Extruded Polystyrene Foam Insulation: a Life Cycle Assessment for Residential and Commercial Construction Applications

Who is Owens Corning?

Founded in 1938, Owens Corning is an industry leader in glass fiber and foam insulation, roofing and asphalt products, glass fiber composite materials and manufactured stone veneer. It currently employs more than 16,000 people in 26 countries. Owens Corning has been a Fortune 500 company for 53 consecutive years.

What is Owens Corning's Commitment to the Environment?

In addition to its environmental compliance and management programs, Owens Corning is committed to sustainability as a balance of economic growth, environmental stewardship and social progress, including addressing global warming. Owens Corning is committed to achieving reductions in greenhouse gas (GHG) emissions in several ways:

1) by manufacturing products which, when put to use, significantly, reduce the demand for energy and its related emissions in the global community
2) by reducing the amount of energy and resources required to manufacture those products
3) by employing economically justifiable strategies that limit their emissions from its manufacturing processes.

During their installed life, all of the insulation products that Owens Corning produces each year result in the prevention of 1 billion tons of equivalent GHG emissions.[1] The extruded polystyrene ("XPS") foam insulation products produced each year of operation at the Gresham plant would save approximately 1.3 million tons of equivalent GHG emissions during their installed life. Internally, Owens Corning has established a 10-year goal to reduce the amount of energy required to make all of its products by 25 percent from 2002 levels and is committed to reduce GHG emissions by 30 percent for the same period. Owens Corning is also a member of the EPA Climate Leaders program and will be setting additional goals for the future.

Why Is Insulation Critical to Obtaining Reductions in GHG Emissions?

According to the U.S. Department of Energy, heating and cooling buildings account for 40 percent of our nation's energy consumption and generate 43 percent of the country's GHG emissions. Insulation reduces energy consumption in existing homes by 48 percent and by more than 30 percent in commercial buildings. Adding more insulation in new and existing buildings represents one of the best opportunities to save energy and reduce GHG emissions, and is the single most cost-effective GHG abatement measure available today.[2]

XPS foam insulation has many unique qualities that set it apart from other forms of insulation and allows it to be used in specific applications unsuited to other types of insulation. When applied to sidewalls, XPS creates a thermal envelope around

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[1] Sustainability at Owens Corning, March 2007, pub # 10002094-B.

[2] McKinsey & Company Report on Greenhouse Gas Reduction, 2007

residential and commercial buildings which eliminates energy loss in framing. Because it is resistant to moisture, it can be applied to building foundations and basements below grade. It reduces the potential for mold and mildew growth by eliminating condensation, and results in improved indoor air quality. Additionally, it is the product of choice in commercial roofing applications for green and cool roofs. With its closed cell structure, it is durable, giving it the ability to withstand significant loads and allowing it to maintain its integrity and insulating quality year after year.

What is XPS Foam?

Extruded polystyrene (XPS) is a plastic foam insulation made from polystyrene resin and a blowing agent. Its insulating power comes from the closed cell structure and the blowing agent used to produce it.

Moisture can come in contact with all types of insulation, not only during construction, but throughout the life of the building. If absorbed, it will significantly reduce the thermal efficiency (R-value) of the insulation. The closed cell structure and lack of voids in XPS helps the foam to resist moisture penetration better than other types of insulating materials. Because XPS foam is essentially a plastic material, it will not corrode, rot or support the growth of mold or mildew. It is resistant to microorganisms found in soil and provides no nutrient value to vermin.

What is the Production Process at Gresham?

The Gresham plant will contain one polystyrene foam board extrusion line and associated utilities, raw material handling, finishing, fabricating, grinding and polystyrene reclaiming equipment. It will produce approximately 120 million board feet of foam insulation annually. The manufacturing process consists of extruding molten polystyrene polymer which has been injected with a blowing agent and mixed with other additives. The blowing agent expands within closed cells in a vacuum chamber to produce a basic board stock which is cooled to a level suitable for further fabrication. It is then trimmed, cut, shaped and packaged.

The scrap foam from fabrication produced at Gresham will be ground up, melted and converted back into a solid polystyrene resin which can be reused in the manufacturing process to produce new XPS foam insulation. The plant will be designed to produce virtually no waste from its manufacturing operation, thus preserving landfill space. It will also be able to recycle scrap foam from other manufacturers by converting it to a solid polystyrene resin and then using that material to produce foam insulation board. This will prevent that waste from going to landfill.

What Makes the Gresham Plant Unique?

The Gresham plant will be the first XPS foam manufacturing plant in the U.S. to use a blowing agent which conforms to the Montreal Protocol. In advance of regulatory requirements, this plant will be able to produce the same high-quality insulating foam board product currently produced at other facilities in the U.S., with significantly reduced greenhouse gas emissions and no ozone-depleting emissions.

The Gresham plant will produce an additional 120 million board-feet of foam board insulation annually. This additional supply of foam board insulation will allow for the insulation of up to 15,000 homes and 2,000 commercial buildings per year that would not otherwise have been able to be insulated in the unique ways that are capable with this product (e.g. providing a more complete thermal envelope and use in moisture-prevalent applications).

