrous Oxide (CO2 equiv)	HCFC 141b (lb)	HCFC 141b (CO2 equiv)
Average freezer (polyurethane insulation)								
Polyurethane insulation production	0.59 (1)	44.3	0.47	9.9	0.0024	0.75	0.085	53.6
Freezer use	94.6	12,742	27.9	587	0.10	30.5	1.79	1,125
Total	95.2	12,786	28.4	597	0.10	31.3	1.87	1,178
Average freezer (fiberglass insulation)								
Fiberglass insulation production	0.11	19.0	0.027	0.57	7.4E-05	0.023	0	0
Freezer use	155	20,822	46.3	972	0.16	51.0	0	0
Total	155	20,841	46.3	973	0.16	51.0	0	0

(1) This total production energy includes 0.18 million Btu of energy of material resource (feedstock energy)

Source: Franklin Associates

polyurethane (using the HCFC-141b blowing agent) were used to calculate the amount of energy needed for the use of a fiberglass-insulated freezer.

As with the refrigerator, the amount of blowing agent lost from polyurethane insulation production is approximately 5 percent of the blowing agent before the foam insulation has cured. The total amount of blowing agent is assumed to be lost from the freezer use emitted over the 19-year life of the freezer and at its end-of-life stage.

It is often easier to relate to physical quantities rather than energy quantities. Table 7 displays physical units of the fossil fuels required to produce the insulations and operate the freezer over its lifetime of 19 years. Using mass or volume, the amounts of natural gas, petroleum, and coal for the polyurethane-insulated freezer are 61 percent of the amounts of these fuels for the fiberglass-insulated freezer.

Table 7

FOSSIL FUEL AMOUNTS FOR THE PRODUCTION OF EACH INSULATION AND FREEZER USE OVER ITS LIFETIME USING EQUIVALENT MASS OR VOLUME QUANTITIES

	Average Freezer Using Polyurethane Insulation	Average Freezer Using Fiberglass Insulation	Difference
Fossil Fuels			
Natural gas (cu ft)	16,044	26,152	10,108
Petroleum (barrels of oil)	0.66	1.08	0.42
Coal (pounds)	4,828	7,870	3,042

Source: Franklin Associates

Finally, Table 8 shows the emissions of carbon dioxide avoided by using the polyurethane insulation rather than the fiberglass insulation in freezers. The difference in carbon dioxide equivalents is approximately 3.6 tons per freezer for its entire lifetime, or about 0.19 tons carbon dioxide equivalents per year per freezer. There are approximately 33.4 million household freezers in use in the U.S., so this equates to about 6,400,000 tons of carbon dioxide equivalents avoided per year. This is assuming that all freezers in the U.S. are 15 cubic foot manual defrost chest freezers using polyurethane insulation. If we were considering a different size freezer, the results would change but would be proportional because there would be more or less insulation per freezer volume used in the different sizes.

In order to calculate savings in greenhouse gas emissions, we have assumed that the reduced electricity originated from the average power grid. The alternative, which is favored by some government agencies and other practitioners, is to assume that the savings result from marginal sources of electricity, primarily coal and other fossil fuels. By this we mean future power plants will use only fossil fuels and not nuclear or

Table 8

CARBON DIOXIDE EQUIVALENT AMOUNTS AVOIDED AND LIFE CYCLE ENERGY SAVINGS BY USING POLYURETHANE INSULATION INSTEAD OF FIBERGLASS INSULATION IN FREEZERS

	Carbon Dioxide Equivalents Avoided		Life Cycle Energy Savings	
	(lb)	(tons)	(Mil Btu)	(kwh)
One freezer over its lifetime (19 years)	7,273	3.6	60	5,400
One freezer over one year	383	0.19	3.2	288
	(billion lb)	(million tons)	(trillion Btu)	(million kwh)
All freezers in U.S. in one year*	12.8	6.4	107	9,619

* Assuming 33.4 million freezers in the U.S. from 1997 Statistical Abstract, which contains 1993 data. This also assumes the use of average (15 cu ft chest freezer with manual defrost) freezers having polyurethane foam insulation in all households.

Source: Franklin Associates

hydropower as fuels. If we had chosen that option, the greenhouse gas emission reductions would have been significantly greater (see Sensitivity Analysis section). Both approaches are in common use, and we have selected the option that shows the least savings.

