

Introduction

First patented in 1913 by the German inventor Friedrich Heinrich August Klatte (Bellis, 2019), Polyvinyl chloride (PVC) is one of the world's most versatile plastics, used in a wide range of applications from medical equipment to building materials.

As PVC technology developed, as did the complexity of the formulation, with modern manufacturing methods requiring a combination of additives to optimise PVC products throughout their lifecycle.

Contributing to those additives are substances known as heat stabilisers. The main function of heat stabilisers is to prevent thermal degradation of PVC, which occurs when PVC is heated above 150° C, a temperature which is often exceeded during manufacturing processes such as extrusion. During the late 1990's and early 2000's lead-based stabilisers with their superior technical performance, dominated the European market.

Baerlocher is a global leader in the manufacture of PVC stabilisers, which they offer as part of their Baeropan one-pack product. This report focuses on how a global shift in the market, prompted them to rethink their business model, product offering and looks at the innovation that paved the way to lead free stabilisers.

Principal drivers for the innovation.

As demand for the polymer increased, so did concerns regarding sustainability and lifecycle of the material. In 1998, PVC production in Western Europe reached 5.5 million tonnes per year, contributing to 26% of global production (communities, 2000). A lack of infrastructure and legislation to manage post-consumer waste, resulted in an estimated 2.6 to 2.9 million tonnes of PVC waste, disposed in landfill (communities, 2000). In addition to the environmental impact posed by PVC, health concerns surrounding the toxicity of its additives, further tarnished the reputation of the product. Communities and governments called for change.

In 2000, the European PVC industry united, launching Vinyl 2010, a voluntary initiative that spanned across all sectors of the industry, from material suppliers to recyclers, the project aimed to clean up the image of the polymer. The 10-year commitment set ambitious targets and a strategic, collaborative plan which included fully phasing out the use of lead-based stabilisers in the EU-27 by 2015.

Baelocher needed to dramatically change their manufacturing process and business model to adapt to the goals of Vinyl2010. They recognised the advantages, proactively committing to change before legislation came into force, this would not only promote a positive image for the business but would also get regulatory bodies working alongside them, rather than against them. Baerlocher committed to fully phase out all lead-based stabilisers from its product offering. Vinyl2010 became the principal driver for the innovation. In an interview conducted with Dr. Jörg Fröhlich (Technical Product Manager, PVC Additives for Window and Technical Profiles, Baerlocher) he commented, "in the late 80's and throughout the 90's there was an agreement inside the industry that the image of PVC needed to be improved, the result was a the Vinyl2010 initiative, this set out a vision until 2010. The initiative aimed to prove to the public and governments that PVC was a sustainably oriented industry, contributing to the wellbeing of everybody" (Fröhlich, 2022).

Barriers and risks faced by the company in developing the innovation

Although there was a recognised need for change amongst the industry, the phasing out of lead presented Baerlocher with considerable barriers and challenges. Lead-based stabilisers were well established and trusted, with decades of research and development. Lead was efficient, optimized and was considered good quality for a reasonable price. Not only did it offer excellent thermostability, but a wide processing window, good pigmentation and high weathering performance (Fröhlich, June 2013). These favourable characteristics reduced the need for higher quantities of other additives within the compound. From a technical perspective, Baerlocher needed to produce an alternative product that could not only match the performance of lead, but would also gain the confidence of the customer. Early developments proved unsuccessful, as Baerlocher attempted to replicate the technical specification of lead-stabilisers using calcium. "Lead stabilisation raised the bar quite high. We thought we had to meet all the technical specifications of lead, which resulted in over-engineering of the product and difficulties with processing. In the early stages, everywhere we took our calcium-based product we caused more trouble than we offered solutions" (Fröhlich, 2022). This prompted Baerlocher to rethink the makeup of their formula and concentrate on the specific performance of each element of the compound and examine how they could enhance performance whilst keeping costs down.

Another challenge was around the infrastructure required to manufacture some of the more complex organic stabilisers required in calcium stabiliser production. Historically the production of metal additives containing lead, were carried out at Baerlocher manufacturing facilities. This self-sufficient process required little open collaboration. Baerlocher quickly realised that the processes and equipment required to produce these new organic compounds were not feasible and would not fit within their existing business model, "We realised that the chemistry involved to replace lead compounds, could not be easily backward integrated into our existing processes" (Fröhlich, 2022). Baerlocher faced the challenge of sourcing new suppliers. Once suppliers were discovered, the quality of potential new materials needed to be defined, tested and analysed within the one-pack compound. When a new supplier was approved, logistical challenges needed to be addressed and new supply chains set up.

