PLASTICS ENERGY AND GREENHOUSE GAS SAVINGS USING RIGID FOAM SHEATHING APPLIED TO EXTERIOR WALLS OF SINGLE FAMILY RESIDENTIAL HOUSING IN THE U.S. AND CANADA - A CASE STUDY

Revised Final Report

Prepared for

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EXECUTIVE SUMMARY

This analysis is a case study that examines energy savings and greenhouse gas (GHG) emission reductions resulting from the addition of rigid plastic foam sheathing to the exterior walls of single family housing in the United States and Canada. The widespread use of rigid plastic foam sheathing on exterior walls is relatively recent, spurred by the energy conservation awareness brought on by the energy crisis of the early and mid-1970's. It possesses excellent structural and insulating characteristics and is considered to be cost effective by most homebuilders today. Its use significantly increases the insulation R-value of walls, and therefore saves energy and reduces GHG emissions.

The results show that typical annual energy savings for a single house in the U.S. resulting from the use of foam sheathing is 3.5 million Btu per year, with a GHG savings of 505 lb of CO_2 equivalents. Over an assumed 50-year life for the insulation, this becomes 175 million Btu and 25,300 lb of CO_2 equivalents. The manufacture of the plastic foam uses energy and releases GHG to the atmosphere. To manufacture the sheathing used for a single house, the energy requirement is approximately 7.3 million Btu of energy along with emission of about 2,800 lb of CO_2 equivalents. Over the 50-year life assumed here, this one-time initial use of energy and GHG releases is not only very small, but the large savings resulting from the use of the product shows that this is a wise use of resources. The "pay-back" times for the manufacturing energy and GHG emissions are about 2.1 years for energy and 12.5 years for GHG emissions. Thereafter, there is a net savings in energy and GHG emissions for as long as the insulation is in place. It is estimated that also approximately 1.5% of the blowing agent contained in the insulation is released each year. Although the blowing agent is also a GHG, these emissions are fully offset by GHG savings from use of the insulation each and every year the insulation is in use.

To put these results into perspective, the cost of household energy for heating and cooling is $7.39 per million Btu. For the entire country, the annual savings in energy cost is $2.58 billion or $128.6 billion over 50 years if all houses were insulated with plastic foam insulation. The GHG savings can be compared to the fact that the family automobile releases 20 pounds of CO_2 into the atmosphere for each gallon of gasoline consumed. Thus, for the country as a whole, GHG savings from the use of plastic foam insulation on all houses is equivalent to the amount of CO_2 that would be emitted from consuming 2.5 billion gallons of gasoline annually, and 124 billion gallons over 50 years.

In Canada, the results show that typical annual energy savings for a single house resulting from the use of foam sheathing is 11 million Btu per year, with a GHG savings of 787 lb of CO_2 equivalents. Over an assumed 50-year life for the insulation, this becomes 550 million Btu and 39,000 lb of CO_2 equivalents. The "pay-back" times for the manufacturing energy and GHG emissions are about 0.4 years for energy, and 3 years for GHG emissions. Thereafter, there is a net savings in energy and GHG emissions for as long as the insulation is in place. As in the U.S., emissions

of blowing agent from the insulation are fully offset by GHG savings from use of the insulation each and every year the insulation is in use.

The Canadian GHG pay-back periods are much shorter than they are for the U.S. This is because of the much colder average temperatures in Canada, which results in greater incremental savings when foam sheathing is applied.

The Canadian cost (in Canadian dollars) is C$6.02 per million Btu. For the entire country, the annual energy cost savings is C$728 million each year or C$36 billion over 50 years if all houses were insulated with plastic foam insulation. The GHG savings from the use of plastic foam insulation on all houses is equivalent to the amount of CO_2 that would be emitted from consuming 300 million gallons of gasoline annually, and 15 billion gallons of gasoline over 50 years.

To carry out estimates of the energy and GHG savings, the dimensions of a typical house constructed in the U.S. or in Canada in 1997 were determined from government statistics for each country, and used for a base case. Only the four exterior walls of single family housing were considered. The walls were assumed to consist of 1/2” gypsum wallboard (sheet rock), 2”X4” wooden wall studs with 3.5” of fiberglass insulation installed between the studs, 1/2” plywood exterior sheathing and 1” exterior wood siding. The heat flow through this wall was compared to an identical wall with 5/8” rigid foam insulation sheathing added. The reduced heat flow resulting from the addition of foam insulation was the basis for energy and GHG savings calculations. Industry experts estimate that 60% of rigid foam sheathing used today is extruded expanded polystyrene foam (XEPS), and the other 40% is polyisocyanurate foam (PIR).

The heat flow calculations require assumptions about both the insulating characteristics and the difference between inside and outside temperatures. The insulating characteristics were determined from standard sources. The differences in temperatures were estimated by using heating and cooling degree-day statistics. Annual average data by climatic zone were used for the U.S. and combined with estimated housing units in each zone to construct a national average composite. A 1997 regional electricity grid for each state was developed for the U.S.

For Canada the heating and cooling degree data shows that almost no energy is expended for cooling, so only heating values were used. However, about 90% of the energy expended for heating in Canada is natural gas, so that other fuels used to generate electricity comprise a small part of the energy fuel profiles. An average Canadian electricity grid from 1994 was used for the Canadian portion of this study.

The life cycle energy and GHG emissions from manufacturing the foam sheathing were also calculated. Separate manufacturing calculations were carried out for the U.S. and Canada, reflecting different sources of fuel for electricity and different practices in those countries.

INTRODUCTION

This analysis is a case study that examines the greenhouse gas (GHG) and energy savings associated with rigid plastic foam sheathing used to insulate single family housing. The two most commonly used plastics for this purpose are extruded expanded polystyrene (XEPS) and polyisocyanurate (PIR). These materials have become common because of their high resistance to heat flow (R-value) and are used throughout the United States and Canada. Fiberglass has historically been used for home insulation and has widespread use currently but the foam sheathing provides additional insulation. Although these types of insulation as well as several others are also used to insulate roofs, ceilings and underneath unheated floor space, only exterior walls are evaluated in this analysis.

This study presents data on walls that are insulated with fiberglass between wood wall studs and an exterior wood siding. This baseline is compared to a similar fiberglass-insulated wall but with foam sheathing added between the plywood exterior sheathing and siding. The baseline wall consists of 1/2” sheet rock, 2” x 4” wall studs with 3 1/2” of fiberglass between the studs, 1/2” plywood sheathing, and 1” of hardwood siding creating an overall R-value of 14. The R-value of a wall with foam sheathing was assumed to be 14 plus the additional thermal resistance provided by the foam. In some applications, the use of foam sheathing eliminates the need for plywood or other rigid board between the wall studs and siding and the plastic foam is attached directly to the studs. In addition, foam sheathing may also have a vapor barrier attached, which would make inclusion of a separate vapor barrier unnecessary. In this analysis we assumed that the base wall remains constant and the additional insulating value due to use of plastic foam is a true incremental difference. Thermal drift (loss of R-value with time) occurs in closed cell type foam insulation due to some of the blowing agent being replaced by air within the cells. However, this is essentially stabilized within the first two years after manufacture (according to the U.S. Department of Energy). For this reason, stabilized R-values best represent the thermal resistance for home insulation since the insulation lasts many years. The stabilized R-values and densities used in this study for both PIR and XEPS are shown in Table 1. It should be noted that some plastic foam insulation products are sold with warranties for long term R-values slightly higher than shown here.