The GHG emission profile of the plant will also be reduced because 100 percent of its energy needs will be purchased from renewable sources. Further reductions will be obtained by retrofitting the building using green building standards which will conform to LEED certification.[3]

Introduction to the Life Cycle Assessment of XPS Foam

In late 2006, Owens Corning commissioned environmental firms Four Elements Consulting, LLC, located in Portland, Oregon, and Franklin Associates, Ltd. to evaluate the life cycle environmental and cost impacts of producing, installing and disposing of XPS foam insulation with a blowing agent that complies with the Montreal Protocol. Additionally, they assessed the benefits of XPS when used to insulate buildings over a 30-year period. Residential and commercial buildings in three cities were analyzed, representing three different climate zones. Emphasis was placed on Owens Corning's Gresham manufacturing facility and the product that will be installed in residential and commercial buildings in Oregon and the Western U.S. for a lifetime of 30 years.

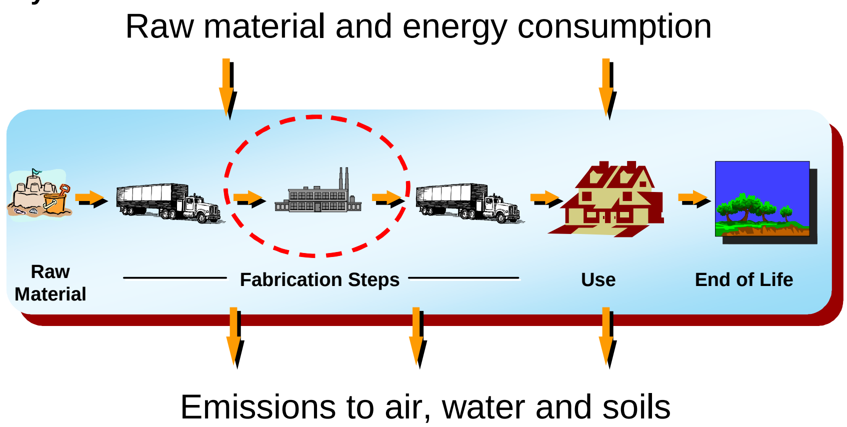
The study has been designed to present the system and individual component impacts of foam production and blowing agent dispersion and the overall environmental benefits that the insulation provides in a transparent manner. As such, this summary provides an overview of the environmental results of the study, aiming to inform interested parties on the environmental impacts and benefits of Owens Corning XPS foam boards produced at Gresham.

LCA Approach

This study was performed using Life Cycle Assessment (LCA). LCA is a tool for the systematic evaluation of the environmental impacts of a product through all stages of its life cycle, which include extraction of raw materials, manufacturing, transport and use of products, and end-of-life management (e.g., recycling, reuse, and/or disposal), as shown in Figure 1.

[3] This LCA study does not currently take into account the benefits of these activities.

Figure 1. Life Cycle Assessment Defined

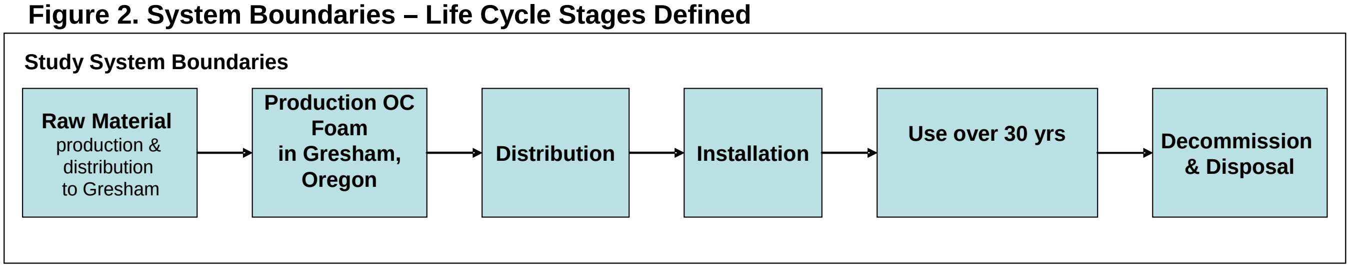


LCA's holistic "systems assessment" approach is useful in identifying the environmental trade-offs inherent in any product system. This study adheres to the International Organization for Standardization's (ISO's) 14040 series of standards for LCA[4] and American Society for Testing and Materials' (ASTM) LCA standard on buildings, ASTM E 1991.[5] It has been third-party reviewed by Dr. Gregory A. Norris, president of Sylvatica consulting firm and visiting professor at the Harvard School of Public Health.

LCA Scope

The scope of this project includes analysis of the life cycle environmental impacts for XPS foam that will be produced at the Owens Corning facility in Gresham, Oregon, its lifetime use, and end-of-life scenario. Figure 2 presents an overview of the project system boundaries using the residential application as an example.

Figure 2. System Boundaries – Life Cycle Stages Defined



Each life cycle stage has been defined as follows:

1. Raw materials and foam board production. Examples of production inputs include resin, blowing agent, process energy, and packaging materials. Outputs include

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[4] ISO 14040:1997(E), the International Standard of the International Standardization Organization, Environmental management. Life cycle assessment. Principles and framework; ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

[5] ASTM International, E1991-05 Standard Guide for Environmental Life Cycle Assessment (LCA) of Building Materials/Products.

packaged XPS insulation products, process solid wastes, and releases to air, including blowing agents. Sourcing and transport of supplies to Gresham is also included.

2. Distribution. Distribution includes transportation of the foam board from Gresham to each building location.

3. Installation. Inputs to installation include insulation and supplementary materials used to install the XPS foam. Outputs include wastes such as packaging materials and installation scrap and the associated blowing agent releases to air.