Also, Table 8 displays the amount of energy saved by using the polyurethane-insulated freezer instead of the fiberglass-insulated freezer. A consumer will have saved 5,400 kwh of electricity, or 60 million Btu, over the lifetime of the freezer with the use of polyurethane insulation. This equates to a little over $375 dollars using a U.S. average electricity cost of 6.97 cents/kwh from October, 1997.

The carbon dioxide emissions avoided by using polyurethane insulation in freezers instead of fiberglass insulation over 1 year is approximately 3.5 times the amount of carbon dioxide emitted during the manufacture of the polyurethane insulation. It takes approximately 2.2 months of the use of a polyurethane-insulated freezer before the energy savings exceed the energy it takes to manufacture the insulation.

ASSUMPTIONS

The principal assumptions made by Franklin Associates follow.

- According to Len Swatkowski of the American Home Appliance Association, 18 to 19 pounds of polyurethane foam are needed for an average refrigerator. The average refrigerator is 19 to 20 cubic feet inside with a top freezer with automatic defrost. Eighteen pounds of polyurethane foam were used in this study for a 19 cubic foot refrigerator. Also, 17 pounds of polyurethane foam are needed for an average freezer. An average freezer is a chest unit 15 cubic feet inside and is manual defrost. The average lifetime of both the refrigerator and the freezer is 19 years. This lifetime is used by American Home Appliance Association as well as the Department of Energy.

- The densities of both insulations and thermal conductivity of fiberglass insulation were taken from ***Appliance Manufacturer***, 1989 and 1990. The thermal conductivity of fiberglass is 0.28 inch Btu/hr ft^2 F; density of fiberglass is 3 pounds/cubic foot; and density of polyurethane is 2 pounds/cubic foot.

- The thermal conductivity of polyurethane insulation using the HCFC-141b blowing agent is 0.135 inch Btu/hr ft^2 F. (Haworth, G. J. Next Generation Insulation Foam Blowing Agents for Refrigerators/Freezers. The Appliance Industry/Government CFC Replacement Consortium, AHAM - Appliance Research Consortium. 1996)

- According to the General Electric Answer Center, a common 19 cubic foot refrigerator uses 712 kwh/year. This energy requirement corresponds to GE model TBX19PAY with the dimensions 64.75" x 29.375" x 31" and a top freezer with automatic defrost using all polyurethane insulation. This energy requirement was generated by GE in accordance to the standard DOE testing procedure for refrigerators. This energy requirement value is somewhat higher than the range given for recommended and best available energy consumption of refrigerators from the web site www.eren.doe.gov/femp/procurement/refrig.html. At that web site, for a 19 cu ft top-mount freezer refrigerator, the recommended annual energy consumption is 655 kwh and best available energy consumption is 533 kwh.

- According to the General Electric Answer Center, a common 15 cubic foot chest freezer uses 437 kwh/year. This energy requirement corresponds to GE model FCM15DA with the dimensions 35" x 46" x 29.5" and manual defrost using all polyurethane insulation. This energy requirement was generated by GE in accordance to the standard DOE testing procedure for freezers.

- The polyurethane and fiberglass insulation were assumed to be equal in thickness for this study. To calculate the energy savings, results from a previous study conducted for APC by the University of Kentucky Center for Robotics and Manufacturing Systems were used. The report is “Plastics—Key Materials for Innovation and Productivity in Major Appliances,” by Ralph S. Hagan and William R. Keelan, February 1994. In that study, the authors use the EPA Refrigerator Analysis Model to calculate the energy requirements for a “standard” refrigerator using polyurethane and one using fiberglass of equal thickness. The refrigerator using polyurethane required 2.37 kwh/day, and the fiberglass-insulated refrigerator required 3.88 kwh/day. We used our value of 712 kwh/year from GE for our polyurethane-insulated refrigerator, and used the ratio from the report, 1.64, to calculate the energy consumption for the fiberglass-insulated refrigerator. The freezer energy was handled in the same way. The resulting differences between polyurethane and fiberglass-insulated refrigerators were confirmed by simple thermal conductivity calculations.

- APC data were used for the manufacture of polyurethane precursors (MDI and Polyol).