Both XEPS and PIR foam insulation possess unique characteristics leading to their increased use over wood products in sheathing applications. The chemistry of manufacturing PIR is very similar to the manufacture of polyurethane (PUR). PIR is a type of polyurethane. Rigid PUR foam is produced by the reaction of a polyether-based polyol and methylenediphenyl isocyanate in an equimolar mixture with HCFC-141b as the blowing agent. The molar ratio of isocyanate to polyol equals 1 for rigid PUR foam. PIR rigid foam manufacture is essentially the same but uses a polyester polyol. To encourage the formation of aromatics which have a high heat resistance

Table 1

PHYSICAL PROPERTIES OF PLASTICS USED FOR FOAM SHEATHING

	Density (lb/cu ft)	Stabilized R value (ft2/Btu/hr/F/inch)
Extruded Expanded Polystyrene (XEPS)	1.5	4.8
Polyisocyanurate (PIR)	2	5.8

Source: U.S. Department of Energy

the molar ratio for PIR foam manufacture is roughly 2.5. Some of the additional isocyanate trimerizes in a self-addition reaction to form isocyanurate rings giving stability to enhance fire-resistance properties.

The current blowing agent used in polystyrene foam insulation is HCFC-142b in both the U.S. and Canada. The current blowing agent used in polyisocyanurate foam insulation is primarily HCFC-141b in the U.S. and Canada. The Sensitivity Analysis section discusses the changes in results if alternatives were used as blowing agents.

The HCFC blowing agents are viewed by the EPA as transition materials and must be replaced by December, 2002 for HCFC-141b and January, 2010 for HCFC-142b. No definite replacement has been found as of yet. Europe is currently using hydrocarbons, such as cyclopentane in PIR, but these produce foams with higher thermal conductivities than the HCFCs and so would increase energy requirements for use. There are also flammability risks during processing and environmental concerns as they are VOC's. According to a study done by the Appliance Industry/Government CFC Replacement Consortium[1], HFC's are a likely replacement for HCFC's. According to the study mentioned previously, the thermal conductivity of certain HFC's are less than 10 percent higher than the HCFC-141b used today.

[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

End of life scenarios have not been included in this study. There is no definite data on what happens to the residual blowing agent in the foam at the end of life. This subject is discussed in more detail in the Sensitivity Analysis section.

The results of this analysis are based on a comparison of the cradle-to-manufacture energy requirements and GHG emissions for the foam sheathing manufacture, GHG emissions during use, and the energy savings and avoided GHG emissions from reduced heating and cooling demand.

U.S. METHODOLOGY

The results compare the life cycle energy and GHG emissions resulting from two insulation scenarios. In the first, a baseline is developed for the exterior walls of a typical house. The second scenario assumes that plastic foam insulation sheathing is affixed to the exterior wall. Also included are the energy and emissions for the manufacture of the plastic insulation, as well as the GHG released from the insulation over its lifetime.

The method used to calculate the plastics data are the established life cycle techniques developed by Franklin Associates over the past three decades. Heat loss and heat gain through the walls were calculated using a simplified steady-state one-dimensional heat transfer equation through a plane wall requiring only thermal conductivities (reciprocal of R-value), wall area, temperature difference, and length along the heat flow path (Kreith, F., Principles of Heat Transfer, 3rd Edition). Statistics on home heating and cooling systems were used to convert heat flow to energy savings.

A house built in 1997 in the United States had an average floor area of 2,150 square feet. Half of the houses were one story and half were two story with split level houses being ignored (Statistical Abstract of the United States 1998). We assumed data for a typical house model, consisting of a hypothetical hybrid reflecting national averages. The hybrid was one-half 2 story and one-half 1 story with a square foundation. The square geometry minimizes total wall area but this difference from actual dimensions is roughly equal to the wall area for windows so this assumption compensates for not subtracting window area. With these assumptions, the wall area is 1,791 square feet. We used this model to represent wall area for all occupied housing so that the typical house in this study is based on current (1997) construction patterns.

Weather data including heating degree days (HDD) and cooling degree days (CDD) for at least one major city at or near an airport in every state are published in Statistical Abstracts. A heating degree day is defined as each degree of mean temperature below 65° Fahrenheit. The mean is simply the average of the high and low recorded for that day. Similarly, a cooling degree day is each degree of mean temperature above 65°F. The sum of all the daily contributions results in annual heating and cooling degree days.

In this study, the HDD and CDD days were used in heat flow calculations which require a ΔT value for the temperature inside and outside of a house. The HDD and CDD are widely used as representative values to calculate energy used in heating and cooling. Because houses are not typically kept at 65º inside, some error is incurred. However, the heating calculations may be underestimated while the air conditioning calculations may be overestimated by using this procedure, so the energy and GHG emissions errors will tend to cancel out. In addition, the annual HDD and CDD contributions near 65ºF are a very small fraction of total annual HDD and CDD values.

Climatic zones are commonly used for weather-related calculations. Each of the five zones used in this study has boundaries that are based upon climate and do not follow geographic boundaries such as state boundaries. Housing statistics are commonly available by geographic zone. In order to create a heating and cooling database for this study, it was necessary to estimate the population and the number of houses in each climatic zone. The assignment of states to climatic zones is shown in Table 2. Since housing data were not available by state, population percentages for

Table 2

ASSIGNMENT OF STATES TO CLIMATIC ZONES

Zone	State or District
1	Maine, Vermont, New Hampshire, Wisconsin, Minnesota, North Dakota, Montana, Wyoming, Alaska
2	Massachusetts, Rhode Island, New York, Michigan, Iowa, South Dakota, Nebraska, Colorado, New Mexico, Utah, Idaho, Nevada, Washington, Oregon
3	Connecticut, New Jersey, Delaware, Maryland, District of Columbia, Virginia, West Virginia, Pennsylvania, Ohio, Kentucky, Indiana, Illinois, Missouri, Kansas, Arizona
4	North Carolina, South Carolina, Tennessee, Texas, Georgia, Alabama, Mississippi, Arkansas, Oklahoma, California
5	Florida, Louisiana, Hawaii

Source: Franklin Associates based on Plastics Used in Building Insulation Study. 1979.

each state (Statistical Abstracts) were used to represent the same fraction of houses in each census geographic zone, which was then used to estimate the number of houses in each state. The states were assigned to a climatic zone along with its calculated number of houses, as shown in Table 3.

To develop HDD and CDD values for each climatic zone, annual heating and cooling degree day statistics by major cities were used. A composite was formed from the reporting cities data by weighting the city data by its population compared to the total population in the climatic zone. The HDD and CDD results are shown in Table 3.

Heat flow from the total number of houses per climatic zone is calculated by multiplying the wall area, number of houses in the zone, annual heating or cooling degree days, and dividing by the heat resistance or R-value. The result is multiplied by 24 to correct for the time unit on which heat transfer equations are based. (See the Appendix for more details of this calculation.) Heat flow is calculated for both the fiberglass-only wall and the wall containing plastic foam and the difference leads to

Table 3

CLIMATE AND HOUSING STATISTICS BY ZONE

Zone	Heating Degree Days (Annual)	Cooling Degree Days (Annual)	1995 Occupied Housing (thousands)
1	7,995	405	5,777
2	6,244	635	21,819
3	5,123	1,153	31,100
4	2,511	1,624	31,678
5	921	3,281	7,320
Total Occupied Housing			97,694
Weighted Avg. HDD	4,381		
Weighted Avg. CDD		1,305	

Source: Franklin Associates and Statistical Abstract of the United States 1998 energy savings associated with foam insulation. Statistics on the type of heating systems (either a forced air furnace or heat pump) and the percentage of houses using air conditioning along with heating efficiencies and refrigeration energy efficiency ratios were used to calculate quantities of natural gas and electricity saved. Additional data and assumptions are listed in the Assumptions Section.