4. Use. Inputs for the use phase include fuel use and cost for heating and cooling of each insulated building during a 30-year period. Outputs consist largely of fuel-related emissions and wastes associated with energy use for heating and cooling. Blowing agent releases during 30 years are included. The US Life Cycle Inventory database[6] Western electricity grid has been applied for the electricity during use phase.

5. End of life. This phase includes insulation removal, transportation, and assumes that the insulation will be sent to a landfill at the end of a 30-year life.

Building criteria used in the study:
Insulation requirements for defined building designs were determined by Owens Corning based on International Code Council's 2006 International Energy Conservation Code (IECC) prescriptive criteria for residential structures, and ASHRAE Standard 90.1-2004 for commercial buildings. Because the use-phase performance of a building is the result of the complete insulation system installed in the building, the energy consumption use-phase calculations take into account the R value of all insulation in the buildings (e.g., foam board plus supplemental fiberglass insulation) required to meet code. Any calculation of savings in this report is based solely on the savings due to the foam portion of the insulating system.

LCA Modeling Tools Used

The LCA models for the process steps in the life cycle of XPS insulation were constructed in SimaPro 7, a commercial LCA software product.[7] This software contains U.S. and European databases on a wide variety of energy, transportation models, materials, and processes in addition to an assortment of European- and U.S.-developed impact assessment methodologies.

The energy used by the residential buildings was calculated with the Home Energy Saver tool developed by the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory (LBNL).[8] The energy used by the commercial buildings was calculated with the DOE-2 building energy-use simulation program via eQUEST® (Quick Energy Simulation Tool), its user-friendly interface.[9]

[6] The National Renewable Energy Laboratory-developed U.S. Life Cycle Inventory (LCI) Database contains critically reviewed LCI data which are used extensively by LCA experts for U.S. data on energy, materials, and transportation.

[7] PRé Consultants: *SimaPro 7.0 LCA Software*. 2006. The Netherlands.

[8] Found at: http://hes.lbl.gov/

[9] Found at: http://www.doe2.com/

LCA Results

Gresham Facility Analysis

Cradle-to-gate environmental impacts are presented for XPS foam produced at the Gresham facility in Table 1. “Cradle-to-gate” encompasses the environmental inputs and outputs that go back to the production of the raw materials and the energy used to produce the foam (the “cradle”), through to the gate of the facility, i.e., the point at which the foam is packaged and ready for distribution to the customer. The “Environmental Impact Absolute #” column in Table 1 quantifies each impact per 1000 board-feet produced in the given category and unit. Each subsequent column provides the percent of that impact of the absolute number. Each column is described in more detail below the table.

Table 1. Gresham Facility Environmental Impacts – Per 1000 Board-Feet of Foam

Env. Impact Category	Unit	Env. Impact Absolute #	Raw Materials Production	Transport -Raw Materials to Gresham	Gresham Manuf'ing Energy	Blowing Agent Emissions	Other Direct "Releases"	Packaging Materials Production
Global Warming	ton CO2 eq.	**2.25**	35%	0.6%	0.8%	63%	n/a	0.1%
Acidification	ton H+ moles eq.	**0.2**	90%	6%	4%	n/a	n/a	0.2%
Smog Formation	ton NOx eq.	**9.8 E-4**	64%	33%	3%	n/a	n/a	0.3%
Criteria Air Pollutants	ton PM2.5 eq.	**1.3 E-3**	86%	10%	4%	n/a	0.1%	0.3%
Total Waste	ton	**1.3 E-2**	92%	1.4%	6.0%	n/a	0.1%	0.4%
Fuel Energy	1000 MJ	**3.82**	84%	4.4%	11%	n/a	n/a	0.6%

Note: percentages may not add to 100% due to rounding.

Raw Materials Production encompasses the upstream production of the blowing agents, polystyrene resin, and the other materials that make up the foam. For all categories, except Global Warming Potential (GWP, which measures GHG emissions), the upstream material impacts make up at least two-thirds or more of total XPS production.

Transport of Raw Materials to Gresham quantifies the truck, train, and ship transport of the raw materials to Gresham. About a third of the smog potential, representing diesel and other transportation fuel-related emissions, comes from transporting raw materials to the plant.

Gresham Manufacturing Energy represents the production and combustion of the natural gas used at Gresham, as well as the production of fuels used for electricity and electricity generation at a utility plant. For Gresham, an Oregon grid mix was used. Overall, plant energy contributes very little to all of the categories in the table. The LCA does not account for the positive effect of the plant’s decision to use 100 percent renewable energy.

Blowing agent emissions are applicable only for the GWP category, and make up 63 percent of the total GWP at the plant. This is in large part due to the blowing agent’s carbon dioxide equivalency (CO_2-eq.), which has a CO_2-eq. value of two orders of magnitude higher than CO_2.[10] This blowing agent is a significant improvement over the material currently used at other XPS production facilities in the U.S. and that will

[10] CO_2 has an equivalent value of 1.