- According to Roy Morgan of Dow Chemical, approximately 50 percent isocyanate and 50 percent polyol is used to produce polyurethane insulation. Approximately 20 to 25 percent by weight of the polyol is blowing agent. This study assumes 25 percent of the polyol is blowing agent.

- HCFC-141b was chosen as the current blowing agent for polyurethane foam insulation in refrigerators and freezers. (Haworth, G. J. Next Generation Insulation Foam Blowing Agents for Refrigerators/Freezers. The Appliance Industry/Government CFC Replacement Consortium, AHAM - Appliance Research Consortium. 1996).

- The blowing agent HCFC-141b was assumed to be produced from 1,1,1 trichloroethane (methyl chloroform) and hydrogen fluoride, as this is a common method of production. No data were available for the 1,1,1 trichloroethane production. Surrogate data were used from the production of vinyl chloride monomer, which is an intermediate used to form 1,1,1 trichloroethane. Surrogate data were also used for the production of HCFC-141b from CFC-11 production data. According to Dr. Richard Crooker of Elf Atochem, the heating processes of these two blowing agents are similar, but the purification process for the HCFC-141b has more steps besides distillation. Therefore, these data may be understated by small amounts, but would not make a significant difference to the results, as only a small portion of the results are from the production of the insulation.

- According to Dr. Richard Crooker of Elf Atochem, up to the point where the polyurethane insulation is cured, small releases (up to 5 percent) of the blowing agent are possible. Surfactants in the polyol are used to aid in keeping the blowing agent trapped so the insulating value stays high. Dr. Crooker estimated that over the lifetime of a refrigerator, it may lose up to 20 percent of the HCFC-141b blowing agent.

- Urea and urea-formaldehyde binder energy data was collected from ***Hydrocarbon Processing***, Petrochemical Processes '97, 1997. Process emissions data for urea were taken from AP-42.

- The cured binder used for the fiberglass insulation was assumed to be urea-formaldehyde according to a Material Safety Data Sheet for Fiberglass Wool.

- The following source was used for Global Warming Potentials: United Nations, Framework Convention on Climate Change (FCCC), Subsidiary Body for Scientific and Technological Advice, National Communications; Communications from Parties Included in Annex I to the Convention: Guidelines, Schedule and Process for Consideration; Possible revisions to the guidelines for preparation of national communications by Parties included in Annex I to the Convention; Addendum; Methodological issues; Note by the Secretariat (Geneva, Switzerland: FCCC Secretariat, 25 June 1996), FCCC/SBSTA/1996/9/Add.1.)

Carbon Dioxide	1
Methane	21
Nitrous Oxide	310
HCFC-141b	630

- Number of refrigerators in the U.S., 106.8 million, taken from ***Statistical Abstract of the United States 1997***, U.S. Bureau of the Census, 117th Edition, 1997.

- Number of freezers in the U.S., 33.4 million, taken from ***Statistical Abstract of the United States 1997***, U.S. Bureau of the Census, 117th Edition, 1997.

- Price of electricity for October, 1997 taken from the electric and gas utilities rankings in ***Energy User News***, February, 1998 issue from the internet. The average (6.97 cents/kwh) was taken for the electric utilities listed. These electricity prices were sourced to DOE from EIA-826 and an Energy User News survey.

SENSITIVITY ANALYSIS

Although some surrogate data were used in this study and only one blowing agent was considered for the polyurethane insulation, the uncertainty in these data would not change the results of this case study with any significance because the appliance energy use and resultant greenhouse gas emissions dominate the study. In this case, only the appliance use data was considered during the sensitivity analysis.

The variables that could change the results include the thermal conductivity of either the polyurethane or the fiberglass insulations and the energy values provided by General Electric. The General Electric Technical Center states that these values were taken from tests that follow the DOE standard testing methods for refrigerators and freezers. A sensitivity analysis was done on these variables only. Table 9 displays the results of changing each of these variables by ± 10 percent.

Comparing Table 9 to the totals in Tables 1 and 5, when either of the thermal conductivities change, there is a 10 percent increase or decrease of the corresponding insulation results. This is because the use phase represents 99 percent of the results. If the electricity use data is changed by 10 percent, the results are the same as changing the thermal conductivity of the insulations by 10 percent.