Electricity savings were calculated using regional electricity generation power grids. Climatic zone specific electricity data were developed using 1997 regional electric production data (North American Electric Reliability Council). The sources of fuel used in the production of electricity were averaged based on the estimated number of occupied houses in each state and the applicable regional grid for that state.

In order to calculate savings in GHG emissions, we have assumed that the reduced electricity originated from the regional 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 the marginal or incremental future power plants will likely use only fossil fuels and not nuclear or hydropower as fuels. If we had chosen that option, the GHG emission reductions would have been significantly greater (see sensitivity analysis). Both approaches are in common use, and we have selected the conservative option that shows the least savings.

U.S. RESULTS

All Houses Using 60% Polystyrene/40% Polyisocyanurate

The total energy requirements and GHG emissions are shown in Table 4 for using a 60% polystyrene/40% polyisocyanurate insulation on all occupied houses. The current (1998) market split of XEPS and PIR was used to calculate a composite R-value reflecting this mix of sheathing sold. Sixty percent of new family housing constructed in 1998 that utilize foam sheathing were built with XEPS and forty percent used PIR (The Dow Chemical Company and Celotex Corporation). The overall R-value of the walls in the typical house is calculated as if the 5/8" thick insulation is composed of 3/8" XEPS and 1/4" PIR resulting in R=17.25 (14+4.8(3/8) +5.8(1/4)), where R=4.8 for the 3/8" XEPS and R=5.8 for the 1/4" PIR. The plastics life cycle energy values are based upon data provided by the plastics industry.

These results include energy savings and GHG emissions avoided over a projected 50 year lifetime as a result of those energy savings. The 50 year period is included to illustrate long term effects. It is considered to be a conservative estimate of results as the lifetime of insulation in a house may be longer. However, remodeling or siding replacement frequently happens in this time span and may result in changes in the insulation at that time.

Table 4

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING FOAM SHEATHING ON EXTERIOR WALLS OF ALL U.S. OCCUPIED HOUSES (ASSUMING A TYPICAL* HOUSE)

	Foam Sheathing**
Energy Savings (Million Btu)	
Annual	3.49E+08
50 years	1.74E+10
Plastics Life Cycle Energy	7.11E+08
Energy Payback (years)	2.04
Greenhouse Gases (CO_2 equivalents in pounds)	
Generated From Plastics Manufacture	2.74E+11
Avoided From Energy Savings	
Annual	4.93E+10
50 years	2.47E+12
Greenhouse Gas Payback (years)* **	12.5

* A typical house has the current (1998) US market split of foam sheathing: 60% extruded polystyrene and 40% polyisocyanurate

** Calculations made using 5/8" thick sheathing and R values/inch of 4.8 for XEPS and 5.8 for PIR.

*** See text for calculation method (p. 9 and Appendix A).

Source: Franklin Associates

As shown in Table 4, the insulation achieves a "payback" in terms of energy savings of roughly 2 years. This means that the energy required to manufacture the plastics foam products is equal to the total energy saved by the end of that period. The payback value for the insulation is approximately 12.5 years for the GHGs. This "GHG payback" is much greater than the energy payback because of the release of some blowing agent during manufacture and the gradual release of blowing agent from the sheathing, estimated to occur at 1.5% yearly. The GHG payback period was found by taking the annual GHG savings from energy conservation and subtracting the emissions from the sheathing each year. This gives the net reduction in GHG for each year. The payback time is when the cumulative amount of savings exceeds the GHG emissions from manufacturing the sheathing. (See Appendix A for more detail.)

HCFC-141b is assumed to be the blowing agent used for the PIR insulation, while HCFC-142b is the blowing agent for the XEPS insulation. The global warming potentials for each of these blowing agents can be found in the Assumptions section.

Annual Calculations For A Single Typical House in the U.S.

A typical house has the same characteristics such as wall area and wall construction as the houses represented in Table 4. Energy savings and GHGs avoided for a single typical house for each zone are shown in Table 5.

Energy savings disaggregated by fuel type (an energy profile) for each zone show that natural gas makes up 36 to 79 percent of the total energy savings. These values reflect the higher heat savings in colder zones that conserve a greater proportion of natural gas compared to other fuels. Coal represents from 13 to 37 percent of the total savings going from colder zones to warmer zones. This trend reflects the higher cooling energy saved in warmer zones that is supplied by electricity generated primarily by burning coal. The decreasing energy payback time as the zones go from warmer to colder is due to the large amount of energy savings associated with heating a house in the colder zones. The U.S. Average column of data is a sum of the energy savings or greenhouse gases divided by the total number of houses and not a mean of the houses in all zones so it is similar to a weighted average.

The GHG data show the contribution of each of the four GHGs to the total carbon dioxide equivalents. The HCFC-141b blowing agent from the PIR contributes 21 percent of the total CO_2 equivalents for the cradle-to-manufacture life cycle of the plastic foam, while the HCFC-142b blowing agent from the XEPS contributes 54 percent. Carbon dioxide gas avoided due to energy savings represents a minimum of 94 percent of the total CO_2 equivalents from energy savings for each climatic zone. GHG paybacks range from 6 to 25 years, with a weighted average of 12.5 years. The GHG payback is much longer than the energy payback due to the release of blowing agent from the insulation over its lifetime.

Table 5

ANNUAL ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING FOAM SHEATHING ON EXTERIOR WALLS OF A TYPICAL HOUSE IN THE U.S.*

	Colder →				Warmer	
Energy Savings (Million Btu)	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**US Avg**
Natural Gas	4.20	3.31	2.70	1.42	0.90	2.37
Petroleum	0.04	0.05	0.02	0.01	0.22	0.04
Coal	0.81	0.55	0.98	0.65	0.93	0.76
Hydropower	0.06	0.09	0.02	0.08	0.03	0.06
Nuclear	0.26	0.17	0.26	0.29	0.19	0.25
Other	0.03	0.02	0.02	0.01	0.23	0.03
Total Annual Energy Savings	5.41	4.19	4.01	2.46	2.50	3.51
Plastics Life Cycle Energy	7.33	7.33	7.33	7.33	7.33	7.33
Energy Payback (years)	1.36	1.75	1.83	2.98	2.93	2.09
Greenhouse Gases (CO_2 equivalents in pounds)						
Generated From Plastics Manufacture						
Carbon Dioxide	609	582	608	580	606	599
Methane	101	100	101	100	101	101
Nitrous Oxide	4.5	4.4	4.5	4.4	4.5	4.5
HCFC-141b	588	588	588	588	588	588
HCFC 142b	1,511	1,511	1,511	1,511	1,511	1,511
Total CO_2 Equivalents	2,813	2,785	2,812	2,784	2,811	2,803
Avoided From Annual Energy Savings						
Carbon Dioxide	716	548	553	318	352	478
Methane	40.6	31.1	30.5	17.3	16.0	26.3
Nitrous Oxide	0.50	0.34	0.59	0.39	0.61	0.47
Total CO_2 Equivalents	757	579	584	336	368	505
Greenhouse Gas Payback (years)**	6.1	9.5	9.5	31.0	25.2	12.5

* A typical house has the current (1998) market split of foam sheathing:
60% extruded polystyrene and 40% polyisocyanurate

** See text for calculation method (p. 9 and Appendix A).

Source: Franklin Associates

CANADIAN METHODOLOGY

The general methodology and assumptions used in the United States study were used for the Canadian study as well. Some key Canadian specific data were used in this study for the calculation of lifecycle energy and GHG emissions for Canada.