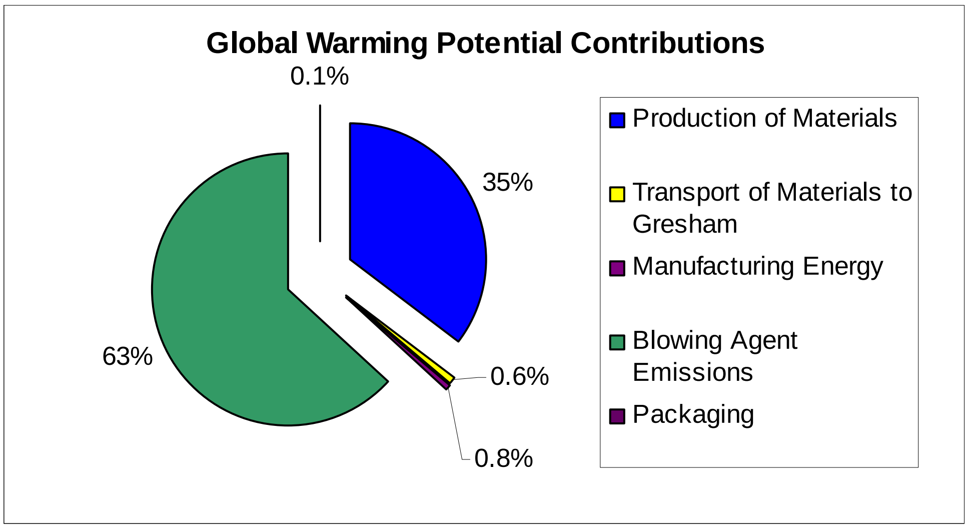
continue to be used until 2010. Those other blowing agents have a CO_2-eq. value of three orders of magnitude higher than CO2 and contain ozone-depleting agents.

Other direct releases that were captured in the environmental categories include particulate matter and solid waste, in the "criteria air pollutants" and "total waste" categories, respectively.

Packaging of the foam boards, which includes the production of the materials used to package foam for shipment, makes up less than one percent of the total cradle-to-gate plant impacts.

Figure 3 depicts the GWP category in Table 1, i.e., the relative contributions of GWP to the various activities associated with the production of XPS at Gresham.

Figure 3. Gresham Facility GWP Contributions



Greenhouse Gas Savings Using Foam

Table 2 presents the GWP in CO_2-eq. tons associated with heating and cooling a single residential or commercial building over 30 years, with and without the use of XPS foam. The structure is modeled as having foam plus fiberglass insulation, while the no-foam structure has only fiberglass insulation. As demonstrated in the table, without XPS foam, the GWP after 30 years in the building is more than 20 percent higher for both types of buildings.

Table 2. Use Phase: GHG Savings With and Without Foam Insulation

	Structure with Foam	Structure without Foam	Net Savings (with foam)	With Foam % Lower
Residential GWP (ton CO2-eq.)	354	457	103	23%
Commercial GWP (ton CO2-eq.)	1051	1329	277	21%

Foam as Applied to its Overall Life Cycle

The previous sections presented environmental impacts of the production of XPS foam and the savings in GHG emissions that the foam provides over its lifetime, respectively. We focus now on the full life cycle, or cradle-to-grave environmental impacts of XPS foam, which includes XPS foam sourced by and produced at the Gresham facility, installed and used in the market, and disposed of at the end of a 30-year life. Overall environmental life cycle results for the residential building are provided in Table 3 and Figure 4 below. The "Environmental Impact Absolute #" column provides the absolute number in the given unit and category, and each subsequent column provides the percent of each life cycle stage to the total.

The most notable of these results is that the vast majority of the impacts are associated with the use phase of the building, i.e., the production of energy required to heat and cool this to-code home for 30 years,[11,12] further emphasizing the impact of the building use energy itself.

Also, recall from Table 1 that blowing agent releases made up more than 60 percent of the Gresham plant's cradle-to-gate GWP impacts. In the complete cradle-to-grave life cycle perspective, this now amounts to approximately one and one-half percent of the life cycle impacts.

<u>Residential</u>

Table 3. XPS Foam Life Cycle – Environmental Results for a To-Code Insulated Residential Building over 30 Years

Environmental Impact Category	Unit	Env. Impact Absolute #	Life Cycle Stages				
			Production	Distribution	Installation	Use Phase	End-of-Life
Global Warming Potential	ton CO_2 eq.	**377**	2.5%	0%	0.2%	95.6%	1.7%
Acidification	ton H^+ moles eq.	**159**	0.6%	0%	0%	99%	0%
Smog Formation	ton NO_x eq.	**0.7**	0.6%	0%	0%	99%	0%
Criteria Air Pollutants	ton $PM_{2.5}$ eq.	**1.0**	0.6%	0%	0%	99%	0%
Total Waste	ton	**27**	0.2%	0%	0.1%	99%	1.0%
Total Fuel Energy	1000 MJ	**5146**	0.3%	0%	0.0%	100%	0%

<u>Notes</u>:
0% means less than 0.1%
Percentages may not add to 100% due to rounding.

[11] As a reminder, the use phase energy takes into account the building with foam and fiberglass insulation.

[12] "Use Phase" is a term of art in LCA that signifies the life cycle stage referring to the functional lifetime of the product being studied.