Key determinants in the process of committing to develop the innovation

With the industry committed to voluntarily phase out lead within EU-27 by 2015, calcium-based stabiliser production saw steady growth, with the production of lead-based stabilisers declining. In the period 2000-2007, lead stabilisers (in EU-15) decreased by 43,014 tonnes (-33.82%), and calcium organic stabilisers (in EU-15 plus Norway, Switzerland and Turkey) increased by 38,243 tonnes (Programme, 2008)

Although Baerlocher set ambitious targets and continued to make advances in the development of calcium stabilisers, it was not their priority to make the transition as quickly as possible. Not all markets were as responsive to the changes as those within Europe, with many countries outside of the EU-27 deciding to continue with lead. As a global supplier, Baerlocher wanted to ensure it retained market share and continued to produce lead stabilisers for these customers.

Baerlocher also experienced less interest in calcium-based products from window fabricators and the industry saw slower demand from the end customer. Once the product was fully fabricated and glazed,

there was no visible differences between lead and calcium-based products. The successes and benefits the industry had achieved were diluting from manufacture to installation, “On the one hand the customer wanted toxic-free, environmentally safe products, but on the other hand, once the window was fitted, the customer could not tell the difference between the two. The idea was not easy to transport to the end customer, so they would ask specifically for a calcium-based window. We also initially had difficulty selling the product to the extruders, who were happy with the existing product” (Fröhlich, 2022).

The drivers for change were still at the forefront of Baerlocher’s vision, however the determining factors to accelerate the program and move completely lead free, had not fully presented themselves. This changed around late 2006-2007. With a global commodities boom, raw materials prices soared. The cost of lead increased to unprecedented levels, from October 2006 – October 2007 the cost of lead rose from \$558 per Tonne to \$3415 per tonne (tradingeconomics, 2022), prompting the global PVC industry to react. With greater developments and optimisation of the new compound, calcium-based became a more cost-effective solution for the customer and cost began to accelerate the switch.



Fig 1. (tradingeconomics, 2022)

The second major determining factor that pushed continued development of the project came in June 2007, when Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), came into force. The aim of the REACH regulation was to place responsibility on industry to manage the risks from chemicals and to provide safety information on the substances (Commission, 2022). REACH called for the industry to do more to manage the risks and hazards associated with substances in their products. This offered greater transparency to the consumer. This factor now directly impacted the industry, from raw material suppliers to businesses selling end products. REACH regulations highlighted that consumers had the right to know if goods they purchased contained substances hazardous to health. They produced a database of what it called a candidate list of ‘substances of very high concern’ (Commission, 2022). Lead featured in this list.

Page 1 of 1	50 Items per Page	Showing 32 results.	← First	Previous	Next	Last →
Substance name	EC No.	CAS No.	Date of inclusion	Reason for inclusion	Decision	IUCLID dataset
Lead	231-100-4	7439-92-1	27-Jun-2018	Toxic for reproduction (Article 57c)	ED/61/2018	

Fig 2. (Agency, 2022)

From this point, all stakeholders within the industry felt the burden of using lead-based stabilisers. During an interview with Chris Robinson, a Technical sales representative at Baerlocher, he commented

“regarding the end customer, REACH forced suppliers to add additional hazardous substances labelling to their products. Suppliers then started to question, why would customers buy lead-based products with warning labels, when the calcium-based products doesn’t have any” (Robinson, 2022). The industry’s mindset changed, the full phase-out accelerated.

Processes and technologies the company used to carry the development forward

Development and testing required Baerlocher to analyse the stabiliser compound, from a molecular to an industrial level. The process was split into three categories:

- Wet laboratory testing
- Laboratory testing
- Production testing

The wet lab process was conducted in the central research and development (R&D) facility in Munich. Individual chemical elements were studied to examine how the raw materials would react with one and other. During this phase, additives from different suppliers were also analysed to determine quality and suitability for the formula.

Once the central development team approved raw materials, recipes were formulated to evaluate the performance of the additives working together as a stabiliser compound. Multiple recipe types were created, each with a different chemical makeup. Laboratory technicians trialed and analysed recipe samples, using a broad spectrum of test equipment. The technology simulated the conditions and processes materials were subjected to during manufacturing.