The average floor size of a Canadian home is assumed to be 1,334 square feet. This is based on the average size of single-detached and singled-attached homes in Canada, results of the 1993 Survey of Household Energy Use and the Survey of Houses Built in Canada in 1994 (Energy Efficiency Trends in Canada 1990 to 1996). Assuming a one story home with a square foundation, the total wall area used for heat loss calculation is 1,169 square feet.

The R-value for the base case average wall (without insulation sheathing) in Canada was assumed to be the same as for the U.S. HDD data from Climate Normal (published by Environment Canada at www.cmc.ec.gc.ca) for at least one major city in each Canadian province were used. These data are reported in Celsius degrees, but they were converted to Fº for these calculations in order to provide a uniform reporting basis for this report. Table 6 displays the average HDD calculated in U.S. units and the number of occupied houses for each Canadian province. (These results are reported in metric units in Appendix B.)

Annual HDD were calculated using 1996 population census (Statistics Canada) of metropolitan areas as the weighted average. CDD data were not utilized since the energy used in space heating for cooling is estimated to be less than 1% of the energy used for heating. (Energy Efficiency Trends in Canada 1990 to 1996).

The energy source for heating for Canada were 77% direct fuel and 23% fuels to generate electricity, estimated from Energy Efficiency Trends in Canada 1990 to 1996.

CANADIAN RESULTS

All Houses Using Either Polystyrene or Polyisocyanurate

The total energy requirements and GHG emissions are compared in Table 7 for using 60% polystyrene (XEPS)/40% polyisocyanurate (PIR) insulation on all occupied houses in Canada. The results in Table 7 are the sum totals of data for all of the provinces and territories described in the Methodology Section. The results also include energy savings and GHGs avoided over a 50 year lifetime.

The table shows that the energy savings are quite large compared to the energy required to manufacture the foam sheathing. The payback period is 0.4 year. This means that the energy required to manufacture the plastics foam products is equal to the total energy saved by the end of that period.

TABLE 6

CLIMATE AND HOUSING STATISTICS BY PROVINCES

Province	Heating Degree Days (Based on °F) (Annual)	1996 Occupied Housing (thousands)
Ontario	7,061	3,951
Quebec	8,494	2,849
British Columbia	5,463	1,434
Alberta	9,964	984
Manitoba	10,605	421
Saskatchewan	10,571	376
Nova Scotia	7,990	345
News Brunswick	8,699	273
New Foundland	8,789	187
Prince Edward Island	8,578	49
NW Territories	15,291	19
Yukon Territory	12,537	12
Total Occupied Housing		10,900
Weighted Average HDD	7,840	

Source: Environment Canada and Statistics Canada

The payback on GHG is longer than for energy because of the addition of released blowing agent from the insulation. The GHG payback period for Canada is 3.0 years. The reason the GHG payback periods for Canada are shorter than for the U.S. is because of the colder climate leads to greater incremental energy savings when foam sheathing is applied.

Table 7

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING FOAM SHEATHING ON EXTERIOR WALLS OF ALL CANADIAN OCCUPIED HOUSES (ASSUMING A TYPICAL* HOUSE)

	Foam Sheathing**
Energy Savings (Million Btu)	
Annual	1.21E+08
50 years	6.04E+09
Plastics Life Cycle Energy	5.05E+07
Energy Payback (years)	0.42
Greenhouse Gases (CO2 equivalents in pounds)	
Generated From Plastics	1.93E+10
Released During Use over 50 Years^	7.81E+10
Avoided From Energy Savings	
Annual	8.57E+09
50 years	4.29E+11
Greenhouse Gas Payback (years)* **	3.0

* A typical house has the current (1998) US market split of foam sheathing: 60% extruded polystyrene and 40% polyisocyanurate

** Calculations made using 5/8" thick sheathing and R values/inch of 4.8 for XEPS and 5.8 for PIR.

*** See text for calculation method (p. 9 and Appendix A).

Source: Franklin Associates

Annual Calculations for a Single Typical House

Table 8 shows the energy savings for a single house in Canada by province or territory. The energy payback ranges from 1.7 years in the Northwest Territories to 4.8 years in British Columbia. This reflects the milder climate in British Columbia compared to the much colder temperatures in the far north.

Because of the dominant use of natural gas for home heating in Canada, the predominant savings is for natural gas. Calculations using the energy profile in Table 8 shows that about 85% of the total savings is for this fuel. The percent of total savings for other energy sources include 5% for nuclear, 4% for coal, 4% hydropower, and 2% for petroleum.

The GHG payback shows a higher result, with the shortest payback being 1.3 years for the Northwest Territories to 5.1 years for British Columbia.

Table 8

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING FOAM SHEATHING ON EXTERIOR WALLS OF A TYPICAL CANADIAN HOUSE*

Energy Savings (Million Btu)	Ont	Que	BC	Alb	Man	Ska	NS	NB	NF	PEI	NwT	YuT	CAN Avg
Natural Gas	0.63	0.76	0.49	0.90	0.95	0.95	0.72	0.78	0.79	0.77	1.38	1.13	0.71
Petroleum	0.23	0.28	0.18	0.33	0.35	0.35	0.26	0.29	0.29	0.28	0.50	0.41	0.26
Coal	2.75	3.31	2.12	3.88	4.13	4.12	3.11	3.39	3.42	3.34	5.96	4.89	3.06
Hydropower	2.73	3.29	2.11	3.86	4.11	4.10	3.09	3.37	3.41	3.32	5.93	4.86	3.05
Nuclear	3.53	4.25	2.73	4.98	5.31	5.29	3.99	4.35	4.39	4.29	7.66	6.28	3.93
Other	0.06	0.07	0.05	0.08	0.09	0.09	0.07	0.07	0.00	0.07	0.13	0.11	0.07
Total Annual Energy Savings	9.93	12.0	7.68	14.0	14.9	14.9	11.2	12.2	12.3	12.1	21.6	17.7	11.1
Plastics Life Cycle Energy	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
Energy Payback (years)	0.47	0.39	0.60	0.33	0.31	0.31	0.41	0.38	0.38	0.38	0.21	0.26	0.42
Greenhouse Gases (CO2equivalents in pounds)													
Generated From Plastics													
Carbon Dioxide	337	337	337	337	337	337	337	337	337	337	337	337	337
Methane	63	63	63	63	63	63	63	63	63	63	63	63	63
Nitrous Oxide	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
HCFC 142b	986	986	986	986	986	986	986	986	986	986	986	986	986
HCFC 141b	383	383	383	383	383	383	383	383	383	383	383	383	383
Total CO2 Equivalents	1,773	1,773	1,773	1,773	1,773	1,773	1,773	1,773	1,773	1,773	1,773	1,773	1,773
Avoided From Annual Energy Savings													
Carbon Dioxide	673	810	520	951	1,012	1,009	762	830	839	818	1,461	1,197	751
Methane	30.3	36.5	23.4	42.9	45.6	45.5	34.4	37.4	37.8	36.9	65.9	54.0	33.9
Nitrous Oxide	1.68	2.02	1.30	2.37	2.53	2.52	1.90	2.07	2.09	2.04	3.65	2.99	1.87
HCFC 142b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HCFC 141b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total CO2 Equivalents	705	849	545	996	1,061	1,057	798	869	878	857	1,531	1,254	787
Greenhouse Gas Payback (years)**	3.5	2.7	5.1	2.2	2.1	2.1	3.0	2.6	2.6	2.7	1.3	1.7	3.0

