Executive Summary

The UK insulation market is estimated to be worth £650m. The PIR and phenolic board share is approx £245m. The market overall is likely to grow year on year, but board is likely to take an increasing large share from EPS/XPS and mineral wool with each step change in Building Regulations in 2010, 2013, 2016. It could become the dominant insulation medium in the market overall, as low lambda values become increasingly important to achieve the required building regulations in the most space efficient way. It is anticipated that the board market could grow to £1bn by 2020. [redacted]

Mineral wool currently dominates the CERT based market, bringing existing buildings up to more thermally efficient standards. This is likely to continue until 2014/15, but boards are likely to become increasingly important post-CERT when retrofit activities begin to focus on hard to insulate properties, ie ETICS. The Government's long term energy strategy (HESP) calls for 6m homes to receive a "whole house" makeover by 2020 with all homes having this "makeover" by 2030. This will be very positive for insulation board as a significant amount of this work will involve either external or internal wall insulation, where this product is very strong.

The board market is currently split 90% PIR, and 10% phenolic. Phenolic is growing, and gets specified where high fire performance is required. On average it also has approximately 10% better lambda value than most PIR products. Selling prices are around 80% higher currently, reflecting 60% higher manufacturing costs, and stronger margins.

The board market is dominated by Kingspan, with approx 55% share, followed by Celotex with a 20% share. 4-5 other manufacturers account for the remaining 25% share of the UK market. Between 2004 to 2007 the board market grew at a compound annual growth rate of 16%, attracting several new manufacturers into the UK market, and a lot of spare manufacturing capacity. Average utilisation is currently around 25%. Assuming no further investment, utilisation would rise to 91% by 2020 due to market growth and lines slowing down as average product depths increase.

The insulated panel and board market is well developed, with over 330 continuous PU lines installed world wide. Polyurethane foam technology continues to develop, improving board properties (fire performance and Lambda value) and reducing costs. There are myriad manufacturers worldwide, backed by some of the world's largest chemical suppliers, such as Dow, Bayer, BASF and Huntsman. However, having in-house polymer engineering capability is critical to controlling chemical formulations, achieving the best performance and keeping manufacturing costs as low as possible.

Phenolic technology is developing, but from a much smaller base with few manufacturers and chemical suppliers. There are around 8 phenolic capable continuous lines in the world, of which half are in the UK/Ireland. There are still some significant issues with phenolic foam in terms of its process ability, water uptake and corrosion performance. There are now PIR products appearing on the market that can meet a similar specification for fire and insulation performance, but at a significantly lower cost.

Fire performance of all boards is inferior to glass wool, but in the majority of applications this makes very little difference in specification. Both types of board achieve 'class 1' performance for use as room linings in the UK Building regulations. Phenolic also achieves 'class 0', the highest rating in the UK.

In a typical fire, the building insulation usually contributes very little to the overall fire load (combustible contents) or quantity of smoke generated, as it is rarely exposed, being usually behind screeds, blocks or plasterboard. The BRE have recommended that tightening regulations in this area would be unlikely to save any lives lost in building fires, so it is not anticipated that regulations will change in the foreseeable future.

The only safety issues of note in PIR board manufacture are potential respiratory sensitisation from MDI and fire risks from using Pentane. History has shown these risks are low, and can be well controlled with current technology. There are no known legacy safety issues associated with board manufacture. Phenolic introduces hazards associated with formaldehyde vapours. Again, the risks in practice are low, with exposure at the same level as glass wool manufacture.

[redacted]

RECOMMENDATION

This study, carried out by an individual with extensive experience of insulation board, provides [redacted] with its most detailed knowledge to date of this product. We now have a detailed understanding of

- The existing market – PUR/PIR/Phenolics
- Future market dynamics
- Production process and costs
- Fire and Health & Safety issues
- Capital costs
- Competitor capacity and market positioning
- The clear and unambiguous conclusion of this report is

- Forthcoming known changes to UK building regulations will deliver very significant growth in the insulation board market, in all likelihood, at a faster rate than for mineral wools
- There are no past, current or likely future fire, health or safety reasons to prevent Saint-Gobain from entering this market

The only significant risk foreseen is the success of the current EURISOL study to demonstrate a significantly lower performance "in-situ" for foam products than claimed by manufacturers.

[redacted] the recommendation is to enter this market by acquisition, [redacted]

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1.0 Market for Board

1.1 Current Market

Market size: Estimates of the UK insulation market vary, but the average estimate is approx £650m in 2007. Of this PIR and phenolic board is estimated to be approximately £245m hence 38% approx. The phenolic board market is estimated to be currently £37m approximately. [1,2]

Distribution / route to market: The majority of insulation board is sold through similar channels to glass wool. The specialist insulation distributors would seem to have approximately 80% of the market, with the remaining 20% being by general builders merchants. There are a few customers who deal directly with the manufacturers (eg Hathaway Roofing with Kingspan), but the vast majority purchase via a distributor. [1]

[redacted]

Suppliers: the UK suppliers are:

- Kingspan
- Celotex
- Ecotherm
- Xtratherm
- Recticel
- Quinn-Therm
- Ballytherm

Market segments: Board can be used in most insulation applications, but in practice tends to be chosen in certain applications:

- Warm roofs: between and / or over / under rafters.
- Cavity walls. Limiting factor 25mm (minimum) or 50mm (normal) air gap.
- Flat roofs, including tapered insulation flat roofs.
- Insulated plasterboard & floorboards
- Ground floors, usually below concrete.
- Wall lining, behind / between studs.

Products on market: There are a great variety of board products on the market.

- A wide variety of depths are sold from 12mm to 200mm. Initially going up in increments of 5mm, then 10mm, then 20mm.
- Average depth (current regs) is approx 70mm, with the most popular depths being 50mm cavity walls, 50mm floors, 100mm warm roofs. As regulations change, the common depths will change.
- Board sizes are 2.4m x 1.2m roofs, floors and general purpose; 1.2m x 0.6m flat roofs; 1.2m x 0.45m cavity walls.
- Edges can be plain or rebated on 2 or 4 sides, (some suppliers offer this, some do not)
- Facing is usually a foil tri-laminate. Different facings are available for different applications, such as flat roofing (glass tissue or bituminous felt), dry lining (plasterboard), industrial roof lining (embossed aluminium).
- Different foam compressive strengths are available for more structural applications such as under floors, flat roofs, insulated gutters.

- Tapered boards are available to provide a fall to flat roofs. These are made-to-order for the specific application, and involve an element of specific design. They sell for a premium, being around 3 times more expensive than standard board. [1]

Stock: The majority of rigid board products are made to stock, with a few products such as tapered panels or custom depths made to order. Distributors will generally hold about 1 week stock on average, and carry all the popular depths and sizes. They will get all other items on a short 2-3 day lead-time. Manufacturers stock levels work out to be around 3 weeks on average, typically carrying stock of all SKU's. [1,3]

Stock Holding: It would appear specialist insulation distributors will generally stock one or two key brands. A tertiary brand may also be stocked as a 'price-fighter', and purchased purely on a cost basis. The primary and secondary brands will be chosen from the market leaders, and the brands that are most often specified (usually Kingspan and Celotex). The tertiary brand will be stocked on a 1-2 year deal based on supplied price. [1]

Market entry givens: A broad range of product types and depth, stock holding and good / rapid service level, aftercare support, technical support, adequate quality, appropriate BBA & fire accreditations.

New build / existing housing: Boards are particularly strong in the new-build market, where their perceived ease and speed of use is seen as an advantage, particularly in floor, wall and warm roof applications. Similarly for extensions to existing dwellings, particularly 'room in a loft' conversions, where the thickness can help reduce height restrictions. Less strong is the retro-fit market, and loft insulation where mineral wools tend to be much stronger, being easier to fit, and easier to handle with limited space loft access etc.

CERT: Obligations on energy companies to reduce greenhouse gas emissions has created a situation where it is cost effective for them to pay to have their customers homes insulated. Customers benefiting most tend to be those on state benefits & income support, pensioners and those in social housing. This scheme is likely to have a significant impact on the market until 2014/15, as other types of households become eligible for the scheme. This retrofit insulation tends to currently favour mineral wools for lofts, and blown systems for cavity walls. Longer term, when 'hard to insulate' homes are tackled, this insulation activity may tend to increasingly favour boards, where rooms are being lined, or the exterior of homes are being insulated and over-rendered.

[redacted]

Acoustic Regulations: The performance of rigid boards in attenuating acoustic energy is poor, as they are essentially a solid, and hence transmit sound quite well. Boards generally have to be used in conjunction with other materials (eg glass wool) in applications where a level of acoustic performance is specified. However, it is not anticipated there will be any further specific changes of regulation in this area.

Pricing: Board selling prices are fairly proportional to depth (as the majority of the manufacturing cost is the foam itself). Prices have fallen considerably over the last year. Raw material prices have also fallen by around 25% from their peak last year, to some extent linked to oil prices (the basic raw material) but indications are that they are starting to inch upwards again.

[redacted]

1.2 Market Development

1.2.1 New Entrant / Consolidation.

[redacted]

1.2.2 Thermal Regulations

The route map for increasing energy efficiency of UK buildings has been established by the government with part L of the Building Regulations. The calculations are based on 2002 Building Regulations. Defined step changes are 2002, 25% reduction; 2006 with a 25% improvement over 2002; 2010 with a 25% improvement over 2006; 2013 with a 44% improvement over 2006; 2016 achieve zero carbon emissions from homes and 2019 achieve zero carbon emissions from all buildings. This will have a significant effect on the type and depth of insulation used, hence the volume of material sold. [6] Practicalities of space utilisation (particularly in home applications) will keep pressure on all manufacturers to continue to offer improved lambda values. *See Figure 1, figure 2.* It is anticipated that these space pressures will see the market increasingly move from XPS, EPS and mineral wools into foam board in some applications.

It must be noted that previous experience has shown that the changes to regulation can take up to 18 months to feed through into increased depths of insulation sold: the regulations only apply to new planning applications submitted beyond the implementation date.

1.2.3 Floors

There is a current trend away from XPS and EPS in floor applications to PIR/phenolic board. XPS in particular is estimated to be declining at 30% annually and it is estimated that PIR/ phenolic board has now taken 70% of the market.[1] [29]. Most common depth currently is 50mm, but exact depth required is dependant on relation between area and perimeter of floor.

It is expected that this market will become almost exclusively PIR/Phenolic from 2010 / 2013, as increasing depths of Rockwool, XPS and EPS make them impractical, with the increased cost of ground works to accommodate the excessive depth of insulation. This is despite wide experience in Europe of great depths of polystyrene being used. This maybe due to the widespread availability of PIR / phenolic in the UK, or differences in labour rates.

1.2.4 Walls

Expressed in m^2, the current market would appear to be fairly evenly split between wools and boards, housing tending to favour the former and commercial applications the latter. [28]

With the change in 2010 regulations, analysis indicates that the market will remain approximately as current, with greater depths of wools and boards used, in conjunction with suitable low U value blocks forming the internal wall. In cavities (the predominant wall construction method) it would appear cavity gaps will be able to stay at the current 100mm. It must be noted though that PIR requirement of 55mm would either require a compromised residual air gap of 45mm, a switch to 0.021 lambda board, or an increase in insulation elsewhere to compensate. [8] There are now some 0.021 products on the market, whilst the norm is still 0.023 W/mK.

With the change to 2013/16 regulations, wall construction methods will have to change.

- Cavity wall depths will have to increase. Board will probably increase share of this market, as the better lambda values offer the prospect of slightly thinner walls. A 5% swing to board from wools is assumed in 2013 & 2016.
  - Currently, walls are 300mm deep (100mm brick, 100mm block 100mm cavity. The cavity is partially filled with board or partially / fully filled with glasswool.
  - 2013 cavity wall, glass wool insulated = 420mm deep, phenolic (or 21λ PIR) board insulated = 375mm deep
  - 2016 cavity wall, glass wool insulated = 590mm deep, phenolic (or 21λ PIR) board insulated = 485mm deep.
- Timber frames may become more popular to minimise overall wall depth.
  - With glass wool insulation, a twin-frame system will be required, along with 3 layers of insulation and wall depth in 2016 of 480mm.
  - Board insulated walls will be able to maintain a single frame system, which is likely to be considerably cheaper, and thinner (Overall depth, 2013 350mm, and 2016 430mm) [8]

1.2.5 Roofs

Again, calculations indicate that not only insulation depths will change, but also insulation types and methods.

- Lofts (cold roofs) are currently almost exclusively insulated with mineral wools. This will continue into 2010, but a 40 lambda product will be required. Currently joists are 100mm, and insulation is applied in line with these with a second layer applied at 90^0 across the joists. 200mm is the current maximum available depth, giving a limit of 300mm depth in total. From 2013, greater depths will be required. A third layer is not a practical proposition, as there will be no visible joists to stand on, so a serious safety risk for the installer. It is believed glass wool production lines can be modified to increase material depths beyond the current 200mm limit. An alternative maybe to augment the mineral wool with additional insulation, most likely plasterboard faced with 45mm PIR or phenolic, below the ceiling. An alternative would be to have no loft access, and blow sufficient depth of glass wool insulation in through the roof. Another alternative maybe to increase insulation elsewhere in the building to compensate. In the growth model [figure 3] is assumed 50% of the new build market will go to board augmentation of the glass wool.

- Warm roofs are gaining in popularity. With existing housing, utilising the loft is a cost effective method of extending living space. Similarly with new dwellings, creating attic rooms is a cost effective way of increasing living space with the same overall foot print, increasing living density. Currently the market segment is dominated by insulation board. From 2010, any mineral-wool based installation would need to be augmented with rigid board under sarking or insulated plaster board to achieve the required U value. [8]

1.2.6 Future Growth Prospects

Analysis of the market (Figures 1, 2, 3) indicate that the board market could grow very vigorously in the UK. There is plenty of installed spare capacity, and the changing Building Regulations environment will tend to favour the board market in three ways:

- Improved U value targets will increase depths, hence volumes sold.
- Difficulty in meeting the requirements with the higher lambda value EPS, XPS, Glass and Rock wools will tend to drive the market toward more thermally and space efficient alternatives: PIR and Phenolic.
- Several applications will require additional layer of insulation across rafters, joists, frames and walls to meet the requirement. It will not be possible to meet the requirement by insulating *between* structural elements only. For example, lofts, traditionally the domain of glass wool, may require a board augmentation below the ceiling from 2013, or a switch to a board based warm roof system.

Taking all these factors into account, along with the general return to growth of the market following recession it would indicate that the PIR / phenolic board market could grow from £245m in 2007 to £1bn in 2020. *[Figure 3]*. This is not without precedent: the board market grew 60% from 2004 to 2007. (CAGR 16%)

1.2.7 Dual Elements & Insulated Plasterboard

As the regulations change, many of the insulation applications go from a single element, eg rafter batts, to dual elements eg rafter batts with under-sarking board. An integrated approach would appear to be a good route to getting materials specified on a project.(ie marketing a range of different insulants). The alternative would be mixed products from different manufacturers on a project.

It would also appear that the insulated plasterboard market could grow very significantly. In each of the above scenarios, with the planned changes in regulations, it is clear that small depths of additional secondary rigid insulation applied across frames, rafters, joists or facing blocks will be an increasingly important way to ensure that the whole system meets regulations, irrespective of whether the primary insulant is glass wool or board. The cold bridging of structural wood elements is increasingly important. The simplest and quickest way for an installer to achieve compliance would be to use insulated plasterboard.

Comparison with the Insulated Panel Market

For several years the commercial building envelope market has been gradually moving from the 'built-up' (inner and outer sheets of steel, with mineral wool in between) to composite (PIR core). It is believed the 50/50 mark was passed around 7 years ago(in m^2 terms) in favour of PIR composite panel, which now has approx 60% of the UK insulated metal cladding market. Both systems meet Building Regulations and

insurance approvals. The balance is essentially between speed and cost: composite panels are more expensive but faster to install with a lower labour content. As regulations change however, the pace of conversion to composite panels is likely to accelerate further. Despite space not being an important consideration, PIR panels will become increasingly attractive as required depths are approx 50% of those required with a mineral wool based system, further favouring the relative speed / cost / ease of installation situation.[9]

Figure 1: Estimated Insulation Depths Required to Meet Building Regulations for UK New Build

	Approved Document L1A: New Dwellings	U value	Glasswool Thickness	λ	Stonewool Thickness	λ	PIR Thickness	λ	Phenolic Thickness	λ
2006	Building Target Emission Rate		20% over 02							
	Air Tightness		10							
	Target U Value: External Wall - brick/block	0.3	85	36	85	37	40	23	35	21
	Target U Value: Floor	0.22	NA	NA	105	36	65	23	60	21
	Target U Value: Roof (Warm)	0.2	200	35	200	35	100	23	90	21
	Target U Value: Roof (Cold - Attic Floor)	0.17	250	43	250	44	NA	NA	NA	NA
	Target U Value: Flat Roof	0.25	NA	NA	145	36	100	23	90	21
2010	Building Target Emission Rate		25% over 06							
	Air Tightness		5							
	Target U Value: Party Wall		75 - 100mm	36	75 - 100mm	37	NA	NA	NA	NA
	Target U Value: External Wall - brick/block	0.24	100	32	100	32	55	23	50	21
	Target U Value: Floor	0.18	NA	NA	140	36	100	23	90	21
	Target U Value: Roof (Warm)	0.15	200+	35	200+	35	165	23	150	21
	Target U Value: Roof (Cold - Attic Floor)	0.13	300	40	NA	NA	NA	NA	NA	NA
	Target U Value: Flat Roof	0.2	NA	NA	185	36	130	23	120	21
2013	Building Target Emission Rate		44% over 06							
	Air Tightness		3							
	Target U Value: Party Wall		75 - 100mm	36	75 - 100mm	37	NA	NA	NA	NA
	Target U Value: External Wall - masonry	0.15	220	32	220	32	150	23	125	21
	Target U Value: External Wall - timber frame	0.15	250	40	250	40	130	23	120	21
	Target U Value: Floor	0.15	NA	NA	200	36	115	23	105	21
	Target U Value: Roof (Warm)	0.13	200+	35	200+	35	200	23	180	21
	Target U Value: Roof (Cold - Attic Floor)	0.1	300+	40	NA	NA	NA	NA	NA	NA
	Target U Value: Flat Roof	0.16	NA	NA	230	36	155	23	130	21
2016	Building Target Emission Rate		0 loss%							
	Air Tightness		0							
	Target U Value: External Wall - masonry	0.1	390	32	390	32	260	23	235	21
	Target U Value: External Wall - timber frame	0.1	330	32	330	32	270	23	260	21
	Target U Value: Floor	0.15	NA	NA	200	36	115	23	105	21
	Target U Value: Roof (Warm)	0.1	200+	35	200+	35	250	23	230	21
	Target U Value: Roof (Cold - Attic Floor)	0.1	300+	40	NA	NA	NA	NA	NA	NA
	Target U Value: Flat Roof	0.13	NA	NA	280	36	180	23	150	21