Figure 4. Residential Building Life Cycle Stage Breakdown

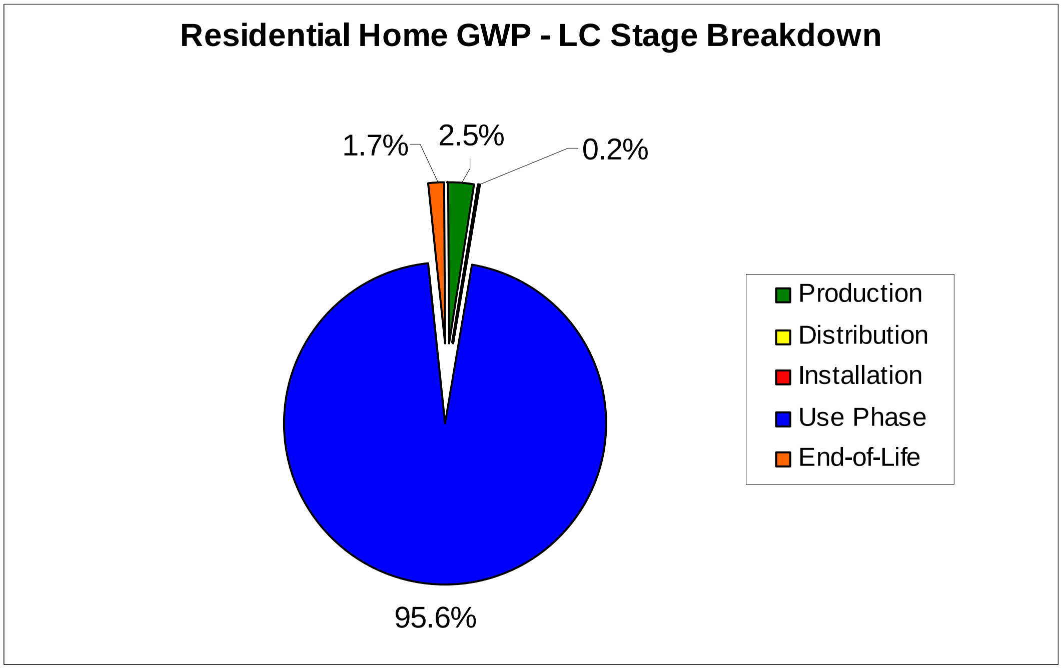
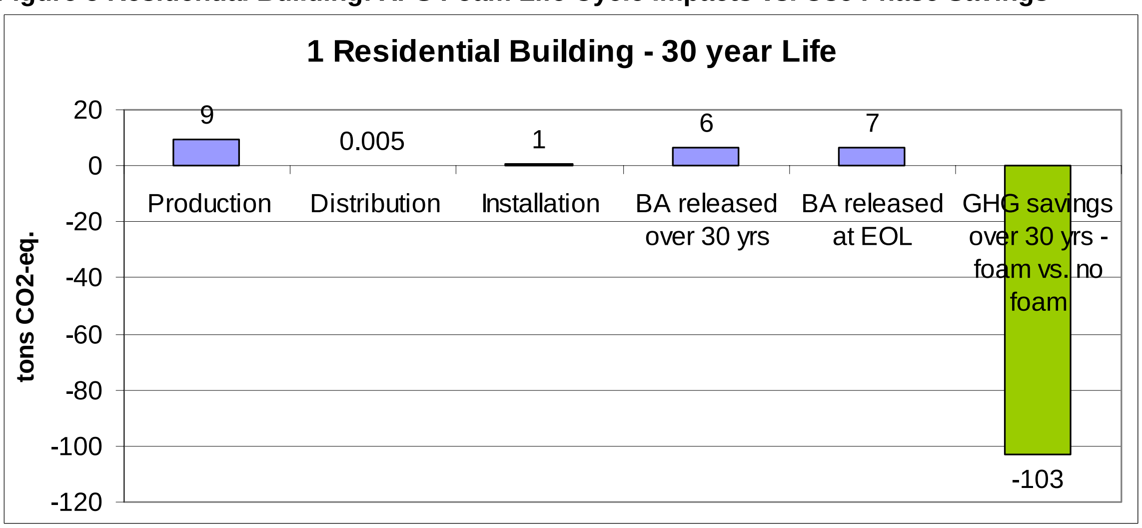


Table 2 illustrates that using foam insulation lowers the GHG emissions due to heating and cooling a home by more than 20 percent. Figure 5 demonstrates that this *savings* during 30 years greatly outweighs the foam's impact from production, installation, and blowing agent dispersion during the installed lifetime and at end of life.

Figure 5 Residential Building: XPS Foam Life Cycle Impacts vs. Use Phase Savings



Commercial

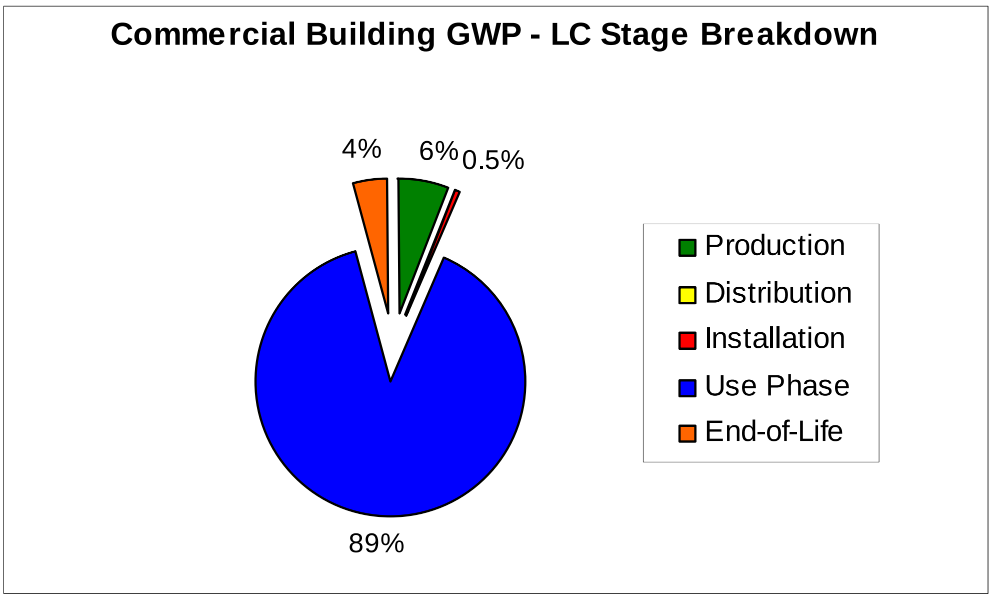
The following table and figures present the overall cradle-to-grave data for XPS used in the commercial building as well as its net savings when using foam vs. no foam at all.