* A typical house has the current (1998) US market split of foam sheathing: 60% extruded polystyrene and 40% polyisocyanurate

** See text for calculation method (p. 9 and Appendix A).

Source: Franklin Associates

Sensitivity Analysis

The values used in this analysis are presented as being useful as a typical case, but no representation is made that they accurately reflect any particular situation, nor a national total. Construction practices are highly variable, including the use of a wide range of thicknesses of sheathing and of standard wall construction. Construction quality greatly affects the functioning of insulation products. Weather is highly variable, as are thermostat settings in homes. The use of degree-days based on 65°F likely leads to an underestimate of energy for heating and an overestimate of energy for cooling. Efficiencies assumed for household heating and air conditioning are generally optimistic, and in many cases may be far lower than is usually used in calculations. The calculations in this analysis use dimensions based upon 1998 practices, but older homes tend to be smaller.

Most of these possible errors, and many others not mentioned above, may mean that the calculations in this study may either be too high or too low. Assigning reasonable ranges are not possible. Most of these errors effect the entire sequence of calculations, and will have a linear effect on results. That is, a 10% error in the assumptions will cause a 10% error in the results. However, due to the random nature of these errors, they may tend to equalize.

One important area of uncertainty is the amount of HCFC-141b and HCFC-142b emitted to the atmosphere. In these calculations we have used a 10% loss during the manufacturing process, as well as a 1.5 percent loss compounded annually for the blowing agent while the insulation is in use. The fate of the residual blowing agent has not been determined for either XEPS or PIR. When the house is finally demolished, the sheathing will be broken into pieces, but probably not shredded so that large pieces will remain and be taken to a demolition waste landfill. If shredded, the blowing agent likely would be emitted to the air, but there is no data on what finally happens to the blowing agent for discarded large pieces. Over decades, the plastic may degrade or change physical characteristics so that the HCFC eventually is released, but there is simply no way to know what its final fate may be.

While there has been some discussion about the “banking” of blowing agents in discarded materials, we have performed a conservative approach calculation assuming all of the blowing agent eventually reaches the atmosphere. If that happens, it lengthens the payback periods calculated in the previous tables. For the U.S., the GHG payback lengthens from 12.5 to 66 years for an average house. For Canada, it lengthens from 3 years to 22 years for an average house.

One other possible area of uncertainty pertaining to the blowing agent is the type used. We have used HCFC-141b for PIR and HCFC-142b for XEPS in this study. Also, another industry contact reports that in Canada the HCFC's are being phased out of the manufacture of PIR, and hydrocarbons are being used in their place. If hydrocarbons are used in the place of HCFCs, they have a global warming potential of 0. The effect on the payback is uncertain because hydrocarbons have a lower R value than HCFCs. Specific hydrocarbons would need to be selected in order to calculate the length of payback. There is no data available on the actual marketplace percentages of each blowing agent used today, so it is uncertain what these differences will do to the results.

In addition, the future is uncertain as to what blowing agents will be used in the next decade. After 2003, the blowing agents may be hydrocarbons (such as cyclopenane) or HFC-245fa in PIR. As described above, if the hydrocarbons become dominant, they have less greenhouse gas effect from direct emissions, but also may result in less energy savings if the products are not redesigned to offset the lower R value. For example, a thicker panel might become preferred by consumers. If the HFC-245fa is used, its R value and greenhouse gas emission factor (which is 790 – a value between HCFC-141b and 142b) would need to be used in new calculations to ascertain the implications as compared to current practice.

In the U.S. some governmental agencies and environmental groups suggest that marginal energy sources used to generate electricity should be considered instead of the actual energy sources used today. In order to examine the effect of using marginal fuels for electricity in the U.S., we recalculated GHG savings for the national electricity grid. To do this, the percentage of fossil fuels in the national average electricity grid were extrapolated to provide 100 percent of the energy for electricity. The results of this recalculation was an increase in the GHG reduction of about 15% for the U.S. The resulting decrease in the payback period is 3 years, to 9.5 years.

The conditions assumed here are reasonably "average" or "typical." Extreme or unusual assumptions were not used. There is no reason to believe that the conclusions reached in this study are in error by very large amounts, nor that they lead to a predictably biased picture.

ASSUMPTIONS

The principal assumptions made by Franklin Associates follow.

- R-values and densities for PIR foam and XEPS foam shown in Table 1 were taken from The U.S. Department of Energy's website www.eren.doe.gov.

- According to Brook Boynton, ICI Polyurethanes, approximately 10 percent of the HCFC-141b blowing agent used to produce PIR foam is lost to the atmosphere. He also commented that using polyether polyol data from the manufacture of polyurethane to represent the polyester polyol in PIR would have an insignificant effect on life cycle energy results. ICI Polyurethanes also commented that HCFCs are being phased out in the manufacture of polyisocyanurate in Canada, and hydrocarbons are being used in their place.

- According to Will Biddle, National Association of Home Builders, 1/2" and 3/4" are the most common thicknesses of foam insulation sold in the United States. We assumed the average thickness to be 5/8".

- According to Scott Young, The Dow Chemical Company, and Joe Hagen, Celotex Corporation, the approximate percentages of foam sheathing sold for use on exterior walls of new home construction in 1998 was 60 percent XEPS and 40 percent PIR.

- R-values/inch of the components of the base wall were assumed to be 3.2 for fiberglass, 0.45 for gypsum, 1.32 for plywood sheeting, and 0.91 for hardwood siding and were taken from **Physics for Scientists and Engineers,** Serway, 4th ed.

- Population statistics in each state were used as a surrogate to calculate number of homes since housing units data were available only by four geographic regions. These statistics were also used to calculate the state contribution of heating and cooling degree days to the zones chosen by climate.

- From the Gas Appliance Manufacturer's Association, efficiency data on 1997 shipments of gas furnaces is broken into three categories. The weighted average efficiency is 85% assuming the less than 80% category averages 75% and the greater than 88% category averages 90%.

- According to Dusty Stillman, Air-conditioning and Refrigeration Institute, the average coefficient of performance (COP) for residential heat pumps is 3.15 and the average energy efficiency ratio (EER) of central air conditioning units is 12,000 Btu/kWh.

- Based on heating system data from the Statistical Abstract of the United States 1998, U.S. Bureau of the Census, 118th edition roughly 75 percent of new homes in 1997 had warm air furnaces installed and 25 percent use heat pumps. The houses built without central air-conditioning (18%) were assumed to be in climatic zones 1 and 2, the two northernmost zones and assumed to require no cooling energy. All other houses were assumed to have central air which accounts for the 82 percent built with cooling systems.

- The amount of PS and PIR insulation foam needed for one house is calculated from the area of the wall (1791 ft^2) multiplied by the thickness of the foam insulation (0.052 ft) multiplied by the density of the material (PS=1.51 lb/ft^3, PIR=2 lb/ft^3). This calculates to 140 lb/house for the polystyrene foam and 186 lb/house for the polyisocyanurate foam.