***Note:** + indicates insulation may need to augmented with board or insulated plasterboard* [52]

Figure 2: Estimated Current Percentage Market Share Wools v Boards **Excludes other forms of insulation, Industrial panel systems, composite sandwich panels, SIPs etc**

Building Elements v Sectors	Private Housing		Housing Association		Appartments		Commercial		Industrial		Modular buildings	
Includes new build and refurbishment	board	glass / rock	board	glass / rock	board	glass / rock	board	glass / rock	board	glass / rock	board	glass / rock
External wall brick and block new	50	50	50	50	50	50	-	-	-	-	-	-
External wall brick and block retro	0	100	0	100	0	100	-	-	-	-	-	-
External wall Timber frame	20	80	20	80	20	80	-	-	-	-	20	80
External steel frame façade system	-	-	-	-	-	-	90	10	-	-	-	-
External Solid wall	90	10	-	-	90	10	-	-	-	-	-	-
Internal solid wall	90	10	-	-	90	10	-	-	-	-	-	-
Party walls block cavity	0	100	0	100	0	100	0	100	-	-	-	-
Party walls timber frame	0	100	0	100	0	100	0	100	-	-	-	-
Partition wall timber stud	0	100	0	100	0	100	-	-	-	-	0	100
Partition wall metal stud	0	100	-	-	0	100	0	100	0	100	0	100
Floors, concrete ground floor	80	20	80	20	80	20	80	20	80	20	-	-
Floor concrete intermediate below	-	-	10	90	10	90	10	90	-	-	-	-
Floor concrete intermediate above	-	-	80	20	80	20	80	20	-	-	-	-
Floors / ceiling suspended	0	100	0	100	0	100	0	100	0	100	0	100
Floor I beam	0	100	0	100	0	100	-	-	-	-	-	-
Steel decks / Concrete roof	-	-	-	-	100	0	100	0	100	0	-	-
Lofts new	0	100	0	100	0	100	0	100	-	-	-	-
Lofts retro	0	100	0	100	0	100	0	100	-	-	-	-
Warm pitched roofs	100	0	100	0	100	0	-	-	-	-	-	-
Cold pitched roof	80	20	-	-	-	-	-	-	-	-	-	-
Flat roofs	-	-	-	-	-	-	80	20	80	20	-	-

[7]

Figure 3: Estimated Growth of the PIR / Phenolic Board Market

Approx market size	Value £M	Average depth	Av selling price £/m2	Market vol growth	Volume m2	Comments
2007	£ 245,000,000	70	£ 5.20	25.0%	47,115,385	Actual Turnovers and growth, estimated average depth and price.
2008	£ 235,200,000	70	£ 5.00	-4.0%	47,040,000	Est turnover, depth price, decline rate
2009	£ 162,288,000	70	£ 4.48	-23.0%	36,225,000	Actual price and depths, estimate decline rate of market size based on Kingspan 2009 H1 interim results.
2010	£ 228,479,725	80	£ 5.27	19.6%	43,325,191	Assume market grows 4.5% pa. Regs change increase average depth from 70 to 80 and 14.5% uplift mainly from extensive use of sarking board, and incremental share gain v EPS, XPS, MW in floors, walls and flat roofs.
2011	£ 238,761,313	80	£ 5.27	4.5%	45,274,824	Assume market grows 4.5% pa
2012	£ 249,505,572	80	£ 5.27	4.5%	47,312,191	Assume market grows 4.5% pa
2013	£ 387,546,794	95	£ 6.26	30.8%	61,884,708	Regs change increases depths used. Some migration to dual board rather than single thickness increases area m² sold. Combined with incremental gains from MW in walls and EPS/XPS in floors. Board may also start to be used to support GW insulated lofts. Gives +25% volume uplift overall, combined with 4.5% market growth.
2014	£ 417,135,992	95	£ 6.45	4.5%	64,669,520	Assume market grows 4.5% pa
2015	£ 448,984,325	95	£ 6.64	4.5%	67,579,648	Assume market grows 4.5% pa
2016	£ 753,852,068	115	£ 8.28	34.7%	91,003,777	Large increase in depths due to regs change but increased use of dual elements keeps average depths down. 29% volume uplift due to this effect combined with incremental gains in walls and flat roofs. 4.5% market growth.
2017	£ 811,408,673	115	£ 8.53	4.5%	95,098,947	Assume market grows 4.5% pa
2018	£ 873,359,726	115	£ 8.79	4.5%	99,378,400	Assume market grows 4.5% pa
2019	£ 940,040,741	115	£ 9.05	4.5%	103,850,428	Assume market grows 4.5% pa
2020	£ 1,011,812,851	115	£ 9.32	4.5%	108,523,697	Assume market grows 4.5% pa

It is assumed that the market grows at 4.5% per year, with price inflation of 3% [redacted] However from 2011 to 2014 price inflation is assumed 0% reflecting a possible [redacted] Building Regulations change 2013 and 2016. **NB Experience has shown that time lags in the market can mean that the impact from step changes in building regulations are not fully felt until up to 2 years later.**

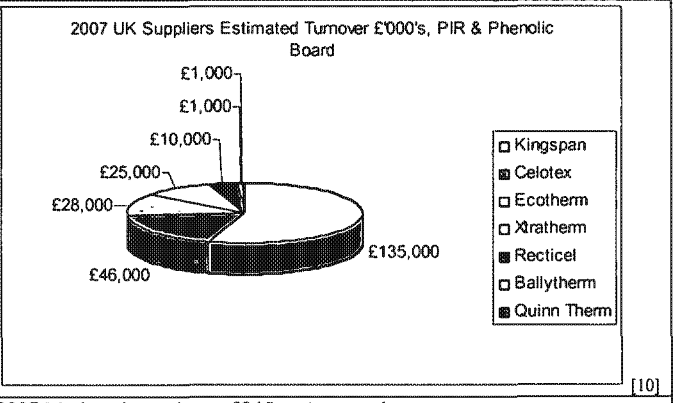
Large steps in 2010, 2013, 2016 reflect changes to UK Building regulations. This will increase the depth of insulation used. In some cases a single thicker board will be used. In other cases, twin boards will be used, driving m² sold. It will also tend to drive market share towards board, away from high-Lambda products, where excessive depths are required to meet regulations.

2.0 Current Insulation Board Suppliers

2.1 UK Market Position

YEAR	2008	2007	2006	2005[1]	2004
Revenue					
Celotex	54,195	46,036	36,573	35,606	31,877
Kingspan	127,310	144,671	116,353	118,501	104,988
Ecotherm		28,129	22,169	19,673	10,649
Xtratherm					
Quinn					
Total		**218,836**	**175,095**	**173,780**	**147,514**
Growth	-4.7%	25.0%	0.8%	17.8%	
Ballytherm					
Recticel: all UK activities		48,404	49,624	49,848	54,285
Gross Margin					
Celotex	8,023	7,066	6,436	7,149	7,733
Kingspan		35,373	27,728	28,280	27,941
Ecotherm		1,466	2,779	2,432	1,052
Xtratherm		1,040	1,431	566	(16)
Quinn					
Total		**47,881**	**40,546**	**39,049**	**38,916**
Margin		21.8%	23.2%	22.4%	26.4%
Recticel		1,509	2,172	622	2,206
Ballytherm	1,891	1,427			
Operating profit					
Celotex	3,669	3,412	2,999	4,189	4,888
Kingspan		14,512	11,487	12,242	12,420
Ecotherm		(984)	984	790	302
Xtratherm		(1,033)	798	(66)	(227)
Quinn					
Total		**15,907**	**16,268**	**17,155**	**17,383**
Growth		-2.2%	-5.2%	-1.3%	
Recticel		(1,119)	(1,683)	(2,913)	(786)
Ballytherm	837	828			

NB Red = est. figures. UK Turnover only. Celotex have August year end. Ballytherm includes Ireland. Recticel includes other foams.



[10]

2007 Market size estimate £245m. Assumptions:

- Kingspan, T/O adjusted down by £10m for Styrofoam business.
- Celotex as per published accounts
- Ecotherm as per published accounts. Loss '07 due to new plant.
- Xtratherm. No turnover declared. £25m figure derived from gross margin and some market stats putting scale on a par with Ecotherm. UK T/O was £10m in 2003.
- Recticel. Assumed only 20% of 2007 turnover derived from insulation board, as quite recent entrant into this market.
- Ballytherm: Have UK accreditations, but distribution seems minimal so assume only 10% of turnover comes to UK.
- Quinn Group is too large & diverse to derive turnover for board alone. Distribution seems very limited, so assume £1m.

2.2 Technology

Competitor	Technology PIR	Technology Phenolic
Kingspan	• Regarded by themselves and customers as the best technology. • Production technology is essentially industry standard contemporary. • Equipment and raw materials suppliers believe they are not that good (Celotex better). Kingspan formulation more PUR than PIR. 230 index • Often move technology on by chance eg knowledge through acquisition, but do have great depth and breadth of skill in polymer engineering team. • Have ability to infinitely vary formulation to meet needs of particularly: density, cheaper ingredients, fire, lambda etc. • Good relationship with all accrediting bodies, industry associations etc. In-house test facilities / R&D labs etc. • Typical Lambda 0.023w/mK	• Significant formulation technology unique to Kingspan. • Significant line technology unique to Kingspan • Protected through secrecy / supplier agreement / patent. • Acquired Kesteren who had developed low-acid technology. • Currently some warranty issues with residual acidity and pipe corrosion. Believe no issues with board. • Significant depth of experience, having worked on development for 10+ years. • Typical Lambda 0.021
Celotex	• Free rise technology unique to Celotex, and kept closely guarded (one line). Patent held by Celotex Corporation, issued in 2000 and expiring 2018. [11] • Should give lower density, better cell structure and lambda. • Increases edge trim scrap considerably (<9% v 1.66% restrained rise) [12] • Other line largely standard Hennecke restrained rise technology. • Line speeds highest in the industry at 75m/min Hipchen, and 50m/min Hennecke. This is believed to be maximum, on thin products, actual average rates believed to be lower. [13] • Hipchen method allows foam to rise through a glass-fibre scrim with a nip roller. Faster, flatter and no need for laminator. Makes harder to cut on site. 'Not good on higher depths, gives undulations' [14] • Suppliers regard them as the leaders: formulation high index PIR (500) • Have developed low Lambda 0.021 and Low smoke class O generating foam. Normal Lambda 0.023	• Not known: no products on market. • Probably won't enter phenolic market as have low lambda / low smoke PIR technology.
[redacted]		

[redacted]

2.3 Estimated capacity available to supply UK market

(2009, current product depths)
(Irish lines assumed to have 50% spare capacity to serve UK market)

[redacted]

From comparing installed maximum capacities to company published annual turnovers and current prices, total utilisation would appear to be currently around 25%. This will increase to around 43% in 2013, 76% in 2016 and 91% by 2020, assuming no new investment in capacity. This is due to five factors:

- Organic growth of market following recession, assumed at an average of 4.5% per year.
- Regulations changes 2010/13/16 will increase average board depths. It is estimated that average depth will rise to 115mm from 70mm currently, so slowing down lines by around 33% by 2016.
- Regulations changes will also require additional insulation application eg between and under rafters, increasing the square meterage sold.
- Increasing depths of insulation required with increased use of PIR/phenolic with their more favourable lambda, at the expense of glass & mineral wool and EPS/XPS.
- Some board depths will begin to get a little unwieldy. Although it is easily possible to manufacture the required depths, it is likely to be easier to use 2 boards, eg 2x70mm instead of 1x140mm (effectively doubling square metrage sold in certain applications). This would also reduce the likelihood of uninsulated gaps where boards meet as joints could be staggered.

Should regulations settle out at a U value of 0.1 [redacted] then insulation depths will tend to rise exponentially to meet the requirement. This will tend to drive the market to lower U value products, as it will keep applied depths within reasonable bounds. At a 50mm depth, changing lambda makes a difference of only a few millimetres. However at a depth of 260mm, reducing PIR lambda value from 0.023 to 0.021 saves 25mm. It is assumed all PIR products will be 0.021 lambda from 2013.

Celotex will probably be the first supplier to run out of line capacity and need to invest in additional capacity, probably by 2016. This is because of the following factors.

- They currently have around 20% market share, but only 2 lines.
- The free-rise line gives poor quality appearance at the greater depths required by the market, so they will probably tend to be increasingly dependant on the single restrained rise Hennecke line as regulations change.

2.4 Market Position, Strengths, Weaknesses.

2.4.1 Kingspan

Kingspan is generally recognised by the industry as the clear market leader, not only in share, but also distribution, technology and understanding of the products and their application. To the extent (rather like 'Hoover' for vacuum cleaners) installers used to describe rigid foam board as 'Kingspan'. Marketing is very strong, with clear consistent branding. Excel at convincing specifiers to constantly use their product, so driving purchase at a price premium, providing user friendly technical staff, website, and free installation training. Back up support is first rate. Installers also regard product as best to use on site, giving fewest issues.

The company is always ready to exploit new opportunities, and not afraid to invest heavily in capital.

The broadest product range, of PIR and Phenolic board, covering all specialist applications, eg tapered panels, alternative facings, compressive strengths etc

Service level is very high, with short lead-times, and rapid response to out of stock situations or responding to a problem on site.

Although distribution is 100% in major outlets, weaknesses are: distribution in builders merchants. Perceived inflexibility in the market, especially with pricing.

2.4.2 Celotex

The number 2 in the market, and generally well liked and respected. Owned by management / investors. Have good PIR technology, seeming to run at the highest Indexes of any supplier. They also use some more unusual grades of chemicals. It is possible that their formulations may be the cheapest and with the best fire performance. The company now have a low Lambda value 0.021 PIR product, that achieves a class O accreditation for fire performance. This can compete directly with Phenolic board, and would indicate Celotex has developed the PIR technology to another level. Probably has a very strong Polymer Engineering skill base in house (the key to board manufacture) [14]

A scrap rate is of 4% is assumed across the industry, but it is likely to be considerably higher with Celotex because of the free rise line. An overall estimate would be perhaps 7%.

Technical support very comprehensive, but not quite as slick / user friendly as Kingspan.

Broad product range. Sell the broadest range of depths from 12mm to 200mm.

The reinforcing mesh used seems to generally make it harder to install, making it harder to cut and pierce the boards, but probably stronger mechanically enabling thinner depths and greater fire resistance. The free rise machine would also appear to give a poor appearance, see photo below.

Distribution very strong in National Distributors and builders merchants.

[redacted]

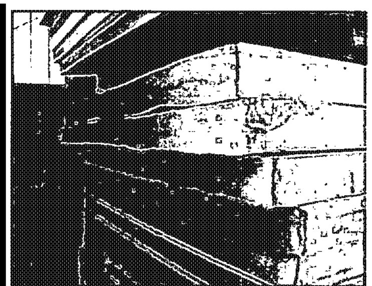
[redacted]

[redacted]

[redacted]

Manufacturers websites [19]

[redacted]



Celotex, appearance less good.

2.5 Suppliers Position, Board v Mineral Wool

It would appear certain market participants take a strong partisan line for their chosen product, and against other insulation products available. This can have a significant affect on specifiers, insurance and government policy.

Kingspan strongly advocates rigid foam insulation. Foam technology is one of its absolute core competencies, and hence takes a highly critical view of mineral wool, particularly Rockwool. Particular areas for attack are: [19]

- Ability of mineral wool to maintain its insulation properties when it gets wet.
- Poor installation quality on site, leaving large uninsulated gaps that do not arise with factory produced foam elements.
- Deterioration of insulation properties over time.
- Strong support of PIR/Phenolic fire performance.
- Strong support of PIR/Phenolic thermal performance.
- Inability of mineral wool to compete at the greater depths required by future thermal regulations.
- With panel particularly, speed, ease and safety of installation.

Supporting the use of other insulation would appear to weaken its proposition. However in Central / Eastern Europe Kingspan markets a mineral wool composite panel to suit local market conditions. In the UK, the company tacitly supports the use of mineral wool as the most effective way to prevent cold bridging in the gaps around composite panels on building envelopes, eg eaves, under top hats.

Rockwool strongly advocate use of mineral wool, and lobby hard / advertise against rigid foam, particularly on fire performance. In particular they brief the industry against the use of polymer insulation: this does not distinguish between EPS, PU, PIR, Phenolic – radically different materials. The market seems unconvinced by these arguments, and mineral wool based systems have been overtaken (60% v 40%) now by foam based construction in the commercial property sector. [9] This trend would look to continue as new building regulations require greater depths. However in the shorter term, Rockwool have probably regained some market share as on-site labour rates have fallen, making a built up system more attractive again.

Corus and Arcelor both participate in PIR composite panel and mineral wool built-up system markets for building envelope solutions, as they recognise there is a market for both. Both companies supply both industries with material. Arcelor supply steel only in the UK market.

Knauf is the leading glass wool supplier in the UK. They take a hard marketing line against polymeric board. However, they do have a foam insulation board line in Auxerre France, purchased in 2003 from OMS. In 2005, further expansion was planned [57] [15]. They are also believed to have expressed interest in buying Celotex [redacted] & 53]

2.6 Worldwide Capacity

Until recently, the worldwide polyurethane industry was supplied almost exclusively by 4 machinery manufacturers, Hennecke, OMS, PUMA and Siempelkamp. New suppliers are now appearing in China (copying European designs) but it is fair to assume 90%+ of worldwide capacity has been installed by the top 4. Just taking into account what they have installed over the last 20 years shows:

- There are 349 double-belt board and panel lines world wide.
- 331 use polyurethane (PUR/PIR)
- 8 are dedicated to phenolic foam board / panel.
- 10 are dedicated to mineral wool.
- 92 are dedicated to PU insulation board.
- 236 are dedicated to PU metal faced sandwich panels (roof, wall, door, floor)
- 9 do both PU board and panel.
- 127 are outside the EU. This area is growing the fastest.