Table 4. XPS Foam Life Cycle - Environmental Results for a To-Code[13] Commercial Building for 30 Years

Environmental Impact Category	Unit	Env. Impact Absolute #	Life Cycle Stages				
			Production	Distribution	Installation	Use Phase	End-of-Life
Global Warming Potential	ton CO2 eq.	**1238**	6%	0%	0.5%	89%	4%
Acidification	ton H+ moles eq.	**474**	2%	0%	0%	98%	0%
Smog Formation	ton NOx eq.	**1.5**	2%	0.2%	0%	98%	0%
Criteria Air Pollutants	ton PM2.5 eq.	**2.7**	2%	0%	0%	98%	0%
Total Waste	ton	**47**	1%	0%	0.3%	94%	5%
Total Fuel Energy	1000 MJ	**16074**	1%	0%	0%	99%	0%

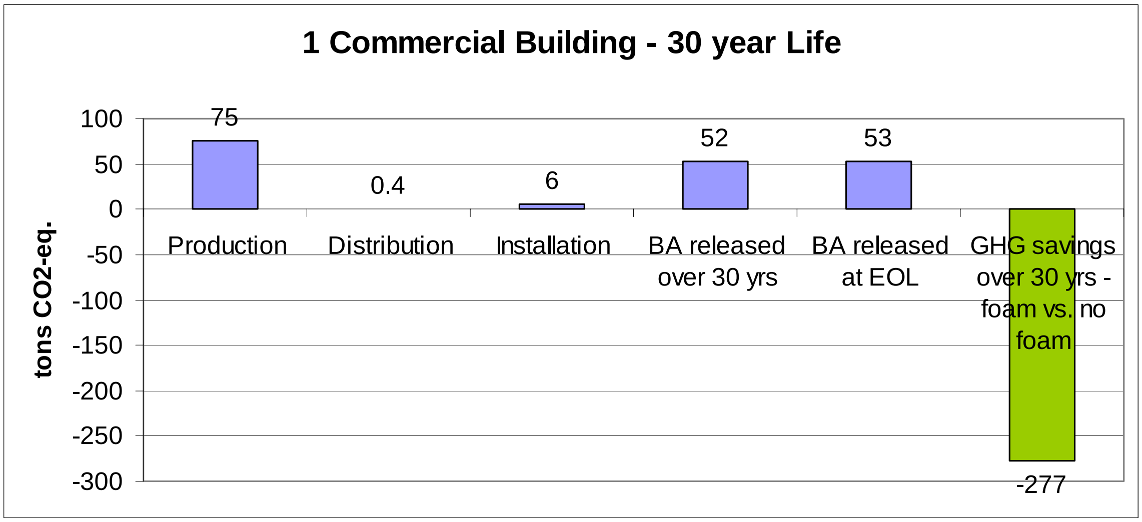
Notes:
0% means less than 0.1%
Percentages may not add to 100% due to rounding.

Figure 6. Commercial Building Life Cycle Stage Breakdown



[13] The ASHRAE Standard 90.1-2004 Climate Zone was used for Commercial building applications.

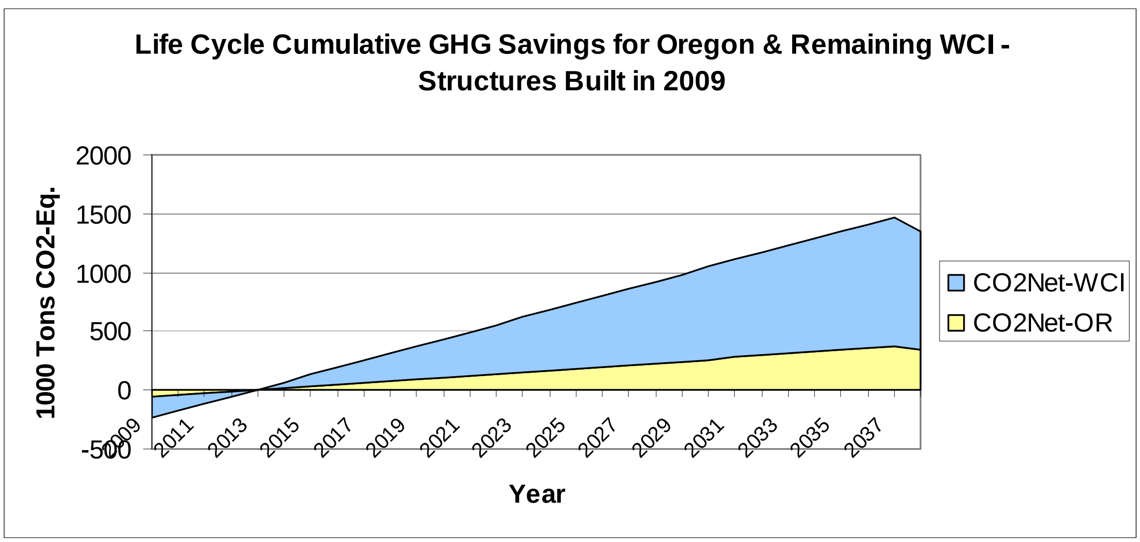
Figure 7 Residential Building: XPS Foam Life Cycle Impacts vs. Use Phase Savings



