Residential Insulation

Chapter 2: FOUR PLAYERS IN AN EXPANDING INDUSTRY

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Today many consider the use of foam insulation a cutting edge technology but history paints a different picture. The rise to accessible and more affordable products available today would take a 50-year journey of development and refinement before arriving at the products we have available today.[a] Rather than describe the myriad of insulating products available, here we have chosen four strong contenders based on availability, proven track record and relevant uses in the future.

Choosing the Right Foam:

It does not matter if you are building new, remodeling the exterior, remodeling the interior or just focusing on keeping the attic cooler in the summer months. There is a foam-insulating product that offers applicable improvement to thermal performance. We start by asking a basic question; As an insulating material, when and where should foam be used? The answer is complex. Manufacturer data will sell the virtues of a specific product while often providing vague, if any, information about drawbacks. Here we take an objective look at the basic considerations (also available in Table 1): thermal performance, moisture control, fire resistance, material cost, physical properties, structural attributes, installation methods and health records of four readily available foam insulation types which, to date, form the backbone of an expanding industry.

Polyisocyanurate or PIR is a closed cell rigid polyurethane derivative insulation typically utilized in rigid ductwork, exterior wall panels and, more commercially, in roof panels. The chemical composition is derived from isocyanurate polymers.[1] The result is a much more rigid structure than icynene polyurethane and lends itself to rigid panel installations rather than spray-in application. This is perhaps the most common expanded foam used in construction today and can be found in most hardware stores in 4x8 panels ranging from ½ to 6" in thickness. In most common residential form it is faced with an aluminum foil coating to reduce infiltration of moisture and reflect radiant heat. (Image 1)

[a] More background information on the historic developments of insulation can be found in Chapter 1 of this series.

Image 1: Foil faced PIR panels (above) and roof deck installation (lower image)

The strengths are many. Often overlooked as a first line of defense by many homeowners and builders alike, PIR is considered the highest performing insulation with respect to R-Value or resistance to heat transfer. R-value per inch is typically in the R-6 per-inch or nearly twice that of regular fiberglass insulation. Since the panels are typically foil covered and it is of a closed cell structure, the material is virtually 99% impermeable to moisture and without the aid of foil; the closed cell structure is not much less at 0.03 perms per inch. It therefore also performs well as a vapor barrier. These qualities not only make it a remarkable insulation but an excellent 'outsulation' (exterior surface insulation) product that can be used near moist surfaces or at the exterior building membrane to stop heat transfer at the outer surfaces of the wall cross section. This location, the exterior of the wall surface, is not as 'glamorous' or immediately visible as a value added option in comparison to, say, spray foam insulation, but it is a highly effective insulating option to combine as part of the wall cavity to yield superior performance over the typical insulating envelope. Due to a very dense and rigid structure, another strength *is* its strength. PIR is quite dense, with a typical weight of 1.86 pounds per cubic foot. When properly installed, the panels can add a light structural element to the building, which typically translates into increased torsional resistance when placed *between* structural members (such as 2x4 studs) or crush resistance when used as a sandwich material on a floor or roofing surface.[2] (Image 1)

From a health perspective, PIR can be an irritant to skin & eyes when in direct contact with construction but there are no statistically significant findings of respiratory diseases or substantial changes to the IAQ (Indoor Air Quality) in associated long-term test data. Life Safety considerations also earn high marks for PIR with a class 1 material based on ASTM (American Society for Testing and Materials) E-86 fire rating. This classification within ASTM means that this material will not sustain a fire on it's own.

Although an amazing material, PIR does have some drawbacks. In terms of application, PIR is not a spray-in material but a pre-formed foam panel that is mechanically fastened or chemically bonded to the structure. This means that the panels must be carefully sealed together to prevent air leakage and moisture infiltration. Since it is not a spray-in application, it is a less effective barrier to air infiltration. There is also the consideration of cost. As a denser closed cell type of foam, it requires more material and therefore more cost to fabricate. Even though the strong R-value performance allows for the largest savings per inch of material, this does not always support a projected return.