3.0 The Product

3.1 PIR, Phenolic and Glass Wool Properties Compared

PROPERTIES	Phenolic Rigid Board	PIR Rigid Board	Glass wool
Lambda	With a thermal conductivity of 0.020-0.023 W/m·K rigid phenolic insulation is the most thermally efficient insulation product commonly available.	Thermal conductivity of 0.021-0.028 W/m·K, approx 10% inferior to phenolic.	Lambda 0.032 -0.044 W/m·K range.
Depth	Utilises the thinnest possible insulation board to achieve required U-values;	Slightly thicker than phenolic for a given U value.	Between 50 and 100% greater depth for a given U value.
Residual air gap	Under NHBC / Zurich warranty must have 50mm air gap *	Under NHBC / Zurich warranty must have 50mm air gap. Where these do not apply, can be 25mm.	Can be full fill cavity, but where Partial fill is required (approx 20% of UK, driving rain) will require cavity to be made larger, or switch to board, or render exterior of wall.
Fire Performance	Achieves BS476 Class 1 and Achieves a Class O fire rating to the Building Regulations / 'low risk' in Scotland. Euro class B, s1, d0	Achieves the required fire performance for the intended application. Achieves BS476 Class 1 fire rating. Euro class B-C, s2, d0	Achieves A1/A2 d0
Smoke generation	Under UK national regs, Achieves the best possible rating of <5% smoke obscuration when tested to BS 5111: Part 1: 1974; Euro class s1	Achieves Euro class s2	Minimal smoke generation, classed as s0.
Acoustic	As a solid, little attenuation of sound energy. No data available.	As a solid, little attenuation of sound energy. Little data available.	Believed to attenuate sound well, but hard to fully quantify. c4dB reduction when 30mm GW & PIR compared.
Moisture ingress	Closed cell structure, but will absorb water where unfaced. Water uptake is <2.5% by volume when submerged without facings, but can increase weight by up to 6 times.	Closed cell structure resists both moisture and water vapour ingress. Water uptake <0.1% by volume. Does not wick up.	Open cell material. Can result in reduced thermal performance in damp / wet conditions. Can be treated to improve moisture resistance.
Air movement	Rigid, closed cell: Unaffected by air movement	Rigid, closed cell: Unaffected by air movement	Open cell material. Air movement can reduce thermal performance.

Lifespan	Provides reliable long term thermal performance over the lifetime of the building, anticipated at 50 years +	Provides reliable long term thermal performance over the lifetime of the building, anticipated at 50 years+	Provides reliable long term thermal performance over the lifetime of the building, anticipated at 50 years+
Transportation	Approximately 50% lower volume U for U, but not compressible.	Approximately 50% lower volume U for U, but not compressible	Smaller pallets. Can get 8:1 compression factor, therefore up to 4x lower transport cost, for a given U val.
Site handling	HSE make no reference to hazards associated with Phenolic dust. No specific safety precautions required	HSE make no reference to hazards associated with PIR dust. No specific safety precautions required	HSE recognises that MMM fibres can irritate skin, throat, respiratory system and eyes. Gloves and face masks recommended by UK HSE. [55]
Ease of fitting	Good for open areas. In confined spaces, uninsulated gaps can remain.	Good for open areas In confined spaces, uninsulated gaps can remain.	Good for confined spaces.
Corrosion	Can reach pH of less than 3 (acidic) in lab tests in tap water. Can contribute to corrosion of metals.	No known corrosion issue. pH neutral.	No known corrosion issue, but can entrap moisture.
Wet weather / flood	Does not significantly affect performance if foil faced. Make take time to dry out after a prolonged flood.	Does not affect performance. Resilient in flood situation.	Open cell. Water uptake significantly reduces insulation properties. Needs to be covered during installation or storage. Takes a long time to dry out. May need to be replaced after a flood
Collapse	Will not sag, slump or collapse over time.	Will not sag, slump or collapse over time.	Can tend to slump in non filled cavities. Sags over time, unless suitably supported.
Cost effectiveness	Around 60% more expensive than PIR depth for depth.	-	Around 50% cheaper per m^2 than PIR for similar U value
ODP	Zero Ozone Depletion Potential.	CFC/HCFC-free with zero Ozone Depletion Potential (ODP).	Zero Ozone Depletion Potential.
GWP	CFC/HCFC-free. The global warming potential (GWP) of PIR is 3, earning it a 'low GWP' classification.	CFC/HCFC-free. The global warming potential (GWP) of PIR is 3, earning it a 'low GWP' classification.	Zero.
BREEAM / Green guide ratings.	Not rated currently.	Board A rated. Celotex A+ rated. *(panels also achieve A+)*	Majority A+ rated, some A rated.

* Insulation board used in a cavity require a minimum of 25mm clear or 50mm clear if NHBC [80% of market] or Zurich insurance are providing a warranty, or if the site is considered unduly exposed by the Local Authority, ie virtually every application. *(Celotex website)*

3.2 Background and properties of boards

3.2.1. Foam types

There are three types of foam currently being used. PUR/PIR and phenolic. All are 'closed cell', where the closed cells give the insulation properties, and make the product resistant to absorption of water etc. The cells are actually usually full of blowing agent and co_2. All three are **thermoset** as opposed to thermoplastic. This means they form an irreversible strongly cross-linked polymer. It cannot be melted with heat or recycled by reprocessing.

The foams are very stable over time. They are largely inert and do not really react with materials they would commonly come into contact with in situ. Foam largely encapsulated within facings has essentially an infinite life-span. The longest lasting and least reactive of all is Phenolic.

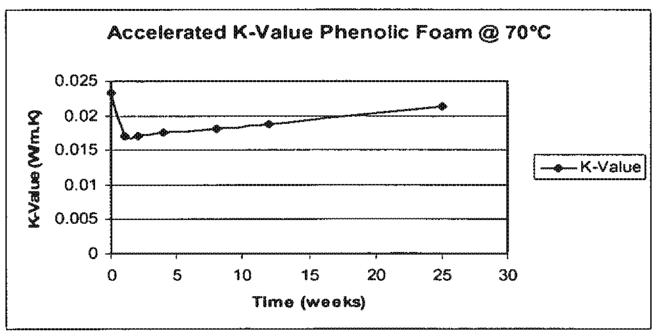
One of the key selling points of foams is that their lambda values remain stable overtime in service. This is used as a marketing differentiator from mineral wools where insulation properties can deteriorate through moisture ingress etc.

3.2.2 Lambda Values

Phenolic: Kingspan K7: thermal conductivity of 0.021–0.024 W/m.K. 0.021 above 45mm depth.

PIR: Kingspan TP10: thermal conductivity of 0.023 W/m.K, Same as Celotex. There are 0.021 lambda products on the market.

PIR Lambda values quoted are generally accelerated aged an elevated temperature, until Lambda decline has stabilised. At this point they are then generally very stable, only changing very slightly over the next 50+ years, hence expected lifespan of the material generally quoted as in excess of 50 years. When the material is fresh, lambda can be as low as 0.018W/m/K.



Phenolic aging of Lambda (K). PIR similar. Tends to stabilise after 26 weeks on test. [2]. PIR similar, stabilises after approx 8-12 weeks.[53]

3.2.3 History

The first generation foams were PUR based. These are very easy to process, but the fire properties are relatively poor. Raw material costs are similar to PIR. They have now been largely eclipsed by PIR in continuous manufacture applications. The ease of process ability means PUR is still the material of choice in discontinuous blowing applications, eg fridges, car dashboards etc.

The second generation of foams are PIR. Initially market acceptance of the fire benefits of PIR were slow, and suppliers were slow to move over to PIR manufacture as processing is more tricky. However, particularly after the 9/11 attacks in New York, the market became much more interested in fire performance, driven largely by the insurance industry. In particular with panels, having American FM (Factory Mutual) insurance accreditation for building envelopes, which only PIR can achieve, drove a full switch to PIR in FM accredited territories.

The third generation of foams are Phenolics. They have 10% better lambda values than PIR, so the products are correspondingly marginally thinner, but currently cost around 60%-70% more to make, due principally to higher density and more difficult processing at only 30-40% of line speed of PIR. Fire performance is better, particularly smoke generation when subjected to flame. Total smoke release is about 90% less than PIR.

3.2.4 Outlook

There would appear to be more development potential in PIR. Although a well developed technology, a lot of development time is still being invested by the different manufacturers including Kingspan, and it is reasonable to assume that densities will probably fall another 10% (majority of cost of product is foam). Lambda values would improve by another 10%, and fire performance will incrementally improve too. The limiting factor is the conductivity of the gas in the cells. Pentane has a lambda of 0.013 approx, so there is still plenty of scope for reduction in the overall foam system.

Phenolics is still in its development phase. It is now being used for board by Kingspan and Xtratherm. There is some use in cold-store panels. Development is currently underway for building envelope panels, but not all the obstacles have been overcome yet. There are problems with corrosion in use that have not been fully overcome yet.

The key driver will probably be specifiers, insurance companies etc. They will want to specify the 'best available technology' to construct their buildings, and reduce their fire risk liabilities. The circa 60% higher price is probably not a big consideration as the insulant is a small percentage of the overall cost of constructing a building. However, where Phenolic is not specified, installers will use the cheapest, most convenient material that meets the relevant building regulations, so PIR will probably continue to be common for the foreseeable future, unless building fire regulations change to mean Phenolic / mineral wool become mandatory. It is possible that the cost will come down over time as more chemical suppliers come into the market, and the board manufacturers master the technology.

It must however be born in mind that whilst phenolic is about 10% of the UK market, world-wide, the market penetration is a lot lower. From studying the top 3 line manufacturers reference lists, only 8 of the 288 continuous board / panel lines supplied world wide have phenolic capability. In total there will be in excess of 300 continuous polyurethane foaming lines world-wide.

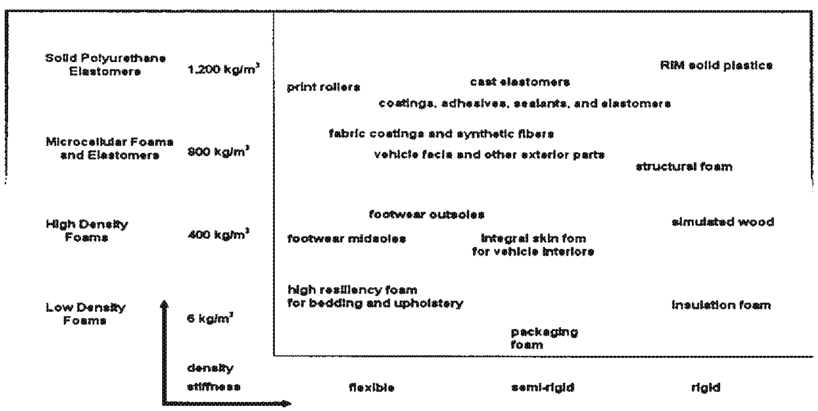
Changes to 2013 and 2016 thermal building regulations will probably tend to favour the insulation products with the lowest lambda value, as this will keep overall insulation depths to a minimum. It would appear the lambda value of glass wool plateaus at 0.032 W/m.K, so the market may tend to move more towards PIR/phenolic based solutions.

3.3 Polyurethane

Polyurethane is used extensively in the home, in: bedding, upholstery, footwear, paints, packaging and fabrics. In construction: insulation, simulated wood; industrial applications such as print rollers and extensively in automotive: interiors, dashboards, seats, door panels etc. It is also the principle material used to construct and insulate refrigerators, freezers and cold stores in domestic, industrial, commercial and road transport applications.

The polyurethane industry is large and influential, supplied and supported by some of the world's largest chemical companies: BASF; Bayer; Dow; Huntsman etc. Not only are there are in excess of 330 continuous lines world wide, and a vast number of discontinuous foaming operations, but PUR foams are present in virtually every refrigerator and car on the planet.

Polyurethane was first used in the 1950's, with PUR and PIR rigid foams being invented in the late 1960's.



[14]

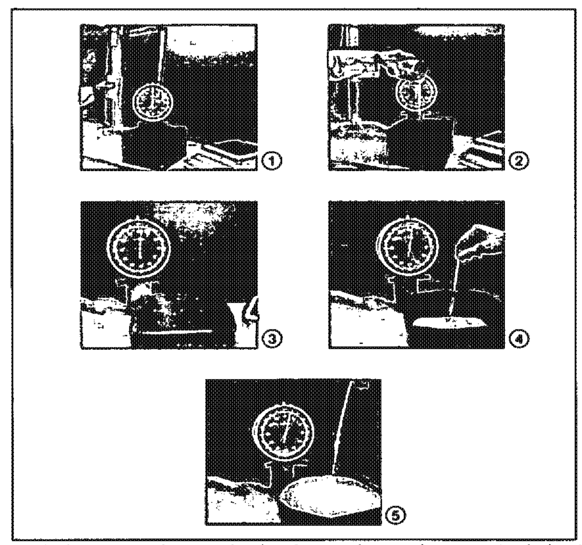
3.4 PUR: Polyurethane Foam

This is first generation rigid closed cell foam. It is easy to process, having wide set-up tolerance bands, and gives good adherence to most facing types, and few issues post cure. It is still used extensively in refrigeration, automotive and some construction insulation plants in Europe. Its fire performance is relatively poor, and has not generally been used in construction or building insulation applications in the UK in the last 5 to 8 years. It has been essentially eclipsed by PIR.

3.5 PIR: Polyisocyanurate Foam [20, 21, 22]

This is the most commonly used foam in construction applications in the UK, and probably world wide. The fire performance is better than PUR. When exposed to flame, it will burn a little, forming a protective char layer that then protects the remainder of the material. It does however smoke considerably during initial exposure to naked flame. Importantly, once the char layer forms, it burns very slowly, with low overall heat release, and it retains its structural integrity during a fire, so will take a long time to collapse if used in a roof, for example.

Processing is more difficult than PUR. Lay-down set up parameters, material specifications etc need to be very carefully controlled to ensure satisfactory processing. Some skill is required to ensure that lab observed performance aligns with the requirements of the manufacturing process. A key attribute is the foam rise profile v time. The 'cup test' shown below is typical: the key point in board manufacture is to ensure the foam rises to meet the top foil laminate when the foam is at its most tacky. The reaction profile can be modified by varying the chemical blend.



Typical cup test. Rise must be timed to touch top substrate at 'tack time' when foam is at its most adhesive.

3.5.1 Polyurethane Foam Chemistry

The production of rigid polyurethane foam requires two main liquid components - a polyol and a polyisocyanate and also a blowing agent. The blowing agent is usually added to the polyol stream together with further auxiliary components such as activators (reaction accelerators), foam stabilizers and flame retardants. The polyaddition reaction that takes place when the polyol and polyisocyanate are mixed together results in macromolecules with urethane structures ***(polyurethanes)***.

During the reaction a considerable amount of heat is released which is used partly to evaporate readily volatile liquids (blowing agents). As a result, the reaction mix is expanded to form a foam. A small quantity of water is normally added to the polyol. The water reacts with the polyisocyanate to form ***polyurea*** and ***carbon dioxide***, which serves as a co-blowing agent but can also be the sole blowing agent. Some of the carbon dioxide ends up trapped in the cells, along with the blowing agent.

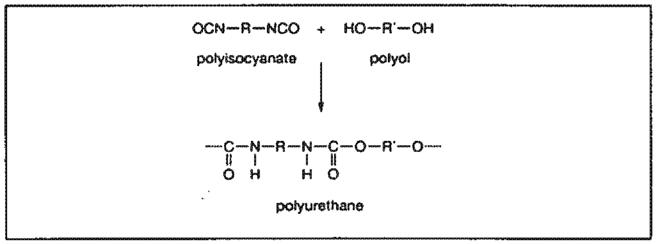


Fig. 1: Polyurethane reaction formula

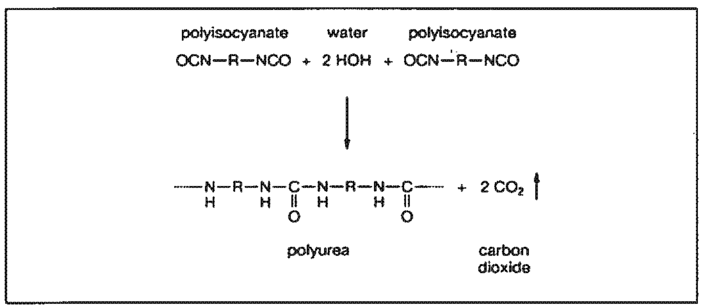


Fig. 2: Polyurethane/water reaction

In the presence of certain activators, isocyanates can react with one another to form macromolecules with isocyanurate structures ***(polyisocyanurate =PIR)***. Reactions between isocyanates and polyols and isocyanates can take place simultaneously or in direct succession, forming macromolecules with urethane and isocyanurate structures ***(PIR-PUR)***. An excess of iso is required to enable the reaction to take place. Rigid polyisocyanurate-polyurethane foams perform better in a fire.

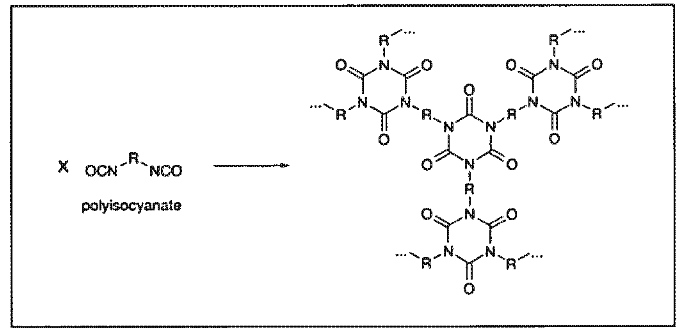


Fig. 3: Reaction of polyisocyanates in the presence of trimerization catalysts

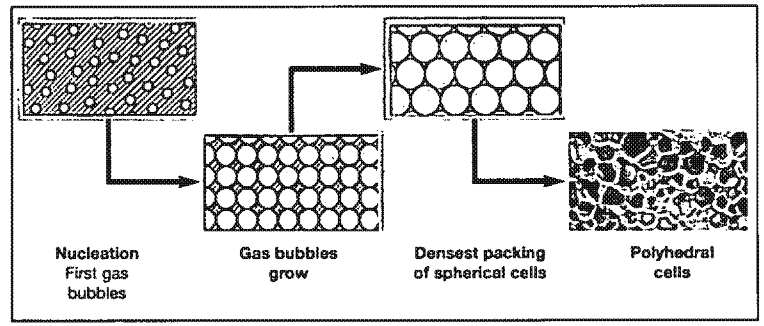


Fig 4 A small quantity of air added to the mix acts as a nucleant for the closed cells.