Equipment Name	Description	Test Conducted
Promixon – 10L High speed mixer	Small batching mixer. Stainless steel blades inside mixing bowl, blend additives to create recipe.	Used to batch trial compounds
Haake – Twin Screw Conical extruder	Small PVC extruder, simulates large scale industrial extrusion process. Small batches fed into heated screw barrel. Sheared, fused and forced through die head.	Melt temperature/ pressure Machine torque Vent pressure Adapter pressure
Brabender Rheometer	Small samples fed into twin head rotor. Changes in torque and temperature measured. Software trends data.	Rheology / Fusion Fusion time Fusion Torque End Torque
Two Roll Mill	Two parallel mounted, driven heated chrome rolls. Material poured between the rolls is kneaded and plasticised	Colour/pigment milling Plasticising Kneading
Werner Mathis	Uniform PVC strips extruded using Haaki (each strip represents a different recipe). Strips placed on a tray, located under heating element. Test temperature and time entered into the control system. Test starts, tray moves away from the heat source in incremental movements	Static thermal stability 200° C for 5min
Congo Red – Oil Bath	Test tube located in heated oil bath. PH paper inserted into test tube. The time taken to turn PH paper red to blue is recorded.	Thermal stability

**Fig 3. Word count for table - 216*

Once Laboratory testing was complete, the development team selected potential formulas for production testing. Although compounds may have performed well at Baerlocher test facilities, compounds were known to behave differently during production trials using industrial extruders. On site trials were conducted, using various extruder types and complex profile dies. Baerlocher lacked the infrastructure and processing experience to trial compounds in a production environment, so off-site testing and collaboration were vital before putting products to market.

How the development relied on resources external to the company and how the deployment of these resources was managed.

Collaboration with customers, suppliers and machine manufacturers was integral to the success of Baerlocher's innovation. Stabiliser compounds are just one of many additives used to manufacture PVC. As Baerlocher's new formulation developed, other co-manufacturers in the industry needed to ensure that their products worked well with the calcium compound, "there was a lot of collaboration with our partners, from machine manufacturers to material suppliers. They helped us and our competitors run trials.

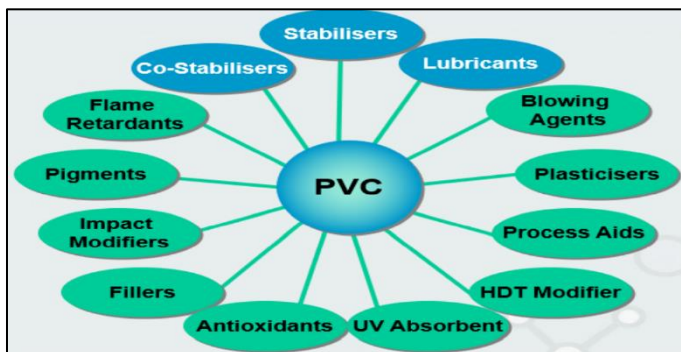


Fig 3. (Robinson, 2019)

They had commercial interests in the project and saw opportunities to optimise, with the changes in stabilisation". (Fröhlich, 2022). The opportunity to expand testing and analysis accelerated as data flowed from suppliers and manufacturers laboratories back to Baerlocher's Munich R&D facility.

Collaboration with PVC extruders also formed a vital part of the development process. Baerlocher's strong relationship with its customers meant many extrusion businesses volunteered to work closely with them throughout the project, "many of our customers invited us to their production lines to test. They were not going to make the switch to calcium stabilisers immediately, but they wanted to know what issues could affect their production process, and they wanted to know early" (Fröhlich, 2022). Baerlocher relied on these opportunities to live test compounds in industrial conditions, with the support of experienced operators.

The external resource networks were managed by the central R&D facility in Munich. The Munich team managed and shared data that flowed to and from the co-manufacturer's laboratories. When a compound was approved for a production trial, the formula was sent to field teams, such as the United Kingdom team located in Bury. The field team laboratory would produce a batch of the formula and arrange with a customer to trial it at their extrusion facility. Field teams were often accompanied by a member of the Munich development team and would collaborate onsite with operators to trial run compounds. Data gathered was then fed back to Munich to modify the recipe accordingly. The process was then repeated.

When the final compound was approved, field teams continued to collaborate closely with the customer, to locally manage the continuous development of the product. Changes in production processes, advances in machinery technology and price negotiation, often meant that the recipe needed to be modified "the calcium based stabilisers we sell today aren't the ones we introduced up to 2010, we're under constant

pressure to evolve the product to meet the demands of technology innovation in extrusion machinery, or commercial teams who are looking for a better price” (Robinson, 2022)

How management overview of the development was maintained

The overall development was managed by the head of R&D and his product development team in the central R&D facility in Munich. The Munich facility led the project and were responsible for developing the standard formula required for the calcium-zinc stabiliser. Munich presented the field teams with compounds to trial. This stage of the development process granted autonomy to the field teams. They were well equipped and had well established networks and relationships with suppliers and customers.