Cumulative Effects of Foam

Figure 8 presents the full stock of Western U.S. residential and commercial buildings insulated with Owens Corning XPS foam produced in Gresham, Oregon, based on 2009 projected production data. It has been assumed that one quarter of the buildings using the foam are in Oregon and the remaining three quarters are in the Western U.S., with a building mix of 50 percent residential and 50 percent commercial.

Figure 8 Cumulative CO2-eq. Savings for the 30-Year Life of XPS Foam

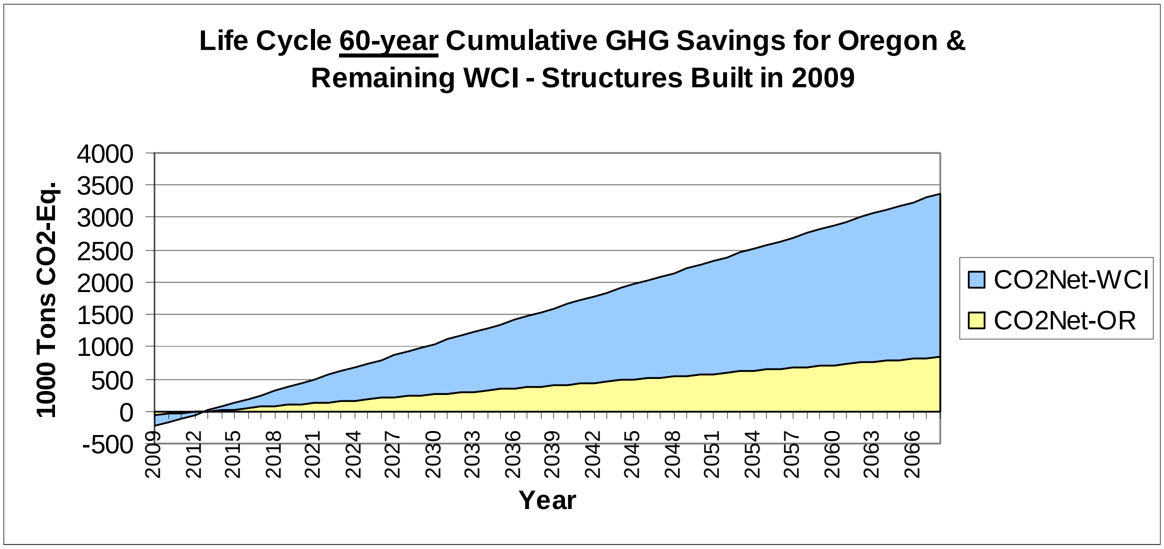


While the GHG savings of the structures built in 2009 and decommissioned in 2039 are considerable, it is worthwhile to present the total cumulative savings when the building is decommissioned after 60 years, which may be a more realistic time frame.[14] Figure 9

[14] The 30-year building lifetime was chosen for this study to establish conservative results.

demonstrates that at the end of a 60-year life and subsequent decommissioning, the total cumulative savings amount to nearly 3.4 million tons of GHGs.