Use of this material is best suited near exterior surfaces and in areas where maximum primary heat gain is anticipated such as west walls, rooftops, or where heat loss is anticipated, such as north facing walls. As stated above, PIR is also quite effective in commercial structures as SIP's or Structural Insulated Panels.[b]

Open Cell Polyurethane, also known as 'lightweight polyurethane', the oldest of the spray foaming technologies is proven, still in widespread use and continuing to grow in popularity. Polyurethane is a broad term for multiple complex polymers that can take many forms. Its creation requires combining two major liquid components each of which have a range of chemicals that produce different properties depending on how they are mixed and in what proportion. The first of these two groups that make up the SPF (Spray Foam) is called an isocyanate.[c] Combining this with, the base polymer, or 'polyols', the second major liquid component (originally petrochemical in origin), completes the chemical reaction, which yields polyurethane. Recent advances have yielded more sustainable polyurethane polymer production derived from vegetable oils such as soy.[3] The open cellular format of polyurethane spray foam, weather plant or petrol based, exhibits marked differences from it's closed cell, medium density, cousin. (Image 3) Currently, the blowing agent of choice is simple water, which combines with the isocyanate stream to produce carbon dioxide bubbles. This, in turn, controls density and cellular closure or non-closure properties. For this section we are looking at the open cell structure that yields different properties from the closely related closed cell cousin to be discussed in the next section.

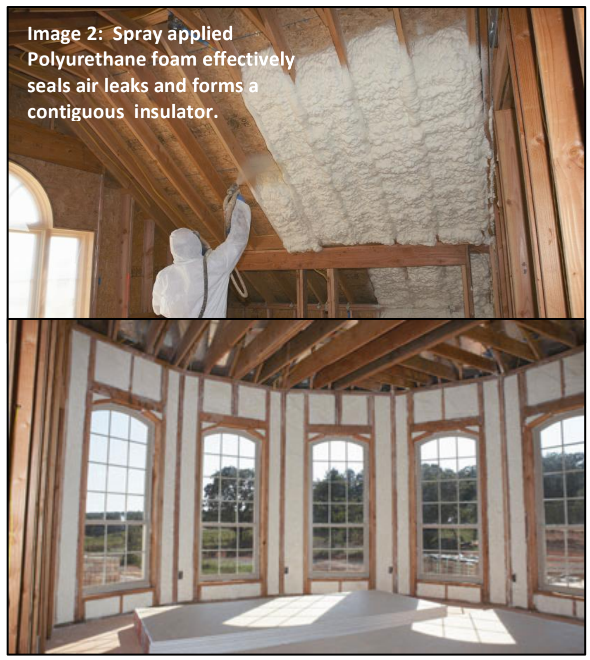

Image 2: Spray applied Polyurethane foam effectively seals air leaks and forms a contiguous insulator.

To consider open cell SPF in the right light we will first look at its weaknesses. The thermal performance of open cell SPF, when compared to that of regular fiberglass insulation is only marginally better (3.0 versus 3.8) in resistance to heat flow per inch with an R-value of 3.8. Since this type of polyurethane is in the neighborhood of twice

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[b] Suggested applications for PIR is addressed in Chapter 3 of this series in more detail.
[c] Isocyanate is a non-toxic compound that contains cyanate molecules related to cyanide, (much like chlorine in table salt is harmless to humand, the compound is rendered harmless by virtue of its bonds.

the price of standard fiber insulation, this begs the question of value or ROI, or Return On Investment over time. Unlike it's closed cell cousin; open cell polyurethane also allows transmission of water vapor at a rate of 9.2 perms for a 3.5" thickness, the most permeable of the group. This means that open cell SPF should not be used near any moist surface including ground contact. As a side note, infiltration can cause the insulation to short-circuit or allow heat transfer via the water spanning the width of the material, further underscoring care in placement of open cell SPF. As a result of its structure, open cell is soft & pliable to the touch and lightweight with a density of only 0.5 PCF, lending to the fact that marginal structural integrity is gained by application of the open cell polyurethane. All of this may sound bad for open cell SPF but the bright spot comes in the form of the application.

With so much stacked against it, you may ask; why consider SPF? The answer is somewhat elusive, or at least the fiberglass industry would have you believe, non-existent. Even though open cell SPF is roughly double the price of fiber insulation, when compared to this test group; it is the least expensive per volume. Moreover, open cell shines as a factor of product application. (Image 2) Since this is truly a spray-foam that expands in place, filling all voids, SPF creates a perfect contiguous barrier to drafts, leaks and air changes, the most common cause of energy loss in structures. This is a huge advantage over loose fill or rolled fiber insulation. The quantitative differences are so great that actual comparative performance typically bests standard fiber insulation by at least twice, or rather, halving the energy cost.