Field teams managed the data accumulated from customer trials and analysed it with the Munich laboratory. Any modifications had to be closely managed with the internal production team, ensuring it could feasibly be produced at their facilities. When the final calcium based product was approved and introduced to the market, the field teams were given the authority to work with individual customers and locally manage minor technical changes to the standard compound, “we always maintained strong links between the product development team and the field team, field teams brought feedback from the market, then from the lab back to the market” (Fröhlich, 2022)

Feedback from the window fabricators and the end customer was managed by the individual extrusion companies. This information fed straight back into the communication loop, to the field teams and on to the product development team.

The Munich team also managed communication with the European Commission to maintain a collaborative relationship. Baerlocher found REACH regulations did not directly impact them as hard as other industries. The European PVC industry had voluntarily planned and progressed a robust phase-out of lead, with the Vinyl2010 initiative. Governing bodies wanted to work with the industry as a support mechanism as opposed to an authoritative figure, “when it came to lead stabilisation, they realised there was already something going on, they didn’t need to push us, or set stringent dates for the industry, as we were already doing it for ourselves. So, they aligned their initiative with ours” (Fröhlich, 2022).

How the innovation process represents best practice

Baerlocer’s innovation project was organised and well structured. They identified and adapted to economic changes and capitalised on opportunities. The importance of adaptability was noted by Paul Trott, ‘corporations must be able to adapt and evolve if they wish to survive. Businesses operate with the knowledge that their competitors will, inevitably, come to market with a product that changes the basis of the competition’ (Trott, 2017, p. 4).

The innovation project model could be compared to an interactive type of model, where consumer and government had progressively become more health and environmentally conscious. This represented market pull factors. The technology push was the removal of lead as an additive and the scientific advances required to find alternative chemical substitutes. By including the customer in the project development, much of the marketing had already taken place, the customer had the opportunity to input into the project, work with the product using its own machinery and adjust processes and equipment in preparation for the changes.

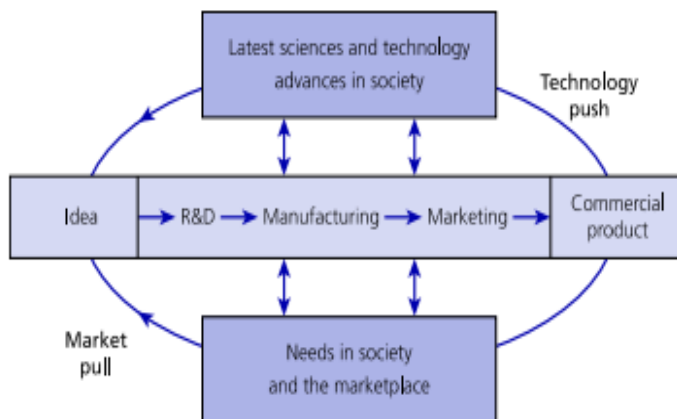


Fig 4. (Trott, 2017, p. 25)

Baerlocher recognised the limitations of their R&D and testing facilities at Munich. To combat the issue, they structured their internal developments around a main centralised Munich facility and also decentralised field laboratories that were closer to the customers. This ensured they utilised the strong network they had built within the industry to draw on external resources and expertise. Paul Trott highlights the benefits of decentralised environments noting, ‘the main advantage of decentralising the R&D function, is to reinforce the link between the business, its products and its markets. It is argued that with a large, centralised R&D effort, it is often too removed from where the technology is eventually applied. By providing each business or division with its own R&D effort, it is argued that this fosters improved communication and product development’ (Trott, 2017, p. 350).

The innovation demonstrated many of the organisation characteristics that facilitate the innovation process and management of R&D (Trott, 2017, p. 356). Baerlocher demonstrated growth orientation as they committed to long term progression through sustainability. Internal and external information was shared, as teams cross-functionally cooperated within organisational structures. As a member of the Vinyl2010 and VinylPlus initiative, Baerlocher demonstrated strong market orientation, as it developed its innovation around global changes in the market. The organisation also remained vigilant as it identified threats to the business, consumer and environment, posed by the use of lead, and acted on it.

Conclusion and personal critique of innovation

Baerlocher faced a global problem that could permanently damage their industry and business. With considerable pressure from government and the public, Baerlocher anticipated the impact regulations could bring and acted before legislation was enforced. They identified strengths and weaknesses within the organisation and utilised their strong network of industry experts, expanding their capabilities and accelerating the project. Customer and stakeholder engagement and collaboration was impressive. This inclusion of external parties throughout the project not only benefitted the development team but prepared other organisations for potential changes to their processes. The technology at Baerlocher facilities allowed the company to analyse the suitability of a compound, before releasing for production

testing. This process was efficient and ensured time at extrusion facilities was used wisely. The project structure, particularly empowered decentralised laboratories and field teams to carry out local R&D, helped stimulate innovation. One negative factor I concluded from the innovation process, was that poor sustainability and toxicity alone was not enough to accelerate the change in the industry. Instead, it was the cost of raw materials and legislation that became the final determining factors that increased momentum to complete the phase out of lead stabilisers.