- Gary Chu of Dow Canada stated that 9.5 percent blowing agent (HCFC-142b) is used in the polystyrene foam in Canada. Brad Gougeon of Dow in the U.S. presented a range of 6-10 percent blowing agent used in polystyrene foam insulation in the U.S. For this study, Franklin Associates assumed 9 percent blowing agent. The amount of HCFC-142b used in the polystyrene insulation is 99 pounds of blowing agent per 1,000 pounds of polystyrene insulation with an assumed loss of 10% of the blowing agent during the manufacturing process.

- The formulation used for the polyisocyanurate foam insulation is 62.5 percent MDI, 25 percent polyol, and 12.5 percent HCFC-141b with a 10% loss of the blowing agent during the manufacturing process. The blowing agent HCFC-141b was assumed to be the blowing agent for the polyisocyanurate foam insulation.

- APC data was used for the manufacture of polyisocyanurate precursors (MDI and Polyol) and polystyrene resin.

- 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 was available for the 1,1,1 trichloroethane production. Surrogate data was used from the production of vinyl chloride monomer which is an intermediate used to form 1,1,1 trichloroethane. Surrogate data was also used for the production of HCFC-141b and HCFC-142b from CFC-11 production data. According to Dr. Richard Crooker of Elf Atochem, the heating processes of the HCFC-141b and CFC-11 blowing agents are similar, but the purification process for the HCFC-141b goes couple more steps beyond 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. Franklin Associates assumed the production data of CFC-11 could also be used for HCFC-142b.

- 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
HCFC-142b	2000
HFC-145fa	790

- The walls of our case study house were considered to have no window openings. The fact that walls do have window areas would reduce the wall area covered by sheathing. However, most houses have rectangular shaped foundations, or have other more complex shapes that have more wall area than the square shape assumed here. The possible errors in neglecting window area is assumed to be compensated for by the underestimate of wall area because of non-square shapes.

- Cost factors were developed for energy savings. To calculate home heating costs in the U.S., we used table 788 of the 1998 Stat Abstracts, which lists fuel and energy prices for major metropolitan areas of the U.S. for 1997. The average for natural gas is $7.00/1000 cu ft. For electricity, the average price was $0.096/kWh. For each one million Btu, the average split for fuels and electricity are 607 cu ft of natural gas and 32.7 kWh of electricity. Using the cost factors from above, the average cost is $7.39 per million Btu.

- The corresponding energy costs for Canada are calculated in Canadian dollars. The price of electricity is C$0.0814/kWh (from Electricity Information 1997, 1998 ed., International Energy Agency). The price of natural gas is C$ 20.60/100 cu m, or C$0.00583/cu ft (from Canadian Gas Association, and Statistics Canada 55-002). For Canada, the sources of heating energy are 75% natural gas and 25% electricity, which for 1 million Btu of energy is 728 cu ft of natural gas and 21.9 kWh. The cost of 1 million Btu for Canada is C$6.02.

- Canadian Heating Degree day data from Climate Normal, Environment Canada website. www.cmc.ec.gc.ca (These data are given in C^{o}, but were converted to F^{o} in order to provide a uniform reporting basis for this report.)

- HDD data are for at least one major city in each Canadian province. Annual HDD were calculated using 1996 population census (Statistics Canada) of metropolitan areas as the weighted average. CDD data were not utilized since the energy used in space heating for cooling is estimated to be less than 1% of the energy used for heating. (Energy Efficiency Trends in Canada 1990 to 1996).

- The average size of a Canadian home is based on:

Single-detached	55.3%	1,375 sq. ft.
Single-attached	10.5%	1,116 sq. ft.
Average	65.8%	1,333.7 sq. ft.

  This data from "Energy Efficiency Trends in Canada 1990 to 1996", pg. 15 June 1998, by Office of Energy Efficiency.

- Assuming a one story home with a square foundation, the total wall area used for heat loss calculation is 1169 square feet.

- Canadian Energy use calculation shows 77% Natural Gas, 23% electric from data extracted from "Energy Efficiency Trends in Canada 1990 to 1996", pg. 15 June 1998, by Office of Energy Efficiency.

- In Canada, CDD is not taken into account as it is less than 1% of the energy used for space heating.

	% energy use in household	normalized
Space Cooling	0.4%	0.65%
Space Heating	61.1%	99.35%

  This data is from "Energy Efficiency Trends in Canada 1990 to 1996", pg. 25 June 1998, by Office of Energy Efficiency.

KEY ABBREVIATIONS/SYMBOLS

APC	American Plastics Council
Btu	British Thermal Units
ºC	Degrees Celsius
CDD	Cooling Degree Days
CFC	ChloroFluoroCarbons
CO_2	Carbon Dioxide
Cu ft	Cubic Foot
DOE	Department of Energy
EPA	Environmental Protection Agency
EIA	Energy Information Administration
ºF	Degrees Fahrenheit
FCCC	Framework Convention on Climate Change
GHG	Greenhouse Gas
HCFC	HydroChloroFluoroCarbons
HDD	Heating Degree Days
HFC	HydroFluoroCarbons
kWh	Kilowatt-Hours
Lb	Pounds
MDI	Methylenediphenyl Isocyanate
Mil Btu	Million British Thermal Units
NAHB	National Association of Home Builders
PIR	Polyisocyanurate
Quad	1 Quad = 10^{15} Btu
sq ft	Square Foot
VOC	Volatile Organic Carbon
XEPS	Expanded Polystyrene Foam

LIST OF SOURCES

Electricity Grid

Monthly Energy Review. Energy Information Administration. U.S. Department of Energy. March, 1998.

Electricity Supply and Demand 1997-2006. North American Electric Reliability Council. 1998.

Electric Power Annual 1997, Volume II. EIA, Office of Coal, Nuclear, Electric and Alternate Fuels. 1998.

Franklin Associates estimate.

Polyisocyanurate Precursors and Polystyrene Resin

Data collected from American Plastics Council for polyol, MDI and general purpose polystyrene resin (GPPS).

HCFC-141b (blowing agent)

Discussions with Dr. Richard Crooker of Elf Atochem. October, 1998.

1992 Census of Mineral Industries. SIC 1422. U.S. Department of Commerce. Bureau of the Census. 1992. Tables 7b and 6a.

Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources. Fifth Edition. U.S. Environmental Protection Agency. July 1995.

Franklin Associates estimate.

Personal communication between Franklin Associates, Ltd. and G. Hancock, Ladrido Drilling. Midland, Texas. February 1989.

Personal communication between Franklin Associates, Ltd. and L. Gobson. U.S. Environmental Protection Agency, NPDES Permits Branch. Dallas, Texas.

U.S. Environmental Protection Agency. **Screening Report, Crude Oil and Natural Gas Production Processes.** EPA Report No. R2-73-285. December 1982.

Electricity Supply and Demand 1994-2004. North American Electric Reliability Council. June 1995.

Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources. Fifth Edition. U.S. Environmental Protection Agency. July 1995.

Hunt, R.G., et al. **Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives.** Volume II. Midwest Research Institute, for U.S. Environmental Protection Agency. Report SW-91-c. 1974.

Collines, G. "Oil and Gas Wells - Potential Pollutants of the Environment." **Journal Water Pollution Control Federation.** December 1972.

Brine Disposal Treatment Practices Relating to the Oil Production Industry. United States Environmental Protection Agency. Prepared by the University of Oklahoma Research Institute. EPA Report No. 660-1-74-037. May 1974.

United States Environmental Protection Agency. Office of Solid Waste. **Report to Congress, Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy.** Volume 1. EPA/530-SW-88-003. December 1987.