Considering life safety, in-situ polyurethane is chemically inert. [4] There are no exposure limits imposed by any regulatory agency and it is also not regulated as a carcinogenic substance. In contrast, application of the product should be performed with special breathing apparatus as the fumes and particles can cause respiratory and skin irritation.[5] Testing of in-situ SPF by Underwriters Laboratory of Canada yielded IAQ of VOC's of less than 1% for products tested to date, which, in terms of pass/fail yielded a solid 'pass.'[6] Within conditions of fire, SPF can be ignited by an open flame and it has a moderate flame spread factor of around 25 depending on the manufacturer data. As a result, some manufacturers and municipalities recommend a minimum 15-minute fire rated barrier between insulation and exposed insulation surfaces.

Open cell SPF, when installed correctly, is an excellent, inert, long-life spray-in type insulation that has stood the test of time. Due to its ability to wick moisture, however, careful evaluation of location is necessary. Any possible contact with moisture will compromise the R-value as water will short-circuit the ability to resist heat transmittal. Essentially, as discussed above, this insulation should not be used at the exterior envelope of a structure or where it will be in direct contact with ground surfaces or moisture. The best application of open cell SPF polyurethane is on the interior voids of walls and ceilings. See Chapter 3 of this series for more information on application recommendations. When first cost is a factor, open cell is the most logical alternative to its cousin, closed cell SPF.

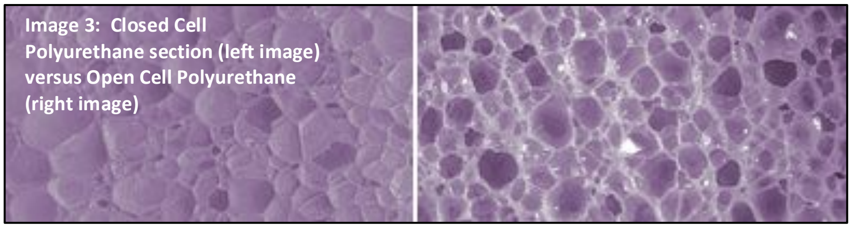

Image 3: Closed Cell Polyurethane section (left image) versus Open Cell Polyurethane (right image)

Medium Density Polyurethane (closed cell SPF): All things equal, closed and open celled SPF share the same chemical composition, however the key difference is density. Closed cell SPF will yield about 35-50 times the original volume once fully expanded while in contrast, the light weight or open cell SPF yields about 60-90 times original volume. Primarily, the closed cell SPF (alternatively called medium density SPF) is a denser product (Image 3) yielding remarkably different properties that, for the most part is inherited from the closed cellular structure.

Among spray foams, the performance of closed cell spray polyurethane rules supreme. Medium Density SPF picks up where open cell leaves off. The R-value, typically much higher, falls between R5 and R7 per inch, which more than doubles that of loose fill or fiberglass insulation and is slightly less than twice in comparison to open cell SPF. Another strength over open cell is the ability to resist wicking of moisture making closed cell SPF a more robust vapor barrier exhibiting a permeability of 2.06, allowing it to be placed near moist areas. Although typically used as an insulator, medium density SPF can alter the structural integrity of a wall or ceiling system as a result of the high adhesive and compressive strength of 15-20psi as a result of its higher density of 1.7-2.0 PCF. The typical yield in racking strength alone has been tested to resist 2 to 3 times the racking loads, which, in tornado or hurricane conditions can make the difference between survival and collapse of the structure. The closed cell structure also offers one other perk, resistance to moisture permeability with a rating of 2.06 PERMS on average.

Derived from the same chemical composition, medium density polyurethane SPF retains nearly the same health and life safety characteristics as its open cell cousin but with a few perks. Flame spread in tests are sometimes a bit better due to it's more dense structure but variations between manufacturer and surrounding materials will vary around a flame spread rating of 25. As a result of surface density, closed cell is less likely to trap moisture (source of mold) and fine dust particles, pollens and other airborne irritants at its surface. Along with being an inert in-situ material, these characteristics offer mild improvements in environmental health performance over lightweight SPF.

Producing an insulation having nearly double the R-Value and yielding nearly twice the thermal performance per inch when compared to Open Cell does create the one major drawback for closed cell or medium density polyurethane. Essentially per square unit of volume, roughly twice the material is needed to cover the same area. This logically translates into cost that is double that of lightweight SPF and approximately four times that of standard fiber insulation. In residential construction this can translate into a rather large first cost that is seemingly difficult to get around without closely considering the long-range payback in terms of utility savings. Unfortunately, the cost puts it above what most homeowners are willing to pay but, when considered as a lifecycle product with growing utility cost projections, it will likely make more financial sense and remain a valuable option.