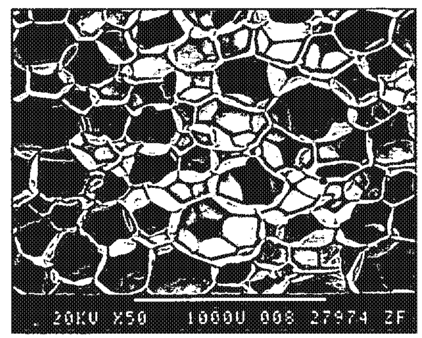


Fig 5 Closed cell structure gives the foam excellent thermal and mechanical properties.

3.5.2 Polyurethane Index

The index gives the ratio of the amount of isocyanate used in practice to react with all the Polyol present, expressed as a percentage. An index of 100 means all the iso has reacted with all the polyol, (stochiometric reaction) and the substance is fully cross linked. With indices over 100, the substance is "over-cross linked". The index must not fall below 100, otherwise the foam will shrink. Rigid PUR foam is usually produced with indices ranging from 105 to 130 and PIR foam with indices ranging from 180 to 500. Due to differing molecular weights and chemical reactivities, an index of 400 is required to give a 50/50 split of PUR and PIR in the foam structure.

A Typical PIR composition by weight:

- 64% Isocyanate: polymeric MDI.
- 27% Polyol polyester (or blend with some polyether polyol)
- 1% Catalyst: a trimerisation catalyst package.
- 1% Flame retardant package.
- <1% Surfactant: a silicone surfactant package to stabilise the foam.
- <1% Water
- 7% Pentane (more actually used, but some flashes off during manufacture)

3.5.3 Raw materials

3.5.3.1 Polyols

Polyols are viscous liquids, the characteristic chemical feature of which is ***hydroxyl (OH)-groups*** based on oxygen and hydrogen. These react with isocyanate groups of the polyisocyanate to form urethane groups. A distinction is made between ***polyether*** and ***polyester*** polyols. Polyether polyols are generally easier to process, whilst aromatic polyester polyols tend to give better fire performance with their hard benzene ring structure. Sometimes a blend of the two types is used.

3.5.3.2 Polyisocyanates

Chemical compounds with ***isocyanate groups*** (NCO-) as functional groups are known as isocyanates. Isocyanate groups are based on nitrogen, carbon and oxygen. Isocyanates based on ***MDI*** (=***m***ethylene ***d***iphenylene di***i***socyanate) are used almost exclusively for producing polyurethane foam. Often these are mixtures of MDI (mainly 4,4'-diisocyanato-diphenylmethane with an isomeric 2,4'-diisocyanato-diphenylmethane content) and higher molecular components. As a molecular unit is repeated in the structure of these higher molecular components, the isocyanate mix is also called polymeric MDI (PMDI) or MDI polymer. The increased number of NCO groups available to react improves the PIR index.

3.5.3.3 Blowing agents

The blowing agent is ideally a low boiling point liquid with a low thermal conductivity and soluble in the liquid foam, but not dissolve in the polyurethane foam produced.

The chlorofluorocarbon (CFC) 11 (monofluorotrichloromethane) which was used for a long time met most of these criteria excellently but gave reason for concern from an ecological viewpoint. The ***global warming potential (GWP)*** of CFC 11 and its potential to damage the ozone layer of the stratosphere ***(ODP = ozone depletion potential)*** led to the decision to discontinue use (Montreal Protocol of 1987).

Hydrogen chlorofluorocarbons (H-CFCs) and ***hydrogenfluorocarbons (H-FCs)*** were next used instead of CFC 11, principally 141b. Again this was phased out due to ecological reasons, and the industry moved to H-FC 245fa and 365mfc. They perform quite well as blowing agents and are reasonably sound from an ecological point of view, but are relatively expensive. For this reason the whole industry has moved over to pentane, which is essentially 6 times cheaper.

Pentanes (typically: n-, cyclo- and iso-pentane) are highly flammable liquids, the vapours of which form explosive mixtures with air. When they are used as blowing agents, certain safety precautions have to be taken with corresponding capital expenditure and safe systems of work. The different grades have different properties, costs and process-abilities. Sometimes a blend is used. Its flammability actually means it makes the fire performance of the foam slightly worse than the alternative CFC-free blowing agents such as '365'.

The cells of the foam end up filled with pentane and carbon dioxide. Carbon dioxide is soluble in polyurethane and therefore escapes from the foam cells by diffusion if the foam is not made diffusion-tight. As a result of the falling gas pressure in the cell the foam can shrink, and get back filled with air, so lambda value falls. Foil facings are a key element to prevent degradation of lambda over time.

Blowing agent	Formula	Mol weight	Boiling point °C	Flammability	ODP	GWP	Thermal conductivity (gas) mW/m · K
CFC 11	CCl_3F	137.4	23.7	–	1	1	8.5 (25°C)
H-CFC 22	$CHClF_2$	86.5	– 40.8	–	0.055	0.36	10.8 (25°C)
H-CFC 141b	$CH_3–CCl_2F$	117.0	32.0	flammable	0.11	0.12	10.1 (25°C)
H-CFC 142b	$CH_3–CClF_2$	100.5	– 9.2	flammable	0.065	0.42	12.9 (25°C)
H-FC 134a	$CH_2F–CF_3$	102.0	– 26.3	–	0	0.25	13.7 (25°C)
H-FC 152a	$CH_3–CHF_2$	66.0	– 24.7	flammable	0	0.03	14.3 (25°C)
H-FC 245fa	$CF_3–CH_2–CHF_2$	134.0	15.3	–	0	0.24	13.0 (25°C)
H-FC 365mfc	$CF_3–CH_2–CF_2–CH_3$	148.0	40.2	flammable	0	0.21	10.6 (25°C)
n-Pentane	C_5H_{12}	72.0	36.0	flammable	0	0.00044	14.0 (25°C)
i-Pentane	C_5H_{12}	72.0	28.0	flammable	0	0.00037	13.8 (25°C)
c-Pentane	C_5H_{10}	70.0	49.0	flammable	0	0.0004	12.4 (25°C)
CO_2	CO_2	44.0	– 78.5 sublimated	–	0	0.00015	16.0 (25°C)

GWP definition: potential to heat up atmosphere, relative to CO2. Therefore, products containing pentane are classed as 3 approx.

3.5.3.4 Catalyst Activators

Most polyols and polyisocyanates only react with one another at a moderate rate at room temperature. The same is true for the reaction of polyisocyanate with water, so accelerators (activators) are added to the reaction mix. These are usually tertiary amines, organo-tin compounds or alkali salts of aliphatic carboxylic acids which particularly promote isocyanurate formation. The best known products are triethylamine, dimethylcyclohexylamine, dibutyltin dilaurate and potassium acetate. Some of the individual compounds from the large number of activators have very different effects on the reactions described. This can be used to control the progress of the reaction and foaming according to requirements.

3.5.3.5 Foam stabilizers

The foam which forms as a result of the developing or evaporating blowing agent is usually unstable and would collapse if the reaction continued without the addition of foam stabilizers. ~~Organo-silicon compounds~~ (polyether polysiloxanes) which have a surface-active effect are used almost exclusively as foam stabilizers, but also function as emulsifiers. Foam stabilizers regulate the foam structure, the open- and closed-cell character and the cell size and therefore have a substantial influence on the foam properties.

3.5.3.6 Flame retardants

Polyurethanes are organic compounds and, as such, are flammable. In order to delay their ignition and reduce the spread of the flames, an appropriate chemical structure and the addition of flame retarding components are required. As already mentioned, aromatic polyester polyols and polyisocyanurate (PIR) structures, for example, contribute to fire safety. The use of halogen-containing polyols is also usual. Non-reactive additives are trialkyl, trishalogen alkyl and triaryl phosphates. Triethyl phosphate, tris-chlorisopropyl phosphate and diphenylcresyl phosphate are typical examples.

3.5.4 System v Self Formulation

Where a 'system' is purchased, there are three basic elements that come together and are mixed immediately prior to the laydown: MDI; Polyol blend; Blowing agent. There will generally be several different polyol blends for given product depths and line speeds. By opting for a 'system', a turn-key package is supplied by one of the large chemical manufacturers, and the formulation is essentially their intellectual property.

The advantage this gives is that:

- The formulation is 'tried and tested' in similar applications elsewhere.
- It is not necessary to employ specialised polymer engineering resource.
- All technical support is provided as part of the purchase price of the chemical blend. This is backed up by the resources of large international chemical manufacturers.

The downside however, is a loss of control and higher cost.

- Where individual elements are used, much more control can be exercised.
- Control / reduction of density is a critical parameter as it dictates cost per metre.

- Change of formulation to use cheaper components.
- Control of mix to influence product behaviour eg fire performance, stick, cure time, line speed etc.
- New ideas / breakthroughs etc can be kept confidential from the material suppliers.

Often new manufacturers will employ experienced polymer engineers, but start initially with a purchased system. This represents the quickest and lowest risk means or entering the market, albeit at a unit cost premium. Once staff are trained and experienced in how to run the line, and the complexities of foam laydown are mastered, generally manufacturers will then develop and test their own formulations, and move over to self blend when confidence is reached.

3.5.5 Key Quality issues PIR: what can go wrong.

- **Adhesion**. Careful control of temperatures, pressures, flow rates, surface contamination etc is critical to ensure foam cures with a good bond to facings.
- **Blister.** Similar to delamination, blister can result from the same issues and causes a local delamination to occur, forming a pocket of gas at the surface of the foam that creates a bulge on the board / panel surface. Often occurs when surface is exposed to a build up of heat eg in sunlight.
- **Collapse.** With PIR, the challenge is to maintain good structural performance at the lowest possible foam density. If taken too far, the foam can collapse when cured, shrinking significantly, or have very low compressive strength in service. The early sign is slightly 'V' shaped cut edges.
- **Surface appearance.** Many features can appear in the surface of the board, such as indentations, and with high-speed stream laydown, knit lines, where one stream has not fully knitted to the next, giving a 'ploughed field' appearance to the surface.
- **Warp**. Careful control of thermal shock, and wrapping of the material is needed after processing to prevent boards bowing along their length or across their width, or picking up witness marks from standing on an uneven surface for a length of time. Alternate boards can be turned to help counteract warp tendency.
- **Underfill / overfill.** Line speed has to be matched absolutely precisely with chemical flow rate. Underfill generally leads to poor finish on rise-to face and insufficient depth / collapse. Slight overfill is OK, but significant overfill can cause poor adhesion and collapse. Overfill is evidenced by a slight darkening of the foam.
- **Voids.** Where chemicals have not mixed properly, or there has been a slight blockage in the dispense nozzles, or an excess of blowing agent, gaps can appear in the foam, especially visible at the cut faces.
- **Foil issues.** Principally creases, tears, foil tracking across and bunching on one side.
- **Good side:** The appearance of the rise-from face is generally always better than the rise-to face, as the foam surface is smoother.

3.6 Phenolic

Phenolic has gained about 10% market share in rigid insulation board market. It is a newer technology, and has not been widely adopted yet. It has excellent insulation, and fire retardancy properties, in particular creates a lot less smoke. It can be used in approx 10% thinner depths for a given R value than PIR. It is the most thermally efficient insulant commercially available. It is more difficult to process than PIR, and a high degree of expertise is required. There are currently very few polymer engineers in the UK with sufficient knowledge to do this, probably about 5. There are Board products on the market from Kingspan, and Xtratherm are planning their launch in September 2009. Kingspan is planning a panel product, but this is not yet ready for launch, suffering delamination issues.

[redacted]

Products made from phenolic resins are heavily cross linked, and very stable at high temperature. Typical applications include Bakelite type products: electrical insulators, saucepan handles, Tufnol etc, use in refractory binders in steel making. It is also the principle binder in glass and rock wool manufacture.

Phenolic foam also has a large share of the technical insulation market eg pipes and ductwork, [redacted] It has a much lower Lambda value, but can only be used for temperatures up to 130°C. Other applications include slab stock, discontinuous panel manufacture, injected in situ, mine infill and other applications, where its inert nature, insulation properties and fire retardancy are important.

Phenolic foam was first commercialised by Koppers in the USA as a building insulant in 1980, know as Exeltherm Xtra. It was sold on its excellent thermal and fire properties, and also there was a national shortage of alternative polyurethane foams. It was withdrawn by Schuller, in 1992 who purchased the business, after issues with corrosion of steel roof decking in industrial and commercial applications. The issue led to many claims, some that are still progressing today. The key issue was where there was a slight leak, or insulation facing damage. The ensuing moisture build up, created an acidic situation that caused rapid corrosion of the roof deck.[23] This was not helped by the tendency of phenolic foams to take up and retain moisture.

Phenolic foam is made from liquid resole phenolic resin, surfactant, an acid catalyst and a blowing agent. After foaming into board on a continuous line, unlike PIR, excess water needs to be driven off (approx 10%), at an elevated temperature of c60°C for 1 to 2 days.

3.6.1 Resin.

The liquid resole is formed from reacting phenol with formaldehyde in approximate ratio 1:2 by molecular weight. The reaction is done in the presence of a catalyst such as sodium hydroxide to yield low levels of free phenol or formaldehyde in the resultant resole. Solids content is about 80%, with free water content of 5-10%. There

is also still some free phenol / formaldehyde remaining. Shelf life of the resin is limited, typically 2-3 weeks at 25degC for example. Essentially, if left at a warmish temperature, the resin will fully cross link into a solid, and become unprocessable.

3.6.2 Surfactant

The resin usually comes with a small quantity of surfactant pre-added. Nonionic and silicon based surfactants are normally used at an addition rate of 1-5%. The surfactant reduces the surface tension of the resin formulation to enable the blowing agent to work, and subsequently stabilise the foam to yield a fine cell structure, >90% closed., critical for insulation and strength, and minimising water uptake. Additional foam stabilisers can also be added to the supplied resin.

3.6.3 Catalyst

Elevated temperatures (c80°C) and moderately strong sulphonic acids are used to catalyse the cross-linking reaction and promote foaming. Around 10-12% acid is added by weight. Exceeding this figure can speed up the reaction, enabling the line to run faster, but can leave the finished foam acidic.

Previously sulphuric and hydrochloric acid were used (Eg by Koppers) resulting in poor corrosion performance with the finished product in service. Using some phosphoric acid can be beneficial as it is not corrosive and improves flame performance. It is believed more advanced catalyst packages based on a number of less common acids are being developed to improve corrosion performance further, using esorcinol novolak, diethylene glycol, xylene/toluene sulphonic acid to end up with an acid free product.

3.6.4 Blowing agent

Pentane, as per PIR. And HFCs

3.6.5 Corrosion

[redacted] lab tests have demonstrated that samples of Phenolic resin placed in tap water will reduce the pH to less than 3 (quite acidic) within 48 hours. Although there is not a direct link between pH and corrosion, below pH 4, the passivating corrosion layer on mild steel can dissolve, allowing the rate of acidic corrosion to increase. If chlorides are also present, the rate of corrosion of steel will accelerate considerably at a low pH. [24,25] The problem is exacerbated by the ability of phenolic to absorb water, and not give it up easily. Where there are dissimilar metals in close proximity and available water, a galvanic corrosion cell can be created.

In the initial introduction of Phenolic insulation in 1980 in the USA {Koppers} resulted in severe corrosion of steel decks. [23] This was traced to the strong mineral acids used to catalyse the phenolic resin to produce the foam. It appears the catalyst acid leeched out, in the presence of water and corroded steel roof decking. The products were withdrawn from the market in 1992. Since then, low-acid technology has been developed by TCB, Kesteren [26] and acquired by Kingspan, using less aggressive organic acids. [2]

According to the resin supplier Hexion, residual corrosion is only an issue currently if too much acid is used in the reaction (to increase rate of reaction and line speed). Where only approx 10/12% is used, "residual acidity is not an issue". However, Kingspan have warranty claims currently with respect to pipe corrosion in the field, it is believed this may have been from using too much acid to catalyse the reaction faster, to enable an increase in line speed.

It would tend to indicate, unless Kingspan or others have developed corrosion inhibiting technology, phenolic insulation should not be used in humid conditions, or areas prone to condensation in the presence of metals. Where it gets wet (say, after a leak) it would indicate that it should be removed and replaced. It would appear that the facing is very important to limit moisture uptake and provide a corrosion barrier. In normal domestic applications, the potential for accelerated corrosion is not a significant issue. However it may be a risk in commercial applications, particularly with steel frames, decking, pipes and ducts.

3.6.6 Water uptake.

[redacted] lab tests have shown that water uptake can be an issue with phenolic. Whilst PIR absorbs a very small quantity of water (less than 0.1% by volume) and gives it up again quickly, phenolic behaves quite differently. After 3 days submerged in tap water, an unfaced sample had absorbed 2.4% water by volume, a staggering 600% increase by weight. It dries out again very slowly. This is clearly a cause for concern with the leeching out of acids, producing a damp acidic environment potentially creating a galvanic corrosion scenario.

This would appear to run counter to manufacturers claims that it is water resistant. However this was a submerged test which is unlikely to happen in practice. The facings will protect the material to a certain extent. It is not believed to actually 'wick-up' water to any great extent.

3.6.7 Other Quality Issues

Densities are usually in the range 32 to 50kg/m^3. There are issues associated with phenolic at low densities of shrinkage, crushing, friability, warp etc. Kingspan seem to have kept these issues reasonably in check at 35kg/m^3, (PIR runs at about 30kg/m^3) but higher densities (c40kg/m^3) are probably advisable if better presentation and lower risk is required. Getting the material to actually stick to facings can be a problem too, particularly at lower densities, and with steel facings.

Water has to be driven off post lamination. As the phenolic resin is aqueous, there is an excess of water left in the board. This usually takes 1 to 2 days at an elevated temperature off line. If this is not done correctly, the boards can warp and shrink badly at a later stage.

Friability can be an issue. The material crumbles easier than PIR, and has a lower compressive and tensile strength. PIR tends to be more resilient, phenolic will tend to

permanently crush when compressed. [redacted]

3.6.8 Other factors

As the chemical system is different, higher temperatures are required than with PIR, the additional off line oven is required, the wet foam corrodes the laminator, the line runs a lot slower (<1.5m/min rather than 40m/min+). Generally manufacturers dedicate a line to phenolic exclusively. However this is not essential. It can be made on a suitably adapted hybrid line. [22] → ORS machine manufacturer.

As manufacture of phenolic foams become more established, it is reasonable to assume suppliers and manufacturers will improve or resolve the issues with acidity in the finished product and process ability. Similarly lambdas and densities are likely to reduce further, bringing costs more into line with PIR technology, but with better thermal and fire properties. It would be difficult to suggest a time scale for this however.