Figure 9 Cumulative CO2-eq. Savings for the 60-Year Life of XPS Foam

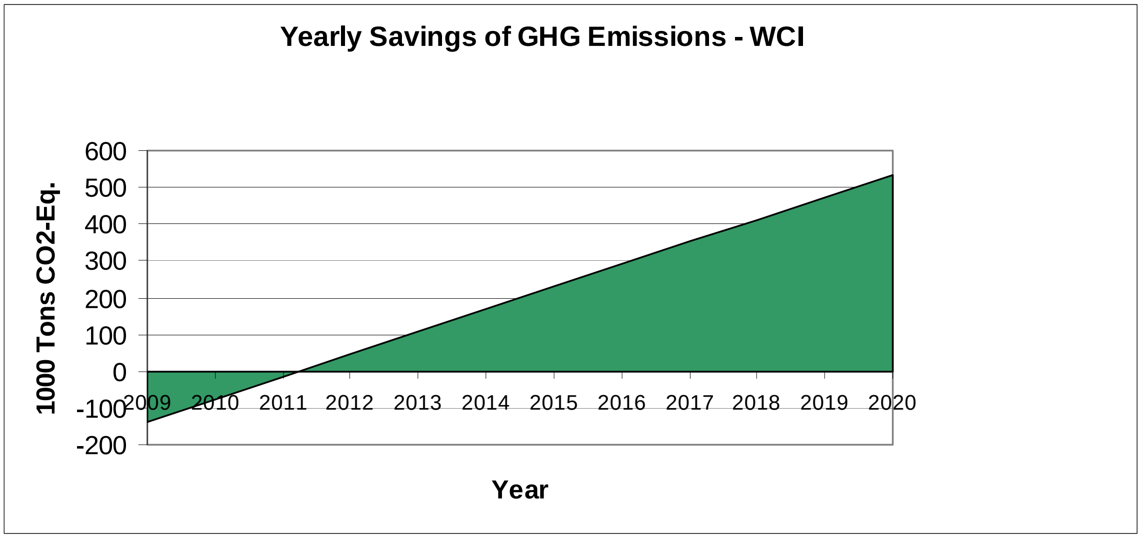


Impact on Western Climate Initiative and Oregon's Mandated Reductions

Oregon is part of the Western Climate Initiative ("WCI"), a landmark partnership with six western states and two Canadian Provinces. The WCI recently announced that it would reduce GHG emissions in the member jurisdictions 15 percent below 2005 levels by 2020.

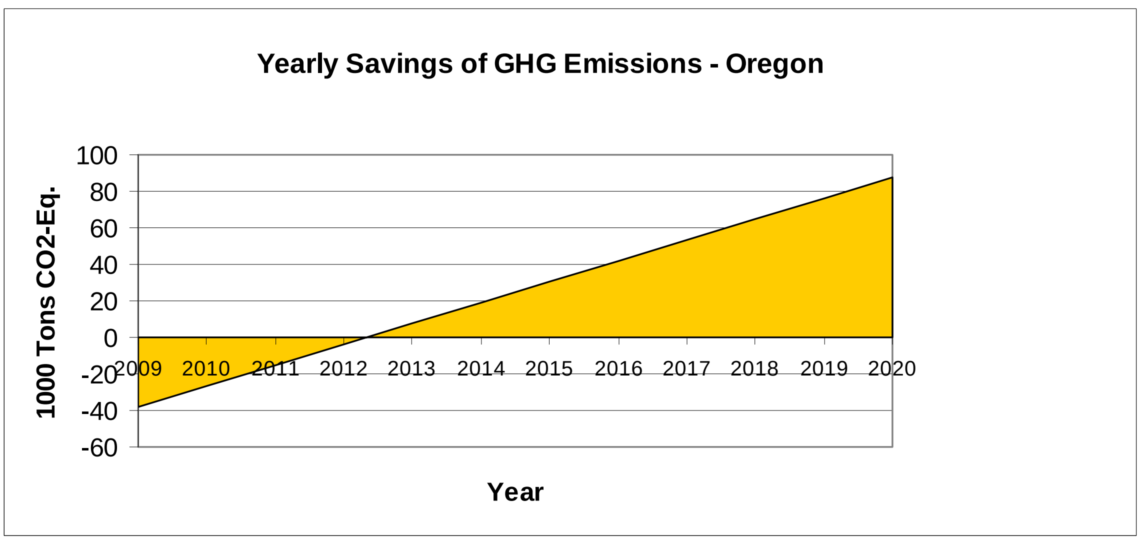
Figure 10, representing the full stock of Western U.S. residential and commercial buildings insulated with Owens Corning XPS foam produced in Gresham, Oregon, presents the yearly savings in GHG emissions between 2009 and 2020 in the western states resulting from the production at Gresham and use in the western states of XPS foam insulation each year. The yearly savings – due to XPS foam being produced and installed on buildings each year – will continue to increase at a positive rate. Cumulatively, this reduction amounts to 2.4 million tons of GHG by 2020. The XPS "burden" in Figure 10 includes production energy and blowing agent dispersion, distribution of foam to installation, installation, and blowing agent dispersion during use, while the savings are due to reduced energy demand through the use of foam insulation vs. no foam insulation.

Figure 10 Yearly CO2-eq. Savings Using XPS Foam – All WCI



Oregon has also established a state-specific emission reduction goal to reduce emissions 10 percent below 1990 levels by 2020. Figure 11 shows the yearly savings in GHG emissions between 2009 and 2020 in Oregon resulting from the production at Gresham and yearly installation in Oregon of the XPS foam insulation. This assumes that one quarter of the buildings using the foam are in Oregon. Cumulatively, this reduction amounts to 300 thousand tons of GHG saved by 2020.

Figure 11 Yearly CO2-eq. Savings Using XPS Foam – Oregon



LCA Conclusions

The goal of this study was to assess the environmental benefits and impacts of XPS foam over its lifetime. Based on the results, several conclusions can be drawn:

- Use phase impacts dominate most of the environmental categories.

- The GWP reductions associated with the energy savings due to use of foam are more than sufficient to offset the impacts of the manufacturing process and the small releases of blowing agent over the installed life of the foam.

- The comparison of use-phase results for foam scenarios and no-foam scenarios, as well as cumulative CO_2-eq. savings present a compelling case for the use of XPS foam insulation. Use of foam results in significantly lower use-phase energy and other environmental impacts.

LCA Limitations

As with any life cycle study, there are some limitations to how it should be used. While LCA is a very powerful and comprehensive environmental tool, LCA results should not be considered to be the only source of information with which to make final decisions on a product or process. Also, as is common for any scientific study, there are limitations to data quality. For LCA, production of upstream sourcing materials varies in data quality, where temporal, geographical, and technological information may vary widely. When hundreds of data sets are compounded into a life cycle system, the result is a snapshot of a system, which has some factor of uncertainty. Nonetheless, the best available data were used so as to minimize uncertainty.