It is possible that the thermal conductivity of either insulation increases over time–the polyurethane insulation because of some blowing agent diffusion and the fiberglass insulation because of the compaction of the insulation over time. If the thermal conductivity of either insulation is changed by 10 percent, the differences between the two insulation results range from the polyurethane being 32 to 45 percent less than the fiberglass in energy and 28 to 42 percent less for carbon dioxide equivalents. Tables 1 and 5 show the polyurethane insulation energy results to be 39 percent less than the fiberglass insulation energy results. The tables also show the emissions results to be 35 and 33 percent less for the refrigerator and freezer, respectively.

If the appliance electricity use is changed by 10 percent, the difference between the two insulation energy results still shows that the polyurethane insulation results are 38 to 39 percent less than the fiberglass insulation results and the emissions results are 33 to 35 percent less than the fiberglass insulation results. This is because if the electricity amounts for the polyurethane-insulated appliance change, so does the fiberglass-insulated appliance, because it is calculated by the thermal conductivity ratio multiplied by the electricity use amount. This means that if there is an error in the electricity use amount, it will stay constant between the two insulation systems.

Some governmental agencies and environmental groups suggest that marginal sources of energy used to generate electricity should be considered instead of the average fuel uses of today. In order to examine the effect of using marginal fuels for electricity, we recalculated greenhouse gas savings for the national electricity grid. To do this, the

Table 9

SENSITIVITY ANALYSIS OF THE MAJOR VARIABLES FOR THE REFRIGERATOR AND FREEZER CASE STUDIES

	Total Energy (Million Btu)		Total Carbon Dioxide Equivalents (lb)	
Refrigerator case study	Polyurethane	Fiberglass	Polyurethane	Fiberglass
Polyurethane thermal conductivity				
+10 percent (.1485)	170	253	25,378	35,573
-10 percent (.1215)	139	253	20,764	35,573
Fiberglass thermal conductivity				
+10 percent (.308)	155	278	23,071	39,130
-10 percent (.252)	155	228	23,071	32,016
Refrigerator electricity use				
+10 percent (783 kwh/yr)	170	278	25,378	39,130
-10 percent (641 kwh/yr)	139	228	20,764	32,016
Freezer case study				
Polyurethane thermal conductivity				
+10 percent (.1485)	105	155	16,051	21,865
-10 percent (.1215)	85.7	155	13,133	21,865
Fiberglass thermal conductivity				
+10 percent (.308)	95.2	171	14,592	24,052
-10 percent (.252)	95.2	139	14,592	19,678
Freezer electricity use				
+10 percent (481 kwh/yr)	105	171	16,051	24,052
-10 percent (393 kwh/yr)	85.7	139	13,133	19,678

Source: Franklin Associates

percentage of fossil fuels in the national average electricity grid were extrapolated to 100 percent, and the results recalculated. The results of this recalculation were an increase in the reduction of greenhouse gases by using the polyurethane insulation in both the refrigerator and the freezer. For the refrigerator, the annual greenhouse gas savings jumped from 12,502 lb (see Table 4) to 18,948 lb, an increase of almost 6,500 pounds of carbon dioxide equivalents per year. For the freezer, the annual greenhouse gas savings increased from 7,273 lb (see Table 8) to 11,205 lb., an increase of almost 4,000 pounds of carbon dioxide equivalents per year. It should be noted that while there would be an increase in the reduction of greenhouse gases, there would also be an increase in the amount of greenhouse gases released if only fossil fuels were used for electricity production.

KEY ABBREVIATIONS/SYMBOLS

AHAM	Association of Home Appliance Manufacturers
APC	American Plastics Council
Btu	British Thermal Units
CFC	ChloroFluoro Carbons
CO2	Carbon Dioxide
Cu ft	Cubic Foot
DOE	Department of Energy
EPA	Environmental Protection Agency
ºF	Degrees Fahrenheit
FCCC	Framework Convention on Climate Change
Ft	Foot
GE	General Electric
HCFC	HydroChloroFluoro Carbons
HFC	HydroFluoro Carbons
Hr	Hour
Kwh	Kilowatt-Hours
Lb	Pounds
MDI	Methylene DiIsocyanate
Mil Btu	Million British Thermal Units
VOC	Volatile Organic Compounds
Yr	Year

LIST OF SOURCES

<u>Polyurethane Precursors</u>

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