Currently of the 300+ continuous board and panel lines installed worldwide, it is believed only 8 have phenolic capability.

10 % Lower compressive strength than PIR typically. Phenolic foam has very low embodied energy per unit thermal performance compared to other insulation materials. Its non fibrous nature has made it the material of choice for use in hospitals, food preparation areas and breweries etc.

3.7 Facings

Facings suppliers

Kingspan use International Converters based in the USA. There are other equivalent products on the market from other suppliers, but these have not been trialled successfully. Mondi are also believed to supply some manufacturers.

The facing has a number of purposes.

- Contain foam during lamination process.
- Add structural strength to the product: it becomes a composite product.
- Adds to R / U value by its reflectance of heat ⇒ Non. Need an air gap to be effective.
- Adds moisture resistant barrier.
- Protects foam from mechanical damage during installation.
- Fire protection: protects majority of board surface from initial exposure to flame.
- A bond-to face in the case of flat roofing, insulated gutters or insulated plasterboard.

The most common foil laminate usually consists of, from inside:

- PIR / Phenolic compatible lacquer
- Aluminium foil

- Paper (adds strength and toughness)
- Aluminium foil, usually printed / branded
- External lacquer – corrosion resistant.

Whilst the majority of board uses foil laminates, some other common facings include glass reinforced paper laminate, glass tissue, embossed aluminium foil. Different facings are used for more specialist applications such as insulated plaster board, bonded or through fix, flat roofing bonding or through fix etc.

During processing, the critical element is getting the PIR or Phenolic to stick to the surface. Any form of surface contamination is a disaster, and will cause the product to delaminate. So, the material used for the inner face of the laminate facing is critical. The ability of the supplier to ensure the properties of this inner face remain constant from metre to metre and batch to batch is absolutely critical.

4.0 Fire performance, Fire regulations and testing

4.1 Fire Performance PUR / PIR

PUR: Performance in a fire is inferior to PIR. It is not accredited by LPCB or FM for building envelope use. Board does not generally achieve class 1 in BS476 fire tests. It will burn steadily and tend to collapse in a fire situation. It will also tend to flashover. It is still used in some applications such as discontinuous manufacture of panels for cold stores, refrigerators and PVCu door infill in the UK, due to its ease of processing. Apart from this, all structural / insulation applications have moved to PIR.

PIR: Has essentially eclipsed PUR. It is generally regarded as safe to use in the majority of construction applications. It is widely approved by regulators and insurers. Classed as 'class 1' non combustible material in BS476 tests. It achieves LPS1181 building envelope tests with suitable facings. It achieves Euroclass B or C, s2, d0 in ISO13823 Single Burning Item tests. [45 Recticel, B,s2,d0] Can be rated to 30 minutes and 60 minutes (FR60) in boundary fire wall situations in a suitable panel system.

Celotex have a PIR product that can now achieve Class '0' [31] It would presumably also achieve Euro B, s1, d0.

However, in use, board is likely to have little exposure of the PIR core to a fire, as it is generally behind plasterboard, block or concrete. Where the board is most vulnerable is at the edges of the panel, where flame can reach the foam surface immediately.

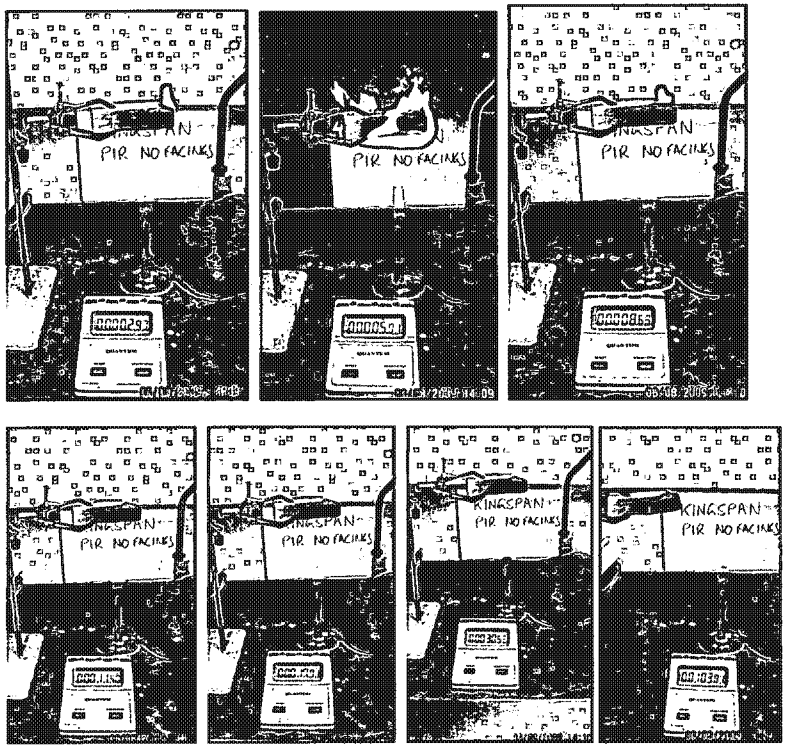
When exposed to flame, PIR foam will tend to burn a little on its surface, with significant smoking. A protective char layer is formed quite quickly, which protects the material below, and significantly reduces the smoke generation. Under prolonged attack, the board is quite stable like this, and will continue to char and burn at a very slow rate. It will take over ½ hour for a 700^{0}C flame to propagate all the way through 100mm of unfaced material. During this time, the board retains its mechanical properties, ie remains rigid, and load bearing capability only diminishes slowly overtime.

The insulation properties of the foam remain intact during the fire, therefore, unless there are any gaps, heat does not penetrate the insulation to any significant degree. For example the standard customer demonstration test involves subjecting foam at room temperature to flame at 1000^{0}C. There is initial smoke generation, and limited combustion until a protective char layer forms. Combustion is self extinguishing, and the flame only raises the opposite site of the board to less than 60^{0}C after 15 minutes.

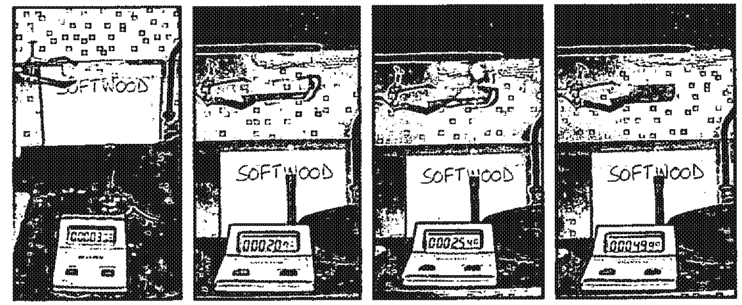
Recent experience has shown that buildings constructed of PIR sandwich panels have remained quite stable for long periods during building fires, and the Fire Brigade will enter burning buildings with PIR envelopes without fear of collapse. Investigations into each of the recent fires in PIR insulated buildings has identified something other than the foam core to be responsible for, or contributed to, the damage and loss. This is often used by Kingspan in industry forums to reinforce the message about safety of PIR. Recent advertising and lobbying by Rockwool and others to say PIR is not safe in a fire has largely been ignored by insurers, specifiers and installers.

~~Smoke generation is however a major issue. PIR generates a large volume of dense acrid smoke when first exposed to fire.~~ This reduces as the foam chars over. The cells in the material contain some pentane, so this contributes in a small way to the burning characteristics. If necessary, this can be substituted for less flammable blowing agents such as 365 / 228 etc, to the detriment of unit cost and lambda.

4.2 Burning characteristics of PIR compared with other materials.

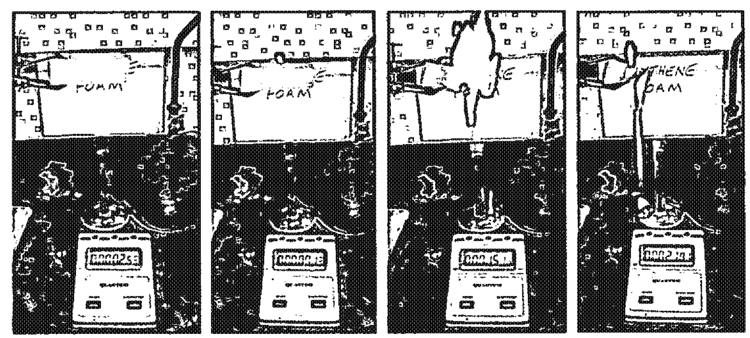


Un faced PIR ignites after 2 seconds, burns and smokes for around 5 seconds and then forms a stable protective char layer, with minimal rate of burn. Does not smoke or support combustion when taken away from flame.



Soft wood takes 20 seconds to ignite, but then burns steadily with only partial char protection.

Isover High performance Duct Wrap ignites after 2 seconds and then ceases to burn after 8 seconds.



EPS ignites after 7 seconds and then burns vigorously. Flaming droplets start at 15 seconds. By 20 seconds there is no material remaining in the flame path.

4.3 Smoke Toxicity

All organic materials such as wood or plastic foam insulation evolve toxic decomposition products when burning. Of the toxic smoke products, carbon monoxide [CO] is recognised as the main toxicant in fires, and is present when any organic material burns, and "*most natural and made-made materials are more similar than different in this regard*" [32]. Hydrogen cyanide (HCN), elevated level of carbon dioxide (CO_2), soot particles and reduced oxygen are also important in their contribution to the asphyxiating characteristics of smoke gases. [33] [36] HCN is present when PIR burns due to the presence of Nitrogen compounds. There are other components in smoke gases that cause sensory irritation to eyes and the upper respiratory tract. These compounds include acid gases produced from the combustion of halogen containing materials [where hydrogen chloride, HCl, is the most common]. Many of these products are present when any organic material burns. Studies have shown that "*The animal experiments, which complied with the test and assessment criteria put forward by the experts of ISO TC92 SC3 'Toxic Hazards in Fire', provided convincing evidence that the overall toxic potency of the decomposition products released by polyurethane foam and PU coatings under comparable fire conditions was the same as for wood or wool.*" [34]

Contaminant	Concentration (ppm)¹		IDLH (ppm)
	Mean	Maximum	
Acrolein	1.9	98	5
Benzene	4.7-56	250	3,000
CO	246 – 1,450	27,000	1,500
HCl	0.8 – 13	280	100
HCN	0.14 -5.0	75	50
NO_2	0.04 – 0.7	9.5	50
SO_2	2.3	42	100
Particulates*	232	15,000	n/a

Table 1: Common combustion product concentrations in residential fires [36]

*Particulates are given as mg/m3. The particulate count can often include glass and mineral fibres liberated when binder burns off. IDLH stands for a concentration defined as "immediately dangerous for life and health". Data taken from Burgess and Crutchfield (1995).

4.3.1 Smoke generation PU v PIR

The behaviour of the specific type of polyurethane is important to determine in any fire test. Most studied discuss 'polyurethane', but this is a broad range of materials including open and closed cell foams, solid materials coatings, and materials with and without flame retardants.

YES

- A key point to note is that PIR forms char layers very quickly when exposed to naked flames. This then reduces the level of smoke generation very considerably, hence quantity of HCN that can develop.
- The majority of PIR foams have an added flame retardant.
- High index PIR burns and smokes much less readily than PU/Low index PIR.

- Toxic gas is produced in direct proportion to smoke, so a low level of smoke generally means a low concentration of toxic smoke. [34]

4.3.2 Type of Fire

There are various scenarios and stages to a fire, and the volume and composition of smoke varies considerably.

- Incipient:
- Growth
- Fully developed
- Decay

This in turn has an impact on the smoke produced.

- Smouldering
- Well ventilated fires
- Poorly ventilated fires (pyrolisis)
- Post flashover fires.

~~Smoke generation is at its greatest after the point of ignition, when full combustion is taking place~~ (Growth, fully developed). When the source of ignition is removed, flame-retarded PUR and PIR will stop burning, and smoke will reduce significantly. This is the opposite of celulosic type materials such as wood, where most smoke occurs in incipient and decay stages.[37]

4.3.3 CO Carbon Monoxide

CO is released when all organic substances burn. It is highly flammable, so if there is sufficient free oxygen, will burn. It poses the greatest threat in hot confined space fires where incomplete combustion takes place.

4.3.4 HCN Hydrogen Cyanide.

Is produced from burning, wool, silk, cotton, nylon, melamine, polyacrylonitriles, synthetic rubber, green wood, vegetation, polyurethane based paint and varnish as well as PIR and PUR insulation. It is also present when mineral wool burns. (It is not produced from Phenolic foam as there is no **Nitrogen** in the formulation). [35]

It is produced when many everyday household items burn. The principle source is man-made plastics and resins eg nylon, polyurethane, melamine, acrylonitrile (ABS). Common sources are therefore clothing, furniture, toys (eg Lego bricks) domestic plumbing, kitchen cabinets, carpets and domestic insulation. All refrigerators / freezers are insulated with polyurethane foam.

It is produced when there is a combination of high temperature and limited oxygen, such as a hot fire in a confined space. HCN, like CO (carbon monoxide) is highly flammable.

It is estimated to be 35 times more lethal than CO. It can incapacitate victims quickly through inhalation and also to a lesser extent, through absorption. It is possible that it may work in synergy with CO to bring on the onset of incapacitation and death. It causes death by metabolic asphyxiation The COSHH MEL is 10PPM for a 10minute or 8hour exposure. LC50 (50% of population likely to die) exposure limit is 135 PPM for 30 minutes, 3404 PPM for 1 minute. [35]

4.4 Fire Performance Phenolic Board

Phenolic foams perform very well in a fire situation. It is regarded as safe to use in the majority of construction applications. It is widely approved by regulators and insurers. Classed as 'class 1' non combustible material, in BS476 tests. It also achieves Class '0' for UK building regulations. Achieves Euroclass B, s1, d0 in ISO13823 Single Burning Item tests.

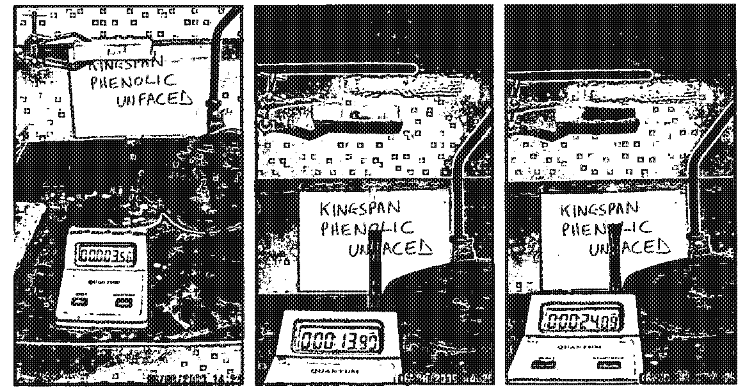
It combines zero or very low flame spread with negligible smoke emission and a very low level of toxic gas emission. Phenolic foam can, in an appropriate form, achieve all the following European fire certifications:

UK Class O
Dutch NEN 6065/6066 Class 1
German B1
Belgian A1
French M1
Scandinavian NT 036 Class 1 [38]

In addition, phenolic foam used in composite panels can achieve up to 2 hours fire resistance rating (insulation/integrity) in the 3m furnace test (LPS1181). It evolves exceptionally low smoke when exposed to fire and is capable of meeting or exceeding all international building regulation requirements. [38]

~~Toxic gas emission from phenolic foam is generally limited to carbon dioxide and carbon monoxide with very low levels of other gases.~~ Phenolic foams can achieve very low toxic gas ratings in tests such as UK Naval Engineering Standard NES 713 and Scandinavian NordTest NT036. Exceptionally low smoke emission - less than 5% when tested in accordance with BS 5111 :Part 1 [38]

However phenolic foam is still an organic material. Although it easily achieves B, s1 standards, Warrington Fire estimate that no product with more than 8-10% organic content would be able to achieve an A1 or A2 in the ISO 13823 SBI test. [30]



The surface of un-faced phenolic burns and smokes very little. A stable, protective char layer is quickly formed.

4.5 Fire Performance in Context

It is important to put the smoke generation, and relative lower fire performance of PIR, and to some extent, phenolic systems compared with glass wools into context.

Although smoke generally plays a decisive role in the survivability of a fire, it important to recognise is that the in the case of fires in buildings clad or insulated with PUR, PIR, Phenolic and mineral fibre panels, ~~the vast majority of smoke and toxic gas is generated by the burning contents of the building. The insulation is not significantly affected until the fire is fully developed and the mass of burning material present in the insulation can be very small compared to the burning mass in the building.~~ Concerns about toxic gas and smoke emissions from the insulation must be put into context compared to toxic gas emissions from all other burning elements within the building. ~~The BRE concluded from analysing 2002 UK fire statistics that wall and ceiling linings were responsible "*for very few, if any, deaths or injuries*"~~. [43]

Tests have shown that with wood based materials, the majority of smoke and fumes are produced before, and after full flaming, so a particular hazard at the beginning of a fire, ie the smouldering phase when people are trying to escape. [37]

With PIR/PUR board, the rate of smoke and fume generation relates to the rate of burn of the material. Therefore, a hazard in a growth / well developed fire only. As the products are used behind other materials~~, it is unlikely that toxicity of gases will become an issue to people escaping from the early stages of a fire, more for fire service personnel bringing a fire under control~~. [37]

It has been proven that in fires involving large quantities of nitrogen / chlorine containing products, smoke toxicity can be the dominant factor in determining survivability. Eg Rhode Island nightclub fire, Manchester Airport Boeing fire. [35]

However, these circumstances are fortunately infrequent. It would appear most buildings do not have sufficient concentrations of nitrogen containing products for it to be a decisive factor.

~~It would appear likely that the probability of survival of anyone remaining in building at the stage where the fire has become fully developed in a significant quantity of the insulation, is unlikely to be much affected by the choice of insulation~~ material.

In practice:

- Boards are always used with a foil facing, and butted together, so the surface exposed to a flame is very low.
- Boards are not generally used as building lining, they are usually behind: Floors: concrete, wood. Walls blocks, plasterboard. Roofs plasterboard. In a fire, they are not likely to be exposed to flame in the early stages of the fire.
- ~~Although PIR begins to breakdown at 260°C, it will not spontaneously combust until exposed to temperatures in excess of 415°C.~~
- When used in a building context, the building is very likely to contain items that will burn much more readily, and produce toxic fumes, such as fabrics, upholstery, wooden/ composite furniture, thermoplastic articles, PVC windows, doors, plastic light fittings etc.
- The risk to people from toxic fumes alone is at its greatest in the earlier stages of a fire. It the later stages, the heat and flame are a much greater risk. In the initial stages of a fire, it is very unlikely that the insulation will play a significant part in the fire.
- All organic products will produce similar products of combustion. Limits on use or organic insulants would also tend to limit the use of wood and other common construction materials in buildings as well.