Natural Gas Annual 1994, Volume 2. EIA, Office of Oil and Gas. November 1995.

Natural Gas 1994, Issues and Trends. EIA, Office of Oil and Gas. July 1994.

Emission of Greenhouse Gases in the United States, 1987 - 1992. Energy Information Administration, 1994?

North American Transportation. Bureau of Transportation Statistics. U.S. Department of Transportation. May 1994

U.S. Department of Commerce. **Census of Mineral Industries, 1982.** "Oil and Gas Field Operations." SIC 1311.

U.S. Department of Energy. **Industrial Energy Efficiency Improvement Program.** Annual Report to the Congress and the President, 1972-1985.

Craft, B.C., W.R. Holden, and E.D. Graves, Jr. **Well Design: Drilling and Production.** Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 1962.

"Oil and Gas Field Operations." **Census of Mineral Industries.** SIC 1311. 1975.

Personal communication between Franklin Associates, Ltd. and the Texas Railroad Commission. January 1989.

U.S. Department of Energy, Energy Information Administration. **Annual Energy Outlook, 1987 with Projections to 2000.** March 1988.

U.S. Department of Energy. **1987 Annual Environmental Monitoring Report for the Strategic Petroleum Reserve.** Document # D506-01728-09. April 1988.

Energy and Materials Flows In Petroleum Refining, ANL/CNSV-10. Argonne National Laboratory. February 1981.

Hydrocarbon Processing- Refining Handbook '92. November, 1992. Volume 71. Number 11.

1989 Industrial Process Heating Energy Analysis. Gas Research Institute. May, 1991.

Gary, James H. and Glenn E. Handwerk. **Petroleum Refining- Technology and Economics**. Marcel Dekker, Inc. 1984.

Hydrocarbon Processing. Refining Handbook. November 1992 and 1996.

Riegel's Handbook of Industrial Chemistry. Ninth Edition. Edited by James A. Kent. Van Nostrand Reinhold. New York. 1992.

Manufacturing Energy Consumption Survey, Consumption of Energy 1988. DOE/EIA-0512(88). Energy Information Administration. May, 1991.

AMOCO/U.S. EPA Pollution Prevention Project, Yorktown Refinery, Refinery Release Inventory. PB92-228550. United States Environmental Protection Agency. June, 1992.

Petroleum Industry Environmental Performance 1992. American Petroleum Institute (API) Washington, D.C. pp. 10-12.

AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants. U.S. EPA. Office of Air Quality. PB90-207242. March, 1990. pp. 136-137.

Environmental Consequences of, and Control Processes for Energy Technologies. Argonne National Laboratories. Noyes Data Corp. 1990.

Gary, James H. and Glenn E. Handwerk**. Petroleum Refining, Technology, and Economics**. 2^{nd} Ed. 1984.

Data developed by Franklin Associates, Ltd., based on confidential information supplied by industrial sources. 1992.

Encyclopedia of Chemical Technology. Kirk-Othmer. Volume 11, Fourth Edition.1993.

Data developed by Franklin Associates, Ltd., based on confidential information supplied by industrial sources. 1989-1992.

U.S. Department of the Interior, Bureau of Mines. **Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4—Energy Data and Flowsheets, etc.).** Prepared by Battelle Columbus Laboratories. Washington, DC. June 1975.

Data compiled by Franklin Associates, Ltd. based on contact with confidential sources. 1992-1993.

North American Chlor-Alkali Industry Plants and Production Data Report - 1995. Pamphlet 10. The Chlorine Institute, Inc. April, 1996.

Radian Corp. **Polymer Manufacturing**. Noyes Data Corp. 1986.

Data compiled by Franklin Associates, Ltd. based on contact with confidential sources. 1990-1992.

<u>Polyisocyanurate foam insulation production</u>

Discussions with Brook Boynton, ICI Polyurethanes. January, 1999.

Discussions with Joe Hagan, Celotex Corporation. January 1999.

Data developed by Franklin Associates, Ltd., based on confidential information supplied by industrial sources. 1991.

Franklin Associates estimate.

<u>Extruded expanded polystyrene foam insulation production</u>

Discussions with Gary Chu, Dow Canada. March, 1999.

Discussions with Brad Gougeon, Dow US. March, 1999.

<u>Heat Transfer Calculations</u>

Hunt, R.G., et al. **Plastics Used in Building Insulation.** Franklin Associates. 1979.

Franklin Associates estimate.

Discussions with Dusty Stillman, Air Conditioning and Refrigeration Institute. January, 1999.

Gas Appliance Manufacturer's Association website www.gamanet.org.

Kreith, F., **Principles of Heat Transfer, 3rd Edition.** Harper & Row Publishers. 1973.

Discussions with Dr. Richard Crooker of Elf Atochem. October, 1998.

U.S. Housing Data

U.S. Department of Commerce, **Statistical Abstract of the United States 1998.**

Discussions with Will Biddle, National Association of Home Builders. January, 1999.

Franklin Associates estimate.

Canadian Housing /Population Data

Statistics Canada, 1996, CANSIM, Matrix 6231.

Statistics Canada, 1996, Cat. No. 93-357-XPB.

Discussions with Ms. Madeline McBride, Office of Energy Efficiency, Natural Resources Canada, April 1999.

Natural Resources Canada, Office of Energy Efficiency, **Energy Efficiency Trends in Canada 1990 to 1996**, June, 1998.

Discussions with Mr. Sylvain Blais, Natural Resources Canada, February - April, 2000.

Franklin Associates estimate.

APPENDIX A

SAMPLE CALCULATIONS

Explanation of Energy Calculations for Table 4

Energy savings = Energy use at R_{14} – Energy use at R_{XEPS} or
Energy use at R_{14} – Energy use at R_{PIR}

Annual Energy Use For Each Zone:

Energy savings from heating + Energy savings from cooling

The energy calculations depend upon the heating degree-day, or HDD. HDD is obtained each day by finding the average temperature, such as taking the high and low temperature of the day, and subtracting it from 65ºF. For example, if the high temp is 70 ºF and the low temp is 52 ºF, the average is 61 ºF, and there will be 4 HDD. The annual HDD is the sum of the HDDs for each day of the year.

The standard heat flow equation is $Q = A(\Delta T)/R$. If the total heat flow were desired for one hour, the HDD for that one day would be used for the ΔT . The equation as it stands using standard units is for the heat flow per hour. If the heat flow is desired for one day, a factor of 24 needs to be multiplied times the value calculated for the heat flow for 24 hours. Thus, the equation becomes $Q = 24A(HDD)/R$, where HDD is the "heating degree day" for that day.

If the heat is desired for an entire year, the daily heat flow needs to be scaled up for the 365 days. In other words, the daily heat flow must be calculated for each day, and the results must be summed. Because the area and R are the same for each day, these can be factored out of the summation, leaving the summation of the daily HDD values, which is just the annual HDD value.

The Annual Energy Savings From Heating Is:

WALL AREA* HDD*24 ÷ R

- wall area is 1791 ft^2
- HDD (heating degree days) is annual sum of (65 °F – Average Temperature_{day}), (note: a day whose average temperature is above 65 °F contributes zero to HDD)
- R is thermal resistivity, which is the inverse of an easier to grasp K-value (thermal conductivity). In this study, the foam insulation is assumed to have a thickness of 5/8 inch.

The cooling degree days are also used in the same way. They also use the 65 °F temperature as a standard for cooling.