Uses of medium density SPF are also much more broad. Again, the closed cell structure is the factor. Medium density SPF is not limited to just the inside cavity of a wall structure but also on the exterior surfaces, performing near or *as* the moisture barrier. Although it is still recommended to have a sheathing or covering when near the outside surface, it is possible to incorporate SPF at ground level and below. This expands the uses to foundation and basement walls. Overall, medium density SPF is a shining performer that can be placed nearly anywhere in a structure but this performance comes at a price.

Polystyrene, EPS and XPS: It keeps our beer cold, its the material from which 'disposable' coolers are made and how we protect precious shipped items. Polystyrene is perhaps the most common and the most encountered solid foam insulation to date. Arriving as a pre-formed solid foam and also synonymous with the product name 'Styrofoam', polystyrene is currently consumed at a rate of several billion kilograms per year. It's popularity, however is not reflective of its performance as an insulator of buildings. The process of making polystyrene, however, requires the vast use of CFC's or chlorofluorocarbons. This greenhouse gas is approximately 1000 times more detrimental to the protective ozone layer than carbon dioxide [7] and begs the question of continued use when considering the environmental impacts. The sister product of EPS, XPS, or Extruded Polystyrene is much the same chemical compound with a slightly different formation process. XPS is extruded through a die and usually pigmented with a signature color to represent a specific products or manufacturers trademark. Chemically, EPS or Expanded Poly Styrene is a hydrocarbon, chemically linked to petroleum, which turns out to present both positive and negative attributes.

Think hot coffee. To hold it you need an insulator; EPS has done this job faithfully for over 50 years. It is no surprise that within construction, EPS/XPS is an excellent closed cell type insulator that is nearly as effective as medium density polyurethane. At R5/inch, EPS has stood the test of time and temperature difference. Now if we revisit that cup of coffee, we also notice that EPS also demonstrates resistance to moisture permeability. Moisture transmittal varies based on density but on average, EPS comes in at best-in-group at 0.66 perms (1 perm = 1 grain of water vapor per hour per square foot per inch of mercury). All of these numbers may look great but there is still one more trick that makes polystyrene an amazing component in construction. EPS and XPS can be formed within a range of compressive strength of 10 to 33 pounds per square inch. This makes for a remarkably strong structural panel, or SIP (structural insulated panel). For typical construction, the density for superior compressive strength is 1.1

PSF. Which, in terms of rigidity/compressive strength per weight, wins hands-down over all other products in test.

Considering the health perspective, the inert qualities of in-situ polystyrene allow us to use it in contact with food and beverages. It also shows no sign of off-gassing or adversely effecting the environment or IAQ (indoor air quality). The health risks are largely tertiary. That is to say, considering our environment, EPS & XPS manufacture is highly corrosive to our atmosphere and increases the amount of skin cancer causing UV that reaches the Earth's surface and has done its fair share of global warming. When we consider the life safety in terms of fire performance, however, the picture is rather grim. EPS has a temperature limit between 160 and 200 degrees Fahrenheit, above which it will melt and can (depending on retardants added) become a flammable liquid that has, in tests, sustained combustion[8]. As a result, EPS was a worst-in-test candidate for flame spread rating. When heated, polystyrene will melt and carry a flame much like wood but with the added ability to melt away at relatively low temperatures.

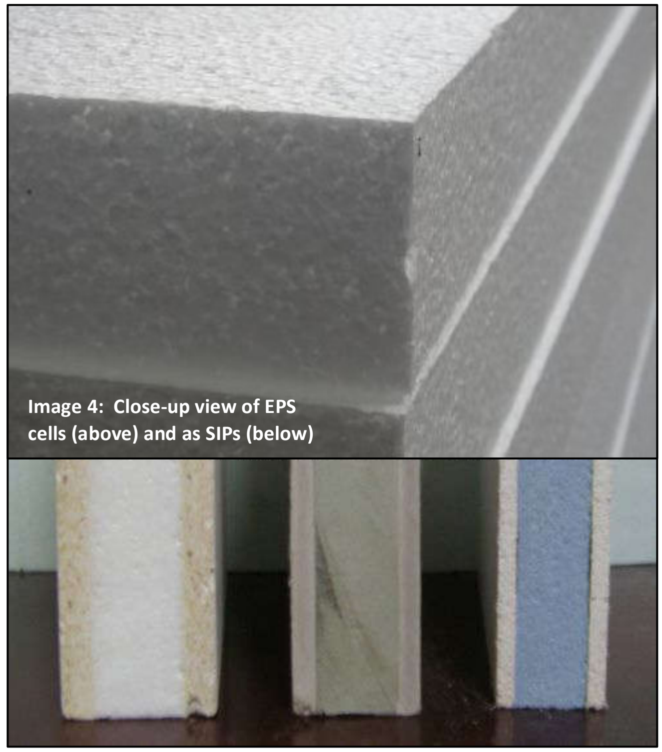

Image 4: Close-up view of EPS cells (above) and as SIPs (below)