It is for these reasons that the several manufacturers favour full-scale tests such as the LPS1181, that realistically simulate products installed as per the manufacturers recommendations, in a realistic fire scenario.[39]

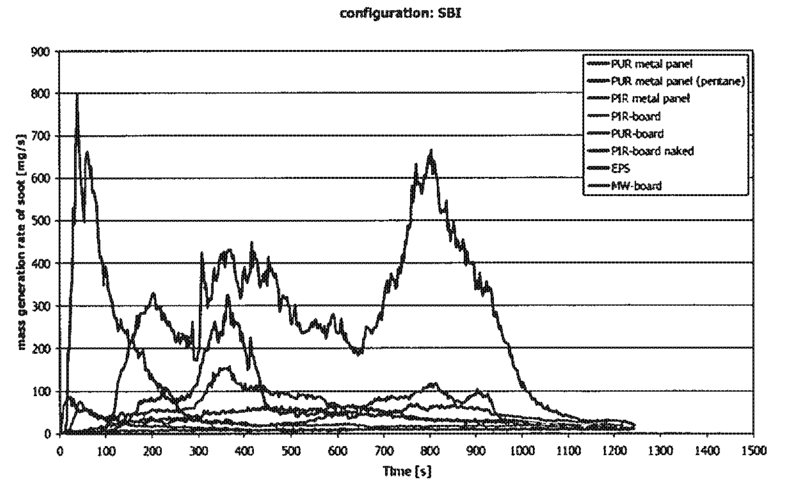


Figure 5.8.1.1: mass generation rates of soot – SBI configuration

Smoke test: PIR (pink, purple) performs significantly better than PUR or EPS (green, dark red, blue, black), but not nearly as well as mineral wool (turquoise line)

4.6 Insulation Products Compared: toxicity

Material	LC_{50} (g)	LT_{50} (min)	CO (%)	HCN (ppm)	Remarks
EPS	5.8	11	1.95	--	
PUR	7.5	17	1.20	130	Fluorocarbon blown, no flame retardant
Cellulose	11.9	21	4.0	--	Blown fibres for insulation
Glass fibres	35.7	25	n.a.	--	4.4 cm building insulation pane with paper and vapour barrier

Table 2: Comparative toxicity of smoke from burning construction materials: all can be fatal dependant on quantity present and length of exposure.

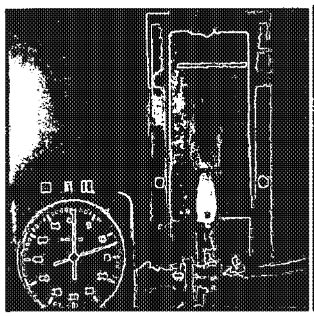
LC50 indicates the amount of material to cause smoke concentration that is fatal to 50% of rats when burnt at 822°C. LT50 shows the time until death of the rats under same conditions. 1% equals to 10,000 ppm (part per million, vol./vol.). EPS denotes expanded polystyrene. Addition of a flame retardant would prolong the LT50 for EPS and PUR. Data taken from Alarie, 1985 and Levin et al., 1987a. Lethality of EPS is regarded as the greatest due to volume of sooty smoke and CO produced.

4.7 Fire reaction and fire resistance

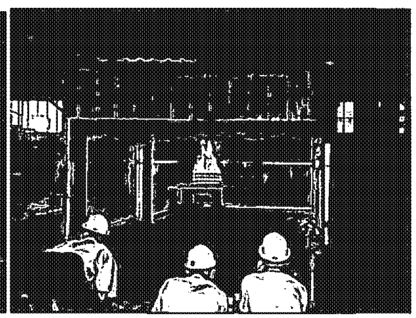
~~Reaction to fire assesses how a specific material or composite product reacts when exposed to heat which can be in the form of direct flame impingement, radiant heat or high temperatures.~~ Typical parameters normally measured include ignitability, flame spread and rate of heat release. In the UK and Ireland reaction to fire is assessed by several parts of BS 476 including Parts 4,6,7, & 11. Over the next few years these tests are being replaced by the Euro classification system. All these tests are relatively small scale and do not allow insulated panel or boards to be tested in realistic as-installed configurations.

A much more relevant reaction to fire test is the LPCB test LPS 1181. This is a large scale test which tests the panels in a realistic situation. The advantage of LPS 1181 is that the grading system covers both reaction to fire and resistance to fire, ~~Resistance to fire is a measure of the passage of heat and flame through the thickness of a material and the test structure comprises a panel system fixed to a furnace.~~ In the UK and Ireland BS 476 Part 22 is used to assess fire resistance. This test will be eventually replaced by European test EN 1364. In the context of cladding systems the insulation rating is the time taken for the non-furnace face to increase in temperature to approximately 200°C. Integrity failure is when flames break through the joint detail. [38]

Both reaction and resistance to fire play a key role in Building Regulations and Insurer Approved tests.



Small Burner test



LPCB LPS1181

4.8 Fire Performance Tests and Regulations

The current UK BS 476 tests are currently widely used to assess the performance of building products against Building regulations. Euro classes were introduced in May 2003, and run in parallel with the National tests. At some point in the future, it is anticipated that the Euroclass system will become harmonised across Europe. Some manufacturers assess their products under both systems, some just one or the other.

There is some resistance to adopt the Euroclass system in the UK. The reason being that materials are tested in a lab scale test (eg Single Burning Item), rather than in a 'installed' context. [38]

Euro class tests are based on a Single Burning Item ISO 13823, in an accelerated burn scenario where flaming is directly on the sample in question. They therefore tend to favour more inert materials such as mineral wools, are fairly realistic for materials that burn readily, and are over critical of products that normally burn slowly, such as PIR foams. [39]

These reasons contributed to the decision to limit the Euroclass fire classification to heat-release only. Building Regulations approved document B, 2006. Contains no limits on smoke production, or limits on burning droplets. [40]

It would appear that national test standards have served quite well in ensuring buildings are reasonably safe in a fire. It maybe that this has created a reluctance to move away from them to new styles of test that might not be realistic enough to actually make buildings safer. A 2005 BRE study into whether UK Building Regulations should be amended to reflect smoke and burning droplets concluded " *In summary, the overall results from this project indicate, at this time, there would be no significant benefit in the introduction of stricter additional classifications for smoke and falling flaming droplets and/or debris for wall and ceiling linings."[43]*

Another concern with the Euroclass system is that it can heavily penalise an item with a surface coating (eg paint) as this will tend to burn quickly and give a poor result, but in a real fire situation have little impact on the overall fire loading.

Insulation materials are usually sold with reference to their performance when exposed to heat and flame as if they were lining materials, but this is generally not actually relevant. It maybe of more relevance to quote a duration the product can be exposed to a fire before flame breaks through, but this is rarely quoted.

When tested for fire resistance to BS476 Part 21, a timber frame wall, with foil-faced PIR insulation and a plasterboard inner face will exceed the stipulated 30 minute duration. This performance can exceed that of a similar wall insulated with mineral wool, as the wool can tend to contract away from the source of heat, allowing fire to pass through sooner. [39]

Paschen & Wittbecker 1995. The fire parameters heat release, smoke density and burning debris in particular are dominated by the underlying scenario. All fire test methods therefore have limitations as far as smoke assessment is concerned, and a correlation between methods is not to be expected. These statements are further confirmed by comparing the results between SBI and ISO 9705. Almost all celulosic materials generated more smoke in ISO 9705 than in the SBI, and vice versa as far as plastics are concerned. It cannot be assumed that the single simulated fire scenario leads to a general risk-oriented assessment.[39]

Their studies have demonstrated that:

- SBI test is a harsh test giving a worst case burning scenario.
- When modelled with Computational Fluid Dynamics it has been found that fire results correlate closely with tests done with an ISO 9705 test hood in place.
- Under SBI, naked products perform reasonably similarly to a realistic scenario.

- Under SBI, products with facings can perform 4 or more times worse than a more realistic scenario.
- Under SBI, wood based products tend to perform better than reality and polymer based products worse than reality.

4.9 Certification |44|

Euro-classification is according to BS EN 13501 -1 which is supported by the test methods:

- BS EN ISO 1716:2002 - Reaction to fire test for building products - determination of the heat of combustion
- BS EN ISO 1182:2002 - Fire test for non-combustibility of building products

However, our Regulations still allow British Standard test certification, as follows:

- BS476 Part 4 - non-combustibility test
- BS476 Part 6 - Fire Propagation test
- BS476 Part 7 - Surface Spread of Flame Test - this gives results of Class 1 to Class 4

In general BS476 is a stand-alone test to show non-combustibility of a product.
Class O is in itself not a fire classification, but a Building Regulations definition. Class O can be achieved either by testing to BS476 Part 4 **OR** passing both the Parts 6 & 7 tests.

Current UK regulations are a bit of a mish-mash, allowing some manufacturers to use BS references (eg Kingspan) and others (minerals wools mainly) using Euroclass. Note that where insulation manufacturers CE mark, they must state the Euro-Class rating.

[redacted] CE marks & thus certify to Euroclass, but also needs BS ratings as many industry specifications still historically call for them.

BS476 Part 3 deals with test method for external fire exposure to roofs.

BS 5111-1, to the best of my knowledge, was withdrawn and replaced with BS ISO 5659 - 2 1994 but is still quoted by some manufacturers, eg Kingspan., which relates to the smoke generation of foam plastics.

BS476: Part 22 certification is required for fire barriers, which relates to fire resistance of non-load bearing construction elements, not just the product.

LPC is needed by producers of insulated panels (foam and rock wool cored)

BBA certification generally does not cover fire, although fire is referenced in BBA certificates to the above BS or EN as appropriate. With BBA certification the fundamental criterion is weather resistance.

4.10 UK Building Regulations Part B1, B2 Fire Safety Dwellings & Non dwellings

Building Regulations currently apply to the materials used to line walls and ceilings, and to the duration of resistance of the building structure. There is no specific building regulation for the insulation material. Under current Building Regulations, there is no reference to 's' smoke production or 'd' burning droplets formation for room linings. Synopsis of what maybe relevant:

B2 Linings of rooms larger than 4m2 must meet Class 1 (Euro C, s3, d2). Parts of the walls can be to a poorer standard, up to a max of half the area or 20m2 can be Class 3 (Euro D, s3, d2).

B3 Structure Defined as resistance to collapse (Euro R), resistance to penetration Euro E), resistance to heat transfer Euro I. Where a requirement is specified, this is generally 30 minutes for buildings up to 5m height, and 60 minutes for buildings above 5m. Roof is not treated as structural unless it has a floor, is used as a means of escape or supports part of the structure. Cavity barriers must achieve 30 minutes where specified.

B4 Boundary. External surfaces within 1m of a boundary must achieve class 0 (Euro Class B, s3, d2.) for 92% of their surface.

Roofs less than 6m from a boundary must achieve National AA, AB, AC (Euro B roof) Tested by BS476 -3.

4.11 Phenolic, PUR and PIR rigid board compared |41|

Table 6.27. Ignition and opposed flow flame spread data for rigid foams (LIFT, NIST)

Foam	$(q_{ig})^a$ (kW/m²)	$(t_{ig})^b$ (°C)	$K_{\rho c}{}^c$ (kW/m²K)2ₛ	Φ^d (kW²/m³)	$(q_s, min)^e$ (kW/m²)	t_s, min^f (°C)
PUR	21.0	445	0.037	8.8	7.7	176
PIR	30.0	445	0.021	28.0	10.8	201
Phenolic	30.0	524	0.11	0.15	28.0	509

[a] (q_{ig}) minimum heat flux for ignition.
[b] (t_{ig}) temperature of ignition.
[c] $K_{\rho c}$ thermal inertia of material (product of thermal conductivity, density and heat capacity).
[d] Φ flame heating parameter.
[e] (q_s), min minimum heat flux for flame spread.
[f] (t_s), min minimum surface temperature for flame spread.

PIR significantly better than PUR, but phenolic has much higher ignition temperature, and requires a much higher temperature before flame will spread across surface.

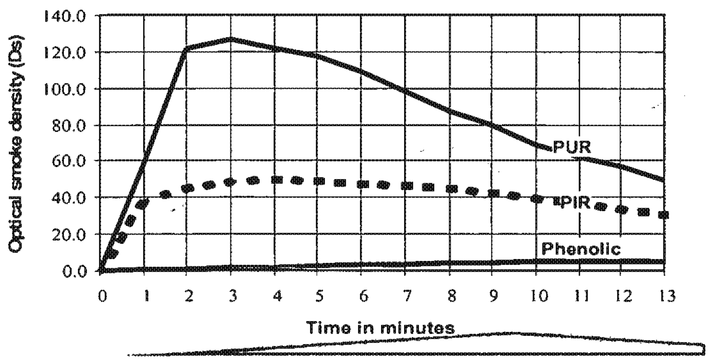
Table 6.28. Cone Calorimeter test data of rigid foams (heat flux = 50 kw/m²)

Foam	$(t_{ig})^a$ (s)	PK HRR^b (kW/m²)	THR^c (MJ/m²)	H_c^d (kJ/g)	σ_m, ave^e (m²/kg)
PUR	4	147	13.9	10.0	403
PIR	3	79	4.7	9.1	264
Phenolic	9	111	36.0	14.2	72

^{a} (t_{ig}) ignition time.
^{b} PK HRR Peak heat release.
^{c} T HR total heat release.
^{d} H_c heat of combustion.
^{e} σ_m, ave specific extinction (obscuration).

PIR ignites quickly, but releases 1/3 of the heat of PUR and 2/3 as much smoke.

Optical Smoke Density Measurement



[2]

Additional sources used, fire performance [42]

5.0 Health & Safety

The specific health & safety issues associated with PIR insulation manufacture are outlined below.

5.1 MDI

Prolonged close exposure to MDI can lead to sensitisation to the material from inhalation of fumes and prolonged skin contact, and can lead to asthma – like symptoms. These symptoms disappear when not in contact with the material. It is believed only one person is so affected in Kingspan, a commissioning engineer, with 30 years service, and repeated long exposure to MDI liquid and vapour. He has not stopped work, just takes more care with limiting MDI exposure.

Generally speaking, MDI vapours are only present in the lay-down area, and extraction for pentane vapour has the dual benefit of keeping MDI exposure low. ~~MDI and uncured PIR foam leave nasty staining on skin. Staff generally always wear disposable gloves when handling these materials.~~ Routine periodic respiratory tests can be done on staff in close proximity to the MDI. Records are kept of who has worked with the material and for how long. [49]

Lab foaming tests are usually done in a fume cupboard vented to atmosphere.

Maintenance is usually done in disposable overalls, gloves, safety glasses. Face masks can also be worn if required.

Area of risk	Countermeasure
Tanker off load	Outside, no special precautions taken.
Storage tank	Internal. Kept at approx 28 deg C. Vent to atmosphere
Supply pipelines	Mild steel, flanged
Main pump room	Well ventilated. Extraction to atmosphere
Laydown area	Extraction to atmosphere.
Laminator enclosure	Extraction to atmosphere.
Boards after lamination but before full cure	Stored in well ventilated area.
Boards, post cure	No precautions taken.

MDI is the most common form of the family of chemicals know as Isocyanates. It is one of the lowest hazard isocyanates. The most common grade is 4,4' MDI, 2,4' MDI is also sometimes used. It is not to be confused with: **Hexamethylene diisocyanate** (HDI) which is an aliphatic diisocyanate. It is produced in relatively small quantities, accounting for (with isophorone diisocyanate) only 3.4% of the global diisocyanate market in the year 2000. Aliphatic diisocyanates are used in special applications, such as enamel coatings which are resistant to abrasion and degradation from ultraviolet light. These properties are particularly desirable in, for instance, the exterior paint applied to aircraft. This is an extreme respiratory irritant, where usually air-fed masks and full skin coverings are used when spraying. These precautions are not normally taken with MDI. HDI would never be used in foam manufacture as it produces long molecular chains not the cross-linked chains required.

Substance	UK Workplace exposure limit 8h mg.m-3	UK Workplace exposure limit 15mins mg.m-3	Highest exposure reached in practice mg.m-3	Comment
Isocyanate	0.02	0.07	<0.0005	HSE class all isocyanates together 'sen': capable of causing workplace asthma.
PIR dust	10	-	1.2	No specific limit as HSE do not class as hazard.
Pentane	1800 mg.m-3 600 ppm [LEL=1500ppm]	-	<15% of LEL	HSE R12, 51/53, 65, 66, 67. Highly flammable, toxic to aquatic life, may case skin dryness, drowsiness, harmful is swallowed.

[46] [47]

5.2 Pentane

Various blowing agents can be used in PIR foams, but most common currently is pentane. This is highly flammable liquid, but boils at a low temperature, between 28 and 36°C dependant on grade. Risks are similar to handling petrol. It is usually delivered by bulk tanker to an above or below ground storage tank. Offload can have deluge sprinkler protection. The tank is double skinned and bunding. It is usually recirculated constantly around the factory and back to the tank to keep the temperature constant. It is pressurised near the line, and injected at the mixing head. There is some release of gas during panel filling, and during start / stops. This is captured by the lay down extraction system.

Where explosive atmospheres can build up, there are Drager sensors usually applied at floor level to detect for leaks as pentane is heavier than air. The usual procedure is to have trigger points 15% of LEL (lower explosion limit) and 30% of LEL. The lower level will set off an alarm. Extraction automatically goes to maximum. Normal procedure is to stop production locally and investigate issue. A 30% alarm would automatically shut down pentane delivery system and the plant. All extraction would go to maximum, and plant will be evacuated except for key personnel investigating and dealing with the issue.

All personnel working around the laydown areas (operators, fitters, polymer engineers) are given detailed training. In practice, the number of incidents are usually very few and minor in nature.

Principle areas of concern are:

Area	Countermeasure
Tanker off load	Controlled access. Close supervision. Deluge sprinkler system.
Storage tank	Located away from main building. Restricted access. Bund.
Supply pumps	Located outside in tank bund
Supply pipeline	Mild steel, all welded construction.
Mixing pump	In separate un-manned enclosure within building. Drager sensors. Extraction to atmosphere. Explosion proof lighting, fittings etc.
Main pump room	Drager sensors, Extraction to atmosphere
Laydown area	Drager sensors. Extraction to atmosphere.
Mouth of laminator	An explosive atmosphere exists in this area inside the laminator. This would extend out side the laminator approx 2m2. Explosion proof lights / fittings etc used in this area.
Laminator enclosure	Drager sensors. Extraction to atmosphere.
Boards after lamination but before full cure	Stored in well ventilated area.
Boards, post cure	No precautions taken.