Total Energy savings = $\sum_{\text{zone 1-5}}$ Energy savings * no. of house at each Zone

Explanation of Greenhouse Gas values for Table 4:

CO_2 equivalents = LCI air emission value * Global Warming Potential
= CO_2 *1 + CH_4 *21 + N_2O*310 + HCFC141b*630

Explanation Of Payback Calculation For All Tables, Using Table 5 As An Example

The total blowing agent in panels per house is 7.56 lb of HCFC 142b and 8.37 lb of HCFC 141b. To calculate CO_2 equivalents:

7.56 lb X 2,000 = 15,120 lb CO_2 equivalents
+8.37 lb X 630 = 5,270 lb CO_2 equivalents
20,390 lb CO_2 equivalents

The example spreadsheet below shows that the three starting values are the original GHG in the panels (illustrated above), the GHG generated by plastics manufacture (from table 5), and the GHG savings from annual energy savings (from table 5).

The first line of the spreadsheet first calculates the emissions from the panels during the first year, which is 1.5% of 20,390 = 305.85. The amount remaining in the panel is 20,390-306=20,804. The net savings is 505-306=199 lb. In the next row, the amount of emissions from panels is 1.5% of the previous years “remaining in panel.” Cumulative columns are summed to keep track of totals. The payback occurs when the cumulative savings equals the amount of GHG emitted during manufacture. Scanning down the right column shows that this happens during year 12, and an interpolation algorithm shows that it is 12.5 years.

SPREADSHEET TO CALCULATE PAYBACK BY NEW METHOD
(single house, US Average)

original GHG Equiv in panel	20,390	lb
GHG Eqiv from Plastics	2,803	lb
Annual GHG savings from energy	505	lb

end of year	emissions from panel	cumulative emissisons	remaining in panel	net savings (ener-emiss)	cumulative net savings	target value 2,803
1	305.85	306	20,084	199	199	
2	301.26225	607	19,783	204	403	
3	296.74332	904	19,486	208	611	
4	292.29217	1,196	19,194	213	824	
5	287.90778	1,484	18,906	217	1,041	
6	283.58917	1,768	18,622	221	1,262	
7	279.33533	2,047	18,343	226	1,488	
8	275.1453	2,322	18,068	230	1,718	
9	271.01812	2,593	17,797	234	1,952	
10	266.95285	2,860	17,530	238	2,190	
11	262.94856	3,123	17,267	242	2,432	interpolation
12	259.00433	3,382	17,008	246	2,678	0.50043539
13	255.11926	3,637	16,753	250	2,928	12.5
14	251.29247	3,888	16,502	254	3,182	

APPENDIX B

CANADIAN TABLES IN METRIC UNITS

The following are unit revisions of Tables 6, 7 and 8. The revisions consist of converting from U.S. units to SI metric units. In Table 6, heating degree days (HDD) are converted from ºF to ºC. In Tables 7 and 8, energy is converted from Btu to Joules and pounds to kg.

TABLE 6 (Metric)

CLIMATE AND HOUSING STATISTICS BY PROVINCES

Province	Heating Degree Days (Based on °C) (Annual)	1996 Occupied Housing (thousands)
Ontario	3905	3951
Quebec	4701	2849
British Columbia	3017	1434
Alberta	5518	984
Manitoba	5874	421
Saskatchewan	5855	376
Nova Scotia	4421	345
News Brunswick	4815	273
New Foundland	4865	187
Prince Edward Island	4748	49
NW Territories	8477	19
Yukon Territory	6947	12
Total Occupied Housing		10,900
Weighted Average HDD	4,356	

Source: Environment Canada and Statistics Canada

Table 7 (Metric Units)

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING FOAM SHEATHING ON EXTERIOR WALLS OF ALL CANADIAN OCCUPIED HOUSES (ASSUMING A TYPICAL* HOUSE)

	Foam Sheathing**
Energy Savings (GJ)	
Annual	1.27E+08
30 years	3.82E+09
Plastics Life Cycle Energy	5.33E+07
Energy Payback (years)	0.42
Greenhouse Gases (CO2 equivalents in kilograms)	
Generated From Plastics	8.77E+09
Avoided From Energy Savings	
Annual	3.89E+09
30 years	1.17E+11
Greenhouse Gas Payback (years)* **	3.0

* A typical house has the current (1998) US market split of foam sheathing: 60% extruded polystyrene and 40% polyisocyanurate
** Calculations made using 5/8" thick sheathing and R values/inch of 4.8 for XEPS and 5.8 for PIR.
*** See text for explanation (p. 9 and Appendix A).

Source: Franklin Associates

Table 8 (Metric Units)

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING FOAM SHEATHING ON EXTERIOR WALLS OF A TYPICAL CANADIAN HOUSE*

Energy Savings (GJ)	Ont	Que	BC	Alb	Man	Ska	NS	NB	NF	PEI	NwT	YuT	CAN Avg
Natural Gas	0.67	0.81	0.52	0.95	1.01	1.00	0.76	0.83	0.83	0.81	1.45	1.19	0.75
Petroleum	0.24	0.29	0.19	0.35	0.37	0.37	0.28	0.30	0.30	0.30	0.53	0.43	0.27
Coal	2.90	3.49	2.24	4.09	4.36	4.34	3.28	3.57	3.61	3.52	6.29	5.15	3.23
Hydropower	2.88	3.47	2.23	4.08	4.34	4.32	3.27	3.56	3.59	3.51	6.26	5.13	3.22
Nuclear	3.72	4.48	2.88	5.26	5.60	5.58	4.21	4.59	4.64	4.53	8.08	6.62	4.15
Other	0.06	0.08	0.05	0.09	0.09	0.09	0.07	0.08	0.08	0.08	0.14	0.11	0.07
Total Annual Energy Savings	10.48	12.62	8.10	14.81	15.76	15.71	11.87	12.92	13.06	12.74	22.75	18.64	11.69
Plastics Life Cycle Energy	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89
Energy Payback (years)	0.47	0.39	0.60	0.33	0.31	0.31	0.41	0.38	0.37	0.38	0.21	0.26	0.42
Greenhouse Gases													
(CO2 equivalents in kilograms)													
Generated From Plastics													
Carbon Dioxide	153	153	153	153	153	153	153	153	153	153	153	153	153
Methane	29	29	29	29	29	29	29	29	29	29	29	29	29
Nitrous Oxide	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
HCFC 142b	447	447	447	447	447	447	447	447	447	447	447	447	447
HCFC 141b	174	174	174	174	174	174	174	174	174	174	174	174	174
Total CO2 Equivalents	804	804	804	804	804	804	804	804	804	804	804	804	804
Avoided From Annual Energy Savings													
Carbon Dioxide	305	368	236	431	459	458	346	376	380	371	663	543	341
Methane	13.8	16.6	10.6	19.5	20.7	20.6	15.6	17.0	17.1	16.7	29.9	24.5	15.4
Nitrous Oxide	0.76	0.92	0.59	1.08	1.15	1.14	0.86	0.94	0.95	0.93	1.65	1.36	0.85
HCFC 142b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HCFC 141b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total CO2 Equivalents	320	385	247	452	481	480	362	394	398	389	694	569	357
Greenhouse Gas Payback (years)	3.5	2.7	5.1	2.2	2.1	2.1	3.0	2.6	2.6	2.7	1.3	1.7	3.0

* A typical house has the current (1998) US market split of foam sheathing:
60% extruded polystyrene and 40% polyisocyanurate

** See text for calculation method (p. 9 and Appendix A).