Even though it has a remarkable R-value of 5, the drawbacks are in direct competition with the strengths of this product, and in a very literal sense. Special care must be taken when using EPS as structural elements or within the walls of SIPs. The chemical composition, so closely related to petroleum, may become chemically unstable, react, melt, off-gas or disintegrate when in the presence of other paints, stains, water repellents, solvents, preservatives, adhesives, and aerosols. As a result, consideration of adjacent materials and finishes should be researched before deciding to implement this material. Finally, due to structural failure upon reaching the melting point, EPS/XPS should be engineered to have a backup sheathing or structure that will prolong the structural integrity during fire as failure is closely related to heat. The final blow to EPS is also the higher cost, which is roughly a bit higher than that of medium density polyurethane.

In practical use, temperature and chemical drawbacks aside, the excellent rigidity has been demonstrated time and again by sandwiching EPS or XPS between two more chemically inert rigid facings to create remarkably strong structures that perform exceedingly well in seismic and wind load tests. In residential construction, these SIPs are usually composed of one face of oriented strand-board on each side of an EPS block or panel. In commercial applications there may be a layer of sheet metal, or fiber reinforced concrete board on one or both sides alone or in addition to a structural element embedded within. These compositions make fabrication structural and insulating membranes that meet fire codes and greatly mitigate consideration of other chemicals that might otherwise adversely affect open panels of polystyrene. SIP's, however, are expensive and require special tools and training for installation. Addition of electrical, plumbing within the wall cavity is cumbersome and has, therefore, found limited acceptance in residential structures. When used properly, however, expanded polystyrene can endure for a lifetime with thermal and structural performance in one preformed product and help still keep your coffee hot.

Research Observations:

Technical data provided by both independent researchers and corporations were considered as part of this comparison. When apparent conflict of data was present, the decision of this author was to obtain additional third party backup data to formulate data in the body and in Table 1. A cautionary note to those who decide to research a specific type further; Many associations produce papers that use the following techniques to cover up actual data:

1) Comparison to other product types using data that may be sourced to associate an exaggerated difference in performance.
2) Vague assessment of actual performance to defend a status or classification by standardized testing. For example, may manufacturers cut sheets will claim a flame spread rating using a more favorable type of testing method or may only claim a performance using an 'equal to or < >' without disclosing actual test numbers results.

Flame spread ratings are a sensitive topic for manufacturers of construction materials. Many articles have been written that claim, for example, that polystyrene products will not combust or carry a flame. You will find that the more reputable corporations will, however place warnings concerning protection from open flame with a barrier of x-minutes or will say outright that their product is flammable. This transparency was observed when researching at least 2 manufacturers of polystyrene products. Moisture wicking and water permeability data, likewise, varies from manufacturer data to independent research, but, generally speaking, of all of the products that may come into contact with moisture, by far the strongest closed cell contender is XPS.

In terms of defaming expanding foam type of insulation, the fiberglass industry has placed it's fair share of lobbying power and propaganda to prevent the adoption of various types within favorable performance classifications. Typically, this is accomplished by using the "R" Value as a singular tool. There are several caveats to using *only* R-value for comparison. Most poignant are the side-by side tests of materials, often yielding far superior performance of thinner foaming materials due to other factors such as infiltration, convection, conductance and outright performance.[9] For this paper, other comparisons were made to clarify the strengths between foam insulations but in performance against standard fiber fill insulation, it is the combination of properties that make foaming insulation, hands down, a truly sustainable option.

The topic of SIPs was only introduced in reference to polystyrene. Excellent alternatives exist for polyurethane and PIR core materials as well. The myriad of combinations of sandwich and sheathing material may also include multiple types of insulation within one panel. For the purpose of simplicity, the OSB (Oriented Strand Board) SIP has been used only to demonstrate one possibility as it relates to most common residential construction practices.