Bibliography

Agency, E. C., 2022. *ECHA Information on Chemicals Candidate List*. [Online]

Available at: https://echa.europa.eu/candidate-list-table?p_p_id=disslists_WAR_disslistsportlet&p_p_lifecycle=1&p_p_state=normal&p_p_mode=view&disslists_WAR_disslistsportlet_javax.portlet.action=searchDissLists

Bellis, M., 2019. *www.thoughtco.com/history-of-vinyl-*. [Online]

Available at: <https://www.thoughtco.com/history-of-vinyl-1992458#:~:text=Polyvinyl%20chloride%20or%20PVC%20was%20never%20patented%20until,came%20along%20and%20made%20PVC%20a%20better%20product.>
[Accessed 25 05 2022].

Commission, E., 2022. *Home - chemical - REACH*. [Online]

Available at: https://ec.europa.eu/environment/chemicals/reach/reach_en.htm
[Accessed 21 05 2022].

communities, C. o. t. E., 2000. *Environmental issues of PVC*, Brussels: Commission of the European communities.

Fröhlich, D. J., 2022. *Phasing out lead based stabiliser at Baerlocher* [Interview] (13 May 2022).

Fröhlich, D. J., June 2013. *Managing the Change From Lead-based to Calcium-based, Stabilisation in PVC Cables & Wires, Pipes & Fittings and Rigid Profiles, Slide 10*. [PowerPoint presentation]. Available at: <https://docplayer.net/58092177-Managing-the-change-from-lead-based-to-calcium-based-stabilisation-in-pvc-cables-wires-pipes-fittings-and-rigid-profiles.html>

Mottram, R., unknown. <https://www.bpf.co.uk>. [Online]

Available at:
https://www.bpf.co.uk/sustainable_manufacturing/introduction_to_sustainability/PVC_Sustainability.aspx
[Accessed 20 05 2022].

Programme, T. E. P. I. S. D., 2008. *Vinyl 2010 Progress Report 2008, reporting on the activities of the year 2007*, Belgium : The European PVC Industry's Sustainable Development Programme.

Robinson, C., 2019. *PVC Technology and manufacturing*. Bury: Baerlocher.[PowerPoint presentation]
Not available online

Robinson, C., 2019. *Stabilisation and Lubrication*. Bury: Baerlocher. [PowerPoint presentation] Not available online

Robinson, C., 2022. *Phasing out lead based stabiliser at Baerlocher* [Interview] (13 05 2022).

tradingeconomics, 2022. *2022 Data - 1993-2021 Historical - 2023 Forecast - Price - Quote - Chart*. [Online]

Available at: <https://tradingeconomics.com/commodity/lead>
[Accessed 22 05 2022].

Trott, P., 2017. *Innovation management and new product development*. 6 ed. Harlow: Pearson.

unknown, 2022. <https://www.anytester.com>. [Online]

Available at: [https://www.anytester.com/TST-300-Congo-Red-Thermal-Stability-Tester-pd6383429.html#:~:text=Technical%20Specification-,TST%2D300%20Congo%20Red%20Thermal%20Stability%20Tester%20is%20used%20to,\(200%C2%B10.5\)%E2%84%83](https://www.anytester.com/TST-300-Congo-Red-Thermal-Stability-Tester-pd6383429.html#:~:text=Technical%20Specification-,TST%2D300%20Congo%20Red%20Thermal%20Stability%20Tester%20is%20used%20to,(200%C2%B10.5)%E2%84%83).

[Accessed 23 05 2022].

unknown, 2022. <https://www.brabender.com>. [Online]

Available at: <https://www.brabender.com/en/product/extrusion-rheometer/>

[Accessed 23 05 2022].

unknown, 2022. <https://www.thermofisher.com>. [Online]

Available at: <https://www.thermofisher.com/order/catalog/product/567-2030>

[Accessed 23 05 2022].

Vinyl2010, 2011. *An Overview of Vinyl 2010, Marking ten years of PVC industry voluntary commitment*, Brussels: Vinyl2010.

VinylPlus, 2011. *The Voluntary commitment of the European PVC industry*, Brussels: VinylPlus.