5.3 Other PIR Chemicals.

Some of the catalyst additives used are potential carcinogens. Which catalysts are used is determined by the polymer engineer developing the formulation. Exposure though is generally very low as they are in fully enclosed systems. Inclusion percentages are less than 1%. Flow rates typically in the range 0.02 to 0.4 litres per minute. Appropriate PPE for maintenance staff limits exposure. Where a chemical 'system' is purchased, all minor additives are already included in the bulk polyol delivery, so there is no possibility of direct exposure to the undiluted potential carcinogen.
Maintenance is usually done in disposable overalls, gloves, safety glasses. Face masks can also be worn if required.

5.4 Safety Issues Phenolic Foam

Pentane: similar to PIR, proportions used similar. As the line would typically run at 1/3 of the speed of PIR, volume of pentane released to atmosphere is proportionately reduced.

Formaldehyde.

Formaldehyde is present in the phenolic resin.

Comparison with Glass wool manufacture.
Phenolic resin used to make binder. Deliveries, 3 tankers per week / Runcorn. Mixed with ammonia etc to form binder. Sprayed onto glass fibres. Majority of excess material will be scrubbed out / disappear to atmosphere via the flue. Low levels of formaldehyde registered in most areas of the plant. Levels usually below 0.020 PPM.

[48]

With board manufacture, bulk handling / mixing of phenolic resin is very similar to glass wool. Exposure can occur principally in three places:

- Laydown, where the phenolic foams. Exposed foam will be approx 5m^2 when running. Area surrounded by extraction.
- Laminator. Usually in a controlled enclosure at an elevated temperature. This is usually a non-working area with controlled access and extraction.
- Oven: formaldehyde is driven off with water over a period of 1 to 2 days. Again this is in a controlled enclosure at an elevated temperature. This is usually a non-working area with controlled access and extraction to atmosphere.

Substance	UK Workplace exposure limit 8h	UK Workplace exposure limit 15mins ppm	Highest exposure reached in practice, ppm	Comment
Formaldehyde	2.0 ppm 2.5 mg.m-3	2.0 ppm 2.5 mg.m-3	0.02 mg.m-3 (0.02 ppm in Glass wool)	HSE R23/24/25, 34, 40, 43 Toxic by inhalation, in contact with skin and if swallowed, causes burns, Limited evidence of a carcinogenic effect, May cause sensitisation by skin contact.
Phenol	2.0 ppm 7.8 mg.m-3	-	0.1 mg.m-3	HSE Sk R23/24/25, 34, 48/20/21/22, 68 Can be absorbed through skin. Toxic by inhalation, in contact with skin and if swallowed. Causes burns. Harmful: danger of serious damage to health by prolongedexposure through inhalation, in contact with skin and ifswallowed. Possible risk of irreversible effects
Phenolic foam dust	10 mg.m-3	-	1.2 estimate	Assume no specific limit as HSE do not list as hazard.
Pentane	1800 mg.m-3 600 ppm [LEL= 1500 ppm]	-	<15% of LEL	HSE R12, 51/53, 65, 66, 67. Highly flammable, toxic to aquatic life, may case skin dryness, dizziness, drowsiness, harmful is swallowed.

[2] [47]

Formaldehyde levels near the fully cured finished products are very low, similar to background levels found typically in homes of 0.05ppm (due to emissions from textiles, furniture etc). It is not expected that the normal 0.05ppm level will be exceeded in homes insulated with rigid phenolic board.

By comparison, Over 1 million homes have been insulated with injected urea formaldehyde foam (UFFI). A largely impermeable inner wall is required to keep ppm levels low in the home post injection. Typically levels will rise to no more than 0.15pmm over the first few weeks post installation, before decaying away. In worst cases levels can rise to 0.5-1.0ppm in the first few days post injection. Good ventilation is required.

5.5 Environmental

PIR (and phenolic) board is regarded as environmentally friendly, securing BREEAM A ratings in their green guide to specifications. Celotex secures as A+ rating for their products. [31]

Kingspan has made sustainability and environmental management a key part of their corporate strategy, taking time to educate the market, and winning numerous construction sustainability awards. This has resulted in the perception of foam to be very positive from an environmental perspective. There have even been instances where products based on foam technology (eg Energi Panel, Gazeley) have helped developers secure planning permission for buildings with a very low environmental impact, that would not have been secured with a more conventional building.

Recycling

Polyol is often made from recycled materials such as PET bottles. Laminate facings can be made from recycled foil and kraft paper.

Energy.

There is moderate gas and electricity consumption in the process. Buildings and materials need to be kept warm, over 25^{0}C, year round. Laminators require heating to approx 70^{0}C, but once the exothermic reaction is going, tend to not to need much additional heat input. ~~A one line factory would probably consume about £200k of electricity and £80k of gas in a year at full output.~~

Solid waste

Foam and foam dust are the principle solid wastes produced from manufacturing board. With conventional restrained rise lines, this probably equates to about 4% of output. With free rise (Celotex) the waste is higher, probably about 7%, due to increased edge trim.

The waste comes from: edge trim (conventional <1.6%, free rise <9%); saw cuts; rebated edges; changeovers; scrap.

The principle outlets for the materials are as follows:

- Use as packaging. Scrap can be cut up to form skids, avoiding the purchase of pallets, and side impact protection blocks.
- Compaction of dust into briquettes and shipping to 3rd parties for use as inert filler. Eg processing with resin into board.
- In particular with panel, reincorporation of foam crumb into the foam liquid laydown, at the rate of <3%. This may also be possible with board.
- The remaining material is generally land-filled.
- It is also possible to fill long bags with foam crumb for use between rafters as loft insulation.
- Other solid wastes are generally limited and can be compacted, stored and recycled eg foil, polythene, cardboard, etc. [50]

Liquid waste

Liquid wastes are very limited. Rejected chemicals are generally returned to the supplier. Polyol blend and MDI are sometimes used to purge lines and do calibrations etc. This can normally be reincorporated at a low inclusion rate. The occasional IBC of mixed chemical spillages etc would be generated during a typical year. This would be disposed of as special waste for incineration. There is no trade waste drainage required on site. Empty drums / IBC's are stored and returned to the suppliers.

Other factory Emissions

A small quantity of pentane and MDI fumes are vented to atmosphere, but these are essentially too low to measure. Similarly with formaldehyde and phenol.

A small amount of foam waste will typically get blown around the site by the wind. Good housekeeping keeps this under control.

The only noisy processes are sawing / rebating boards. These are usually enclosed in acoustic enclosures. There is virtually no noise emission outside the building.

Site waste

Site waste takes the form of board off-cuts. These are generally sent to land fill. There is **no** restriction on this unlike other materials such as plasterboard, for example.

End of life Solutions

It is generally expected that the insulation board / panel will last the life of the building, certainly 50 years plus. Polyurethane foams have only been used for around 30 years, so the issue of recycling has not become a pressing one yet.

As foams have developed over the years, the composition has changed significantly, particularly in terms of blowing agents, where early generation foams contained ozone depleting CFC's and HCFC's with high ODP / GWP. It is not really possible to check a foams provenance when a building is being demolished.

Currently, there is no restriction on land filling these materials. Due to the ODP/GWP potential of early foams, it is best not to break up the foam too much, as the entrapped gas will be released.

The most viable solution for these legacy foams would be incineration in municipal waste incinerators. Currently, these are more common in Europe than in the UK. Generally a temperature of over 415^{0}C is required to ensure combustion. The calorific content of foam is similar to coal at 25,000kJ/kg, higher than Municipal Solid Waste (MSW) but the density is much lower. [50] In trials, the density has proved to be an issue. A practical incorporation rate with MSW of 2% by weight, 30% by volume is the limit. Emissions during combustion are similar to MSW.

6.0 Factory Operation

6.1 Factory process steps [51]

Process	Comments	Process	Comments
Facings goods in / storage.	• Facings on large coils, 1000m plus. Warm, dry store under cover.	Chemical off load.	• Pentane, Polyol, ISO usually delivered by road tanker at a specific temperature eg 28^{0}C Smaller components in IBC.
Facings unwind	• Usually 4 decoilers (2 top, 2 bottom) with auto cut / splice facility. Load and unload with overhead crane to mandrels.	Chemical storage	• Pentane, ambient tank, above / sub-terranean • Poly / Iso bulk storage tanks, temperature controlled. Temperature controlled pipe work. • Other components temp controlled rack storage
Facings conditioning.	• Unlike panel, he facings are usually not pre – conditioned. • Facings are always preheated top / bottom to around 40deg C.	Mixing	• Can either be polyol mix off line (batch) with all of the smaller components, and add Iso and Pentane at the mix head. • Or inline injection, where all components are injected into polyol stream before mix head.
Laydown	• Liquid chemical stream is laid onto moving facing material and begins to foam immediately. • Critical process: very careful control of temperatures, pressures, speeds, flow rates etc. • Upper facing meets foaming stream to form sandwich.		
Lamination	• Facings / liquid foam enter heated double-belt conveyor. • The chemical system and line speed must be balanced so that the foam rises to meet the top face at its most sticky phase. • Foam cures in between moving belts heated to approx 70deg C. Residence time 1 to 3 minutes • Foam constrained at edges by belt flights.		
Post lamination	• Product exits laminator hot but slightly soft solid. Sometimes boxed in to retain heated environment.		
Flying cut	• Cut to length, usually 2400mm. Rotary saw, clamps on to board.		
Phenolic cure (not PIR)	• Phenolic panels enter large moving oven, where heat drives off moisture and allows foam to cure. Residence time 2 days.		
Accumulator	• Stores product, vertically. Residence time gives buffer and allows panels to cool.		
Side milling	• Mill edges to 1200mm.		
Central cut	• If required to 2 x 600mm.		
Cut to size	• Small sheets if running high line speeds		
Wrapping	• Shrink-wrap into small bundles, labelling.		
Stacking	• Onto pallets / skids.		
Offload and store	• Offload to storage. • Usually store to fully cure at approx rate 1 day per 25mm.		

6.2 Factory Operation

Process control

Controlling the laydown process is generally the critical part of the operation. Usually the chemicals are injected and mixed together at the laydown head under computer control. Control is critical - if proportions change, temperatures or pressures vary, the foam behaves in very significantly different ways. The key control on the line is the line speed. The speed can be adjusted by very small increments up and down to ensure that the point where the chemical foams and hits the rise-to face (rollback) is always in exactly the same place. This is usually done with laser position control.

Much tighter control of the process, and more consistent quality can be achieved by application of SPC (Statistical Process Control). All the key parameters at the laydown (around 30) are constantly over-monitored for trends that are taking the variables out towards spec limits. Analysis / improvement plans can be done off-line.

Utilisation

Board / panel operations generally work best when the line is run continuously through the week, with stops only for changeovers and planned maintenance. The foam process can sometimes take a while to settle down properly. In particular, temperature fluctuations can cause major variation when chemicals have been left to rest in pipe work for example. If the plant is well designed, it will cope with low utilisation use.

Waste foam

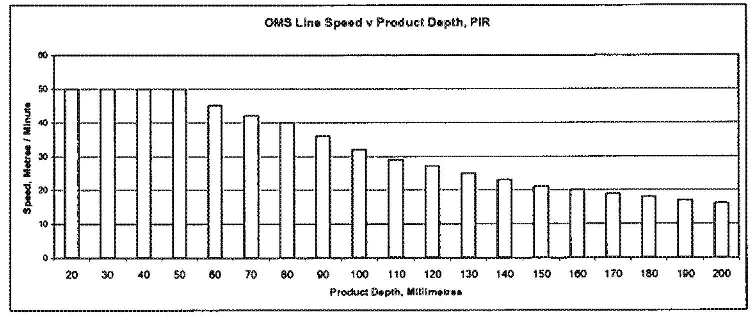
Waste is generated from start / stops of the line, product depth changes, edge trim and quality issues / malfunctions etc. Facings are 1220mm with restrained rise and 1309mm with free rise. This excess is partially foam filled and needs to be trimmed off, once product has cooled and shrunk a little. Overall waste should be up to 4%, probably double this with free-rise. Dust is also generated from saw cutting (3-4mm blade width) and from routing rebated edge boards. Other waste streams are minimal.

OEE = Overall equipment effectiveness

This is dictated by degree of utilisation, but would generally be expected to be in the 90's, if run 24hour / 6 ½ day per week, with an additional approx 12h per week of planned maintenance time. Foil and product format changes should take place on the run. Depth changeovers should take approx 5 minutes or less, sometimes these can be done on the run too.

Output

A new PIR line would generally be specified to run between 20 and 50 linear metres per minute, dependant on product depth. Therefore, with a 1200mm material width, 85% utilisation 6 ½ days a week, output would be approx 350,000 m2 per week on one line, depending on mix of depths (see below).



Line stops

Emergency line stops are to be avoided if at all possible. The line can be brought to a controlled stop within about 20m. This is where the lay-down chemical flow is stopped, and the foam travels several metres into the laminator. In an E-stop, the line stops immediately and the foam in flight expands without control. Significant down time and equipment damage often occur, as well as significant contamination of the lay down area.

Temperature

Temperature is critical at the wet end, it is very important when the board leaves the laminator. At this point it is a solid, and has quite good mechanical properties. It is still hot however (laminator runs at about 70°C PIR, 80°C phenolic), and is still undergoing its exothermic reaction, so core temperature is still rising (up to about 150°C).

The panel need to be kept moving in temperature controlled conditions (eg gradual transition back to ambient temperature. If the board is kept stationary on an uneven surface, it will tend to take on witness marks. If it cools too quickly, it tends to warp. Wrapping the boards into a bundle as soon as possible in warm ambient conditions is the best way to keep them flat as they cool as a block.

The exothermic reaction and the laminator will tend to keep the whole factory warm unless roller doors are left open for long periods.

Curing

The foam will stay warm in the pack for a considerable time (many hours). Full curing is generally regarded as being achieved at the rate one day per 25mm. So 100mm = 4 days. In practice, boards & panels can be stored and despatched before this time has elapsed, but it is best to wait for the full cure, especially in winter.

Line design

It is best if the line is designed so that the laydown process is the bottleneck, and everything else can run at a faster rate. It is best to have back up options eg take-off conveyors to keep the process running in the case the saw or stacker stops etc.

Housekeeping

The factory and its environs should be very clean. If the dust extraction is working correctly, and materials correctly stored, and chemicals handled without spillage, there is little contamination.

6.3 Resource requirements

The majority of the skills required to manufacture board can be trained, but some prior experience is critical. In particular knowledge of the chemical process.

The critical jobs in the plant during a new start-up are:

Role	Importance	Desirable Experience
~~Polymer engineer~~	~~Critical~~	~~Board or panel, 4 years+~~
Plant engineer	Very important	Board or panel, 1 year+
Production manager	Important	Board or panel, 1 year+

Support from equipment and chemical suppliers is very important in the start up phase and when difficult problems are encountered, dependant on the experience of the team.

Chemicals can either be specified and purchased separately, or purchased as a 'system'. ~~Where a chemical system is purchased, the supplier devises the necessary formulation, and the polymer engineering experience is not as important: a competent chemist would suffice in the short term.~~ The system supplier will charge a premium of 15-20% over the base price of the raw materials for the intellectual property supplied, and is a good, low risk way of getting into the market. Longer term, it is obviously much more cost effective to be self supporting and self-formulate. This requires an experienced polymer engineer.

The equipment suppliers (especially if buying a turn-key installation) can also provide ongoing project engineering resource to commission and develop the line, maintenance programme etc, if an experienced plant engineer is not available. If an experienced engineer is available, the line can be more closely specified to meet the needs of the business, and plant items can be cherry picked from different suppliers, resulting in the best overall line performance at the lowest capital cost.

The experienced production manager will galvanise inexperienced people into action, knowing what each person should be doing in each role to ensure best performance and least scrap and rejects.

Other roles can probably be trained. All lead operators, fitters and technicians will need early training with suppliers before plant installation, remainder can learn on the job. During running, the laydown operators (usually 2 for continuity) drive the line, and are most important roles to ensure quality and consistency of output. A line would generally run with 5-7 operators dependant on speed and complexity.

6.4 Factory Staffing (Based on model in Investment Appraisal)

It is assumed there will be some sharing of overhead with the existing glass wool business, such as security, finance, Exec team etc. Therefore only incremental staffing has been considered. Staffing plateaus after 10 years of the plan. (see below). Five additional staff have also been assumed in sales overhead in the investment appraisal.

	YR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
DIRECT LABOUR	**0**	**14**	**21**	**28**	**35**	**42**	**42**	**49**	**56**	**63**	**70**
CHEMICALS	0	3	3	4	4	4	5	5	5	5	5
CUSTOMER SERVICE	0	4	4	4	4	5	5	5	5	5	5
ENGINEERING	0	5	6	7	9	9	12	12	12	12	12
GENERAL OPS	0	2	3	3	3	3	3	3	3	3	3
PURCHASING SUPERVISOR	0	1	1	1	1	1	1	1	1	1	1
QUALITY	0	3	3	3	3	3	4	4	4	4	4
HSE	0	1	1	1	1	1	1	1	1	1	1
SHIFT MANAGEMENT	0	3	6	6	8	8	10	11	11	11	11
DESPATCH	0	3	3	4	6	8	8	8	8	8	8
INDIRECT LABOUR	**0**	**25**	**30**	**33**	**39**	**42**	**49**	**50**	**50**	**50**	**50**
FACTORY HEADCOUNT	**0**	**39**	**51**	**61**	**74**	**84**	**91**	**99**	**106**	**113**	**120**

NB Line teams of 7. 2nd line from Year 5.