Market Projections:

Running behind most of the developed nations, North America continues to be the largest market for fiber-fill insulation to date but the domestic market share held by this insulation type is expected to decrease in proportion to foaming type insulations. A 2010 study conducted by the US based research firm, The Freedonia Group, Inc., projected the domestic Insulation Industry to reach over $6 billion at the close of 2009. Although fiberglass insulation holds market share in residential structures within the United States, foam insulations continued to gain market share through 2009, likely based on green initiatives, education, demand for more efficient structures, codes, and increasing availability.[10] This, however, is only an economic indicator, is not a clear representation of actual real-world use of the material. Additional data is still needed to track actual material production.

The continued use of fiber and loose fill insulation is confounding but clearly situated on first cost, economic conditions, lack of consumer education and societal values. It is also disturbing to see that what is considered one of the most advanced nations continuing to push back against logic. Unfortunately, of all drivers (logic seemingly last), the most likely to continue and to accelerate transition to more sustainable insulating materials may be what we have encountered in the past, economic forces.

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Table 1:

COMPARATIVE PROPETIES OF COMMON EXPANDED FOAM INSULATING PRODUCTS										
Material Type	R-Value	PERM(4)/In.	Flame(5)	Cost	Closed/Open	Health	Density PCF	Structural	Application	ROI(1)
Polyisocyanurate (PIR)	6	0.03 / 1	25 / best	$$$$	Closed	Good	1.86	Yes	Ridid	7
Polystyrene (EPS) Type 1 (2)	5	.66 / 1	45 / poor	$$$	Closed	Poor	1.1	Yes	Rigid	5.5
Polyeurothane SPF (3)(Closed Cell)	5.9	2.06 / 1	25 / good	$$	Closed	Best	1.7-2.0	Yes	Spray	4
Polyeurothane SPF (3)(Open Cell)	3.8	9.2 / 3.5	25 / good	$	Open	Best	0.5	No	Spray	5

(1) Return on investment calculations based on first cost data of new homes of equal size utilizing overall systems (no hybrid insulation types) reflected in numbers of years
(2) EPS is considered as preformed and not in conjunction with SIPs or Structural Insulated Panel installation, XPS similar but not independantly represented
(3) SPF common industry acronym, referrs to Spray Eurothane Foam to denote the application type and final prodcut state
(4) Resistance to the transmission of water vapor per inch of material with exception of open cell SPF above. ASTM E96 Test data, 2008
(5) ASTM E84 flamespread and smoke development method

Table 1: Data comparison from sourced articles and fundamental experience of author with practical application of materials. Testing standards and incongruent measurement data accounted for in notations to foster

Sources:

[1] Polyisocyanurate; http://en.wikipedia.org/wiki/Polyisocyanurate; last updated 4 August 2011

[2] "Polyios Insulation: The Clear Winner"; PIMA Technical Bulletin #201, page 2; Polyisocyanurate Insulation Manufacturers Association) 7/2011

[3] "New Twist on Green: 2008 Ford Mustang Seats Will Be Soy-Based Foam". Edmunds inside line. July 12, 2007. Archived from the original on 2008-05-31. Retrieved 2010-06-15.

[4] DERNEHL, CARL U. M.D. (1966); Pg. 59, Health Hazards Associated with Polyurethane. *Journal of Occupational and Environmental Medicine*. http://journals.lww.com/joem/Citation/1966/02000/Health_Hazards_Associated_with_Polyurethane_Foams.2.aspx

[5] Craig DeWitt, PhD, PE; "SPRAY-IN-PLACE POLYURETHANE FOAM INSULATION"; pg 3 March 11, 2002

[6] Underwriters Laboratory of Canada 705.1-98 test method, http://www.foam-tech.com/faq/faq_urethane.htm

[7] IPCC Third Assessment Report, Climate Change 2001: Working Group I: The Scientific Basis. Section 6.12.2 Direct GWPs.; published to the web by GRID-Arendal in 2003

[8] Fire Performance in Walls and Ceilings; PIMA Technical Bulletin #103, Pg. 2, July 2008; http://www.pima.org/BulletinFiles/tb103.pdf

[9] The 'R' Value Myth, by David B. South; Excerpt from: The Polyurethane Foam Book; Chapter 4, pg. 32; ©2008 Southwest Building Industries; http://www.swbet.net/R-Value-Myth-Foam-Fiberglass.html

[10] "US Demand for Insulation To Exceed $10 Billion in 2014"; © RIMA International (Reflective Insulation Manufacturers Association International); http://www.rimainternational.org/index.php/technical/freedonia-study/