6.5 Factory Variable Costs

Product Costing - PIR Board

		50mm £	60mm £	70mm £	80mm £	100mm £	110mm
Foil facing External		0.32	0.32	0.32	0.32	0.32	
Foil facing internal		0.32	0.32	0.32	0.32	0.32	
Facings scrap		0.01	0.01	0.01	0.01	0.01	
Foil facings inc scrap		0.65	0.65	0.65	0.65	0.65	
ISO MDI	32kg/m3	1.40	1.68	1.96	2.24	2.80	
Polyol		0.73	0.88	1.02	1.17	1.46	
Pentane		0.05	0.06	0.07	0.08	0.10	
Packing & consumables		0.05	0.05	0.06	0.06	0.08	
Labour		0.06	0.06	0.06	0.06	0.06	
Waste		0.12	0.14	0.15	0.17	0.21	
Total Standard Product Cost / LM		**3.06**	**3.52**	**3.98**	**4.44**	**5.36**	
Total Standard Product Cost / m^2		**2.55**	**2.93**	**3.32**	**3.70**	**4.47**	
Total Standard cost for 2.4M board		**7.34**	**8.45**	**9.56**	**10.65**	**12.87**	
Foam system cost, add per board		0.52	0.63	0.73	0.84	1.04	
Distribution cost per Board	85% efficiency	0.61	0.74	0.88	1.01	1.28	
Distribution % of sales		6.5%	6.6%	6.8%	6.8%	7.2%	
Selling price / Board	**TP net costs: 50, 75, 110mm**	**9.42**	**11.15**	**12.90**	**14.75**	**17.86**	**19.01**
Variable Margin		**16%**	**18%**	**19%**	**21%**	**21%**	
VM with system		**10%**	**12%**	**13%**	**15%**	**15%**	

NB Includes labour. Energy content is small, and is classed as overhead. Selling prices based on [redacted] actual net prices paid for 50mm board, 75mm cavity board and 110mm board. Others depths extrapolated.

Product Costing - Phenolic Board

		50mm	60mm	70mm	80mm	100mm
		£	£	£	£	£
Foil facing External		0.32	0.32	0.32	0.32	0.32
Foil facing internal		0.32	0.32	0.32	0.32	0.32
Facings scrap		0.01	0.01	0.01	0.01	0.01
Foil facings inc scrap		0.65	0.65	0.65	0.65	0.65
Phenolic resin & system co:	50kg/m3	4.05	4.86	5.67	6.48	8.10
Acid catalyst	inc in system cost	0.00	0.00	0.00	0.00	0.00
Pentane	inc in system cost	0.00	0.00	0.00	0.00	0.00
Packing & consumables		0.05	0.05	0.06	0.06	0.08
Labour		0.29	0.29	0.32	0.35	0.38
Waste		0.20	0.23	0.27	0.30	0.37
Total Standard Product Cost / LM		**5.24**	**6.09**	**6.97**	**7.85**	**9.57**
Total Standard Product Cost /m^2		**4.37**	**5.07**	**5.81**	**6.54**	**7.98**
Total Standard cost for 2.4M board		**12.58**	**14.61**	**16.72**	**18.83**	**22.98**
Phenolic resin: c15% vol discount subtract per board.		-1.08	-1.30	-1.51	-1.73	-2.16
Distribution cost per Board	85% efficiency	0.61	0.74	0.88	1.01	1.28
Distribution % of sales		3.7%	3.5%	3.6%	3.6%	3.7%
Selling price	[redacted]	**16.32**	**21.25**	**24.63**	**28.15**	**34.50**
Variable Margin		**19%**	**28%**	**29%**	**30%**	**30%**
VM with volume discount		**26%**	**34%**	**35%**	**36%**	**36%**

6.6 Factory Overheads (based on model in Investment Appraisal)

£ '000	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8
Electricity	100	150	200	250	320	380	380	380
Gas	40	60	80	110	130	152	152	152
Total Energy	**140**	**210**	**280**	**360**	**450**	**532**	**532**	**532**
Motor and Travel	48	61	64	77	86	96	96	96
Factory consumables	119	151	159	191	215	239	239	239
Repairs and Maintenance	258	327	344	413	464	516	516	516
Waste Disposal	83	105	110	132	149	165	165	165
Equipment Hire	66	84	88	106	119	132	132	132
Health and Safety	43	54	57	68	77	86	86	86
Training	28	35	37	44	50	56	56	56
Rent & Rates	110	110	110	110	110	110	110	110
Factory costs	**754**	**926**	**969**	**1,141**	**1,270**	**1,398**	**1,398**	**1,398**

Constant prices. 2nd line year 4. Overhead spend stable from year 8 onwards.

7.0 Factory Location / Transport / Storage / Warehousing

7.1 Location

Ideally a board factory should be located reasonably close to the market which it serves, due to the relatively high cost of transporting what is essentially a bulky finished product. As the process expands the raw materials approx 30 times, being close to sources of supply is not a major consideration.

~~The site should have room for at least 2 lines,~~ and at least some warehousing space.

- As with many products, there is an economy of scale with board manufacture, particularly in terms of capital expenditure, and sharing of human resources between lines. ~~The optimum on one site is between 2 to 4 lines.~~
    - With 1 line ROCE is poor, and overheads per metre are very high.
    - Beyond 4 lines, the site becomes too big to manage efficiently, and site logistics become complex, and it makes more sense to introduce a second site to serve a particular regional market.
- It is also necessary to have at least some warehousing space on site. The product needs to be kept warm whilst fully curing to avoid warping. Timescale is generally regarded as 1 day per 25mm (probably less in summer). At current average depths of 70mm this equates to approx 3 days output needing to be kept on site. This will rise to 4-5 days as average depths increase.

From this point of view [redacted] ~~is a good choice~~, with close links to the motorway network, and a central location in the principal English markets. The possibility of hauliers being able to find back loads to this area is probably high. ~~The advantages of being closer to the key South East UK market would probably be outweighed by the lower operating and labour costs in the East Midlands.~~ There are also advantages from having the Exec team on site, and economies of scale with existing site operations, eg security, glass-wool logistics etc.

~~It is proposed to build a factory building of approx 9300m^2 to house up to 2 lines.~~ This will be sufficient capacity to secure a 20% share of the UK market up to 2020. Once the factory is in operation with one line, it is proposed to build a large ~~warehouse of 15,000m^2~~ and 15m height. There will be some synergy with the existing logistics operation on site, so stock from both product streams and distribution can be combined. Both buildings would be constructed on the flatter portion of the site, and involve demotion of the old small warehouse, and the current unit 7 office block.

This plan assumes certain factors.

- Some of the land required would be Green-Belt. It is assumed restrictions would be relaxed in favour of the creation of quality employment in the area.
- Whether the size and height of buildings, traffic movements and bulk pentane storage would also be acceptable to the planning authorities.
- There is only limited contamination of the proposed land, and straight forward ground works. It is estimated that costs associated with this area would be less than £2m, and would be offset by East Midlands Regional development assistance. This could be 10% of the capital spend of a project of this size, and likely to be linked to ground remediation, training, and creation of jobs.

Should the ground contamination be an issue, tax relief is currently set at 150% of ground remediation expenditure. [56]

[redacted]

7.2 Transport & Distribution

[redacted]

7.3 Stock holding & Warehousing

The stock holding, and warehousing requirements are based on a number of factors such as the number of production lines, number of SKU's, and service level aspiration.

Kingspan and Celotex have 3.3 and 2.9 weeks respectively of stock on their balance sheets. Assuming 80% is finished goods, this would give 2.5 weeks stock cover? [redacted]

Lines & Stock Holding	Weekly output m^3	2.5 weeks stock m^3	Warehouse size, 9m to eaves m^2	Warehouse size, 15m to eaves m^2	Space Available in production building (9m high) m^2
One line 33% output	10,082	25,205	4,001	N/A	4000
One line 50% output.	15,276	38,189	6,062	3,637	4,000
One line 100% output	30,551	76,378	12,123	7,274	4,000
Two lines 75% output	45,827	114,566	18,185	10,911	1,000
Two lines 100% output	61,102	152,755	24,247	14,548	1,000

NB: Assumes 100mm depth product

Applying this cover to board:

Phase 1: The line will be able to commence production, with finished goods housed in the production building up to the line reaching 33% capacity. Beyond this, an increasing amount of space will be required elsewhere to store the residual stock.

Phase 2: As production ramps up, more warehousing will be required. To meet the full requirements of the proposed business plan, where 2 lines are at full output, and around a 20% share of the UK market is secured, a large purpose build warehouse would be required. This would be up to 15,000m2, with 15m to eaves height. Warehousing currently costs between £350-400/m^2. Options would be to phase this build, or use warehousing elsewhere. However, space for a minimum of 4 days output must be available on site to enable the product to fully cure in controlled conditions.

[redacted]

8.0 Capital requirements

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

9.0 Investment Appraisal, PIR

[redacted]

[redacted]

10.0 Project time plan

[redacted]

11. Appendices

11.1 Competing with Kingspan

Any participant in the Board market will have to make headway against the industry leader, Kingspan. The majority of points below are specific to panels, but the insulations business operating strategy is very similar.

Marketing: Is generally well resourced. A large number of product guides are produced, particularly technical manuals, that specifiers in the industry regard as 'the bible' and this in turn drives Kingspan being specified on projects. The Internet in the last few years has been developed as a key resource to market the company and provide support to specifiers and installers. Web traffic is very carefully monitored and analysed for trends and leads. All material is very strongly branded, and designed to be as user-friendly as possible.

Pricing: ~~Kingspan price at a premium to the market, and will walk away from deals that do not offer an appropriate margin. They will avoid price wars that will bring overall market price down.~~ Mainly for historic reasons, and Kingspan's dominance in home markets, margins in UK / Ireland are far higher than elsewhere. In insulated panels 'margin monitor' software flags up to the Sales Director if his staff selling any products below the specified margin. The sales staff below the sales director (and even country General Managers) are not allowed to see actual product costs, BOM's etc. The supply prices they see tended to stay fixed except in the upward direction, therefore efficiency savings in the plants or through purchasing would show through as positive manufacturing variance. For instance at Holywell this represented an additional 3% net profit.

Leads generation: The role of the sales force external and internal is to track leads. It does this principally by not offering pricelists, so that customers have to call to get prices. Also through technical enquiries, web traffic etc. Set questions are then asked to enable projects to be tracked. This year the threshold meterage was dropped to track above $500m^2$ projects (previously $2000m^2$). Software used, sales achiever. These leads in turn were passed on to relevant installers, giving them the inside track in many instances.

Customers: transactional and non-transactional: The company courts both customer groups with equal vigour. Transactional customers, ie those actually buying and installing the products, and specifiers, architects, developers, insurance industry representatives, fire service, construction companies etc. The objective being to get specified, sell the benefits of its products and develop close and enduring working relationships.

Training: A free service is provided to train installers in correct methods, and accredit them etc. Also an opportunity to get a captive audience up to speed with new products. On site training facilities at the major sites. Field Service engineers will also provide field technical support to customers, and advise end clients on installation standards.

Lobbying / industry forums: Increasingly, Kingspan is aggressively taking the lead with driving the market through: lobbying government: CPD etc training for insurance companies, fire services; industry forums.

Secrecy: Internally chemical formulations / technology are very closely guarded, and are purely on a need to know basis. For instance, even production managers or quality staff are not told when adjustments are made to formulations: this is done by the polymer engineering team. Equally the company is very careful not to reveal anything of its plants to either competitors, or suppliers who supply competitors also, except very generic suppliers such as Siemens etc.

Innovation: This takes two forms technical, and helping make customers lives easier. Generally the company will try to lead its chosen market in differentiated technology, with products that are specifically engineered for particular applications. It will also be responsive to feedback from customers on ideas that can speed up installation on site. This generally helps support market price premiums, and accelerate client's moves from more traditional building methods.

Technical: The company is well resourced with very knowledgeable, able and motivated technical experts in each particular field, such as polymer technology, building regs, structures etc. The technical experts have largely remained with the company during recent restructuring.

Ethos: Kingspan is generally staffed with high-calibre people that are committed to the company. Value is placed on loyalty, length of service, and demonstration of total commitment to the cause. There is a great focus placed on delivery of results, irrespective of the obstacles and setbacks. Staff that do not demonstrate the required approach tend to fall by the wayside. The personality of the Founder Eugene Murtagh (Chairman) and his son Gene Murtagh (Chief Exec) still strongly shape the company culture. Internal customer service is usually high: everyone generally answers their phone immediately, and responds to e-mail requests rapidly.

Service Level: This is the critical measure in Kingspan. It is measured in two ways: OTIF delivery, and Customer satisfaction survey. Everyone in Kingspan is totally committed to total customer service. If a line breaks down, everything that is humanly possible must be done to ensure customers are not let down.

If a customer would like any particular custom service, the answer will generally always be 'yes', and a premium will be charged if possible unless it risks losing the order. Examples being custom sizes, packaging, delivery etc.

Lead-time: Kingspan will always ensure they lead their market with the shortest lead-time. This is done partly through scale and capacity, and the commitment of the staff to take a flexible approach and do whatever is required to manufacture and deliver the order. Kingspan will NEVER lose an order on lead-time.

Cost base: The company generally has the scale, investment in facilities, efficiencies and technology to operate at or near the lowest cost in the industry. Recent restructuring has concentrated particularly on overheads, where the business is now really very lean, and also on direct staff where line / peripheral operators have been cut to the lowest practicable level.

~~Generally all products are run at the bottom / slightly below dimensional specifications, as Lambdas have got better over time (and densities lower), so the stated U-value can be met with a thinner product~~

~~As Kingspan has full control of its chemical formulations, cost reduction of foam is a constant activity. This takes the form of a) density reduction, b) chemical substitution This is always balanced by the need to meet structural, quality and fire performance considerations.~~ Fear of PIR blistering is always uppermost in everyone's thoughts, so changes are thoroughly tested on an accelerated aging rig. This is less of a concern in board rather than panel unless things go very wrong.

Until very recently, the company has always been very happy to invest in the best equipment, and make acquisitions, even when the paybacks have not been particularly strong.

Insularity: The company tends to be quite inward focussed from the point of view of competition and technology. Generally low opinion of competitor's ability to compete with them, so tend to be dismissive. Occasionally the company is surprised when making an acquisition that others are as far ahead as they are. For example the chronic, expensive panel blistering issue was solved by acquisition of ATC and use of their Elastogran pre-laydown.

Opportunities: The key opportunities would be:
~~Recent~~ cost cutting has ~~left the company too lean~~ to react and maintain control.
~~Indebtedness~~, insufficient cash to make significant investments or acquisitions. Focus on maintaining profit to not breach banking covenants.
~~Insularity~~: the company believes they are the best and everyone else's approach / technology is inferior.
~~Sales:~~ Strangely enough, the sales team (at lower levels) are generally not that strong, particularly in technically knowledge. They are generally not motivated and creative enough to sell newer products. ~~Attention to small customers is particularly poor~~.

Current Development areas, panels: Amongst other areas, launch of phenolic panels energy contributing panels, and a strong focus on value-added façade systems. Board, not know.

11.2 Plant & Equipment suppliers

OMS

Italian based. Complete turnkey supplier of all equipment required from tanker offload to pallet wrapping. Core expertise wet side / lamination. Have supplied approx 12 of the 16 continuous lines in the UK/Ireland, and all those installed in last 3 years. Also 1 panel line. Quality generally very good. Systems capable of 50m/min. Line cost high at €6m+. http://www.omsgroup.it/

Hennecke

German based. Until recently wholly owned subsidiary of Bayer. Core expertise wet side / lamination. Have supplied at least 2 of the UK/Ireland lines. 6+ UK part panel lines. Team up with Keil, another German supplier for tanks, pipe work etc. and Kraft for down stream equipment. Quality very good. Systems capable of 50m/min. Line cost medium at €4m+. http://www.hennecke.com/hennecke/index_e.htm

PUMA

Italian based. Can supply complete turnkey system from wetside through to pallet wrap. Quality not as robust, and prices generally reflect this. Systems capable of speeds up to 30m/min. At least 1 full, and several part panel lines in UK. Line cost low at €2m+. With an experienced engineer, certain items can be sourced from them cheaply and with few problems. http://www.pumasrl.com/

Siempelkamp

German based. Core expertise wetside / lamination. Not known UK board lines. Have supplied 2+ UK panel lines. Team up with Keil, another German supplier for tanks, pipe work etc. Costs believed similar to Hennecke.
http://www.siempelkamp.com/Company.607.0.html

Bumby

UK based. High quality supplier of stacking and accumulation systems for panel / board. http://www.bdc-ltd.co.uk/

11.3 Chemical Suppliers

Principle Suppliers PIR

Elastogran (BASF): Subsidiary of BASF. Specialise is supply of complete 'turn-key' chemical systems: polyol blend, MDI, pentane. Turnover £120m in UK. Supply 50% of UK polyurethane industry. Do not generally supply individual components except MDI which is seen as a commodity essentially. ~~Have a great deal of technical expertise, employing half of the UK PIR polymer engineers~~ (7). Can supply full support to specify, commission a new plant, train staff and provide ongoing support. This service is all included in the cost of the chemical system. Can also arrange all testing and accreditation of products. Would enable an entry into the market with no in-house polymer expertise. Their Elastopir 1032/xx system will run at 20/25m/min, with density of 32kg/m3, lambda 0.022W/mk. Cost per kg July 2009 €1.45-1.50 euros/ kg all in.

~~They believe they will have a fire "class 0" product developed within a year, with~~ a ~~lambda value of 0.021 Wm/K, and typical density of around 30kg/m3.~~
http://www.basf.co.uk/ecp1/Group_companies_UK_Ireland/Elastogran_UK_Ltd

Celotex λ 21?

Dow Large scale. Supply full range of chemicals for polyurethane industry. Also supply complete foam systems.
http://www.dow.com/polyurethane/index.htm

Bayer Large scale. Supply full range of chemicals and systems. Otto Bayer invented polyurethane in 1937.
http://www.bayer-baysystems.com/BMS/BaySystems.nsf/id/01_LEV_EN_Industries

Huntsman Large scale. Supply full range of chemicals for polyurethane industry.
http://www.huntsman.com/PU/

BOC Supply pentane to the entire industry, and a full range of technical support.
http://www.boc-gases.com/products_and_services/by_product/propellants/index.asp

Chemique prelay adhesives, MDI based.
http://www.chemique.co.uk/

Stepan Specialist polyols
http://www.stepan.com/en/markets/polyurethanes.asp

Invista Supplier of specialist polyol, Terate. High aromatic activity give strong fire performance.
http://terate.invista.com/e-trolley/page_8691/index.html

Albion Chemicals Specialist polyols manufacturer / distributor.
http://www.brenntag.co.uk/en/

Principle Suppliers Phenolic

Hexion. Now own original site where phenolic foams were developed by Pilkington and BP JV. Supply Kingspan with phenolic resins.
www.hexion.com

Ashland. Believed capable of supplying phenolic foam systems.
http://www.ashland.com/industries/

Dynea. [redacted] phenolic supplier. Believed also capable of supplying foam systems.
http://www.dynea.com/solutions/insulation/

Facing supplier

International Converter: Used by Kingspan, Celotex and others
http://www.ici-laminating.com/

Mondi can also supply an equivalent material

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