Legacy additives in rigid PVC and progress towards sustainability

A closer look at recycling and the circular economy in Europe

February 2018

The Natural Step

SUMMARY

This statement outlines The Natural Step's view on managing rigid PVC waste in Europe. It is our long-standing conclusion that all PVC products need to be managed in a controlled-loop system in order to align with the principles of sustainability advocated by The Natural Step. The design and formulations of new PVC articles (the REACH term for what is more commonly called 'products') should be optimised for use in a controlled-loop management system, while those reaching the end of their use phase should be recycled wherever possible. A closer look at managing waste from rigid PVC applications (e.g. window profiles and pipes), suggests that their recycling can make a significant contribution to the circular economy, with appropriate controls to safely address the issue of 'legacy additives'. We also conclude that alternative disposal options (incineration and landfilling) perpetuate the linear economy, risk the subsequent systematic accumulation of harmful substances in nature, demand use of productive land, and require new feedstocks and higher energy inputs. These alternatives also represent a significant loss of a highly valuable and functional material that could form part of sequential material and product loops serving human needs over the next two centuries or more.

PVC is an inherently adaptable, durable and recyclable material. Significant savings of environmental impacts can be achieved by re-using PVC from recycled waste streams, such as window frames, compared to virgin PVC resin[i]. In some applications there is the potential for PVC to be recycled several times without any perceptible impact on material or processing quality[ii]. In long-life applications of 30-50 years or more, this represents an enormous opportunity for resource efficiency and a major contribution to the European aspiration of a circular economy.

Within the long and often contentious history of debate about PVC issues, it is easy to overlook the long-term benefits to society from keeping functional materials in successive material loops, and the steps being taken to close the loop. The quantity of PVC recycling is growing in Europe: in 2016, 568,696 tonnes were recycled under the controlled-loop system that is being developed on a voluntary basis by the European PVC industry[iii]. This is double the volume recycled five years previously. Almost half of the recycled volume (256,607 tonnes) is from window profiles, which is probably Europe's largest PVC application, closely followed by pipes. It is an urgent priority to scale up such systems if we are to make the shift away from an unsustainable, linear production and consumption model.

It needs to be acknowledged that the potential for recycling PVC, including treatment and reuse options, is largely influenced by the chemical formulation and the choice of additives. Given the range of additives that allow PVC to be used in multiple applications, PVC formulations can vary significantly, and they should therefore not be treated as a uniform material family. The management requirements for different PVC articles should be looked at on a context-specific basis. Certain generic principles will apply for some applications, and here we comment specifically on rigid PVC in applications such as pipes and window profiles.

One of the main implications for recycling rigid PVC and other materials, especially in long-life applications, is the issue of 'legacy additives'. It is known that post-use waste streams contain substances that were permitted at the time of manufacture, sometimes decades ago, but that have since been phased out voluntarily and / or restricted under more recent chemicals legislation. For example, some of the more problematic legacy additives in PVC rainwater goods and window profiles include cadmium- and lead-based stabilisers (these were fully replaced in PVC production in Europe in 2001 and by the end of 2015 respectively). With the benefit of hindsight, technology advances and better understanding of chemical effects, we could simply conclude that these substances don't have a place in our industrial system. Yet, now that they are in the material flow, they need to be managed in the best way while ensuring that further entry of such substances is restricted in new articles.

As a general principle, we do not believe that legislation should jeopardise efforts to close the resource loop, at least not without closer examination to identify the optimal outcome from a total system perspective. Matter does not disappear and the waste streams from articles and materials that society has used in the past need to 'fit' somewhere in either biological or technical cycles even when there are legacy additives present. Failure to allow reuse of resources in society simply increases dependence on virgin materials for new articles and increases waste volumes, which is fundamentally unsustainable. There is also a risk of locking in linear production and consumption if evolving chemicals legislation for new articles isn't reconciled with the need to take account of emerging waste streams arising when articles already on the market reach the end of their use phase. This is a particular challenge for long-life materials, yet these are the very materials we aspire to use in a resource-efficient circular economy. Overall, this highlights the complexity of sustainable development strategies that need to look at optimal outcomes at any point in time, always keeping in mind the long-term goal of sustainability.

Given this paradox, it is The Natural Step's view that science-based *principles of sustainability* provide a precautionary systems lens for evaluating both new material choices and transition pathways for increasingly circular material flows that integrate existing waste streams in the most sustainable way. In a previous analysis, we have used such a set of principles (The Natural Step 'System Conditions for a sustainable society') to look at the key challenges and potential for PVC to contribute to a sustainable society[iv]. The European PVC industry has since committed to addressing these challenges in its sustainability roadmap, VinylPlus®[v]. The same principles were used in a supporting analysis for this assessment covering three basic alternatives for managing waste from PVC window profiles: landfilling; incineration; and recycling (see Supporting Analysis attached). We concluded again that recycling with certain safeguards is clearly the preferred option from a resource-efficiency perspective, with alternative disposal routes creating a range of sustainability problems. These conclusions are likely to hold for other types of rigid PVC products, such as pipes.

Basic principles of sustainability also provide an evidence-based approach to assess risks to the environment and human health from legacy additives when they are present in recycled materials. For example, allowing substances to systematically increase in concentration in nature over time is used as one indicator of un-sustainability. A range of studies, many commissioned by VinylPlus® to provide information for input to EU legislative consultations, indicate that metal-based stabilisers are bound in the rigid PVC compound's polymer matrix with very low 'migration rates'[vi] (leakage). This question has also been taken up directly with the industry's Additive Taskforce and is included in the development of an 'Additive Sustainability Footprint' methodology for the industry[vii]. From this, we consider that rigid PVC articles such as window profiles and pipes containing these legacy additives can be used in the circular economy without the substances migrating and violating this particular sustainability principle. It should also be noted that the other alternatives to recycling would violate this and other sustainability principles.

If recycled materials are to be used in the circular economy, there needs to be market trust and acceptance of their safety, and this requires clear guidance around particular management safeguards for social sustainability. These may include ensuring that recyclate is directed to approved applications, implementing systems for material traceability, and guidance on precautionary design approaches for new articles. Standards and guidelines for preserving the highest functional value of material flows are also needed. We understand that VinylPlus® and industry associations such as EPPA (European PVC Profiles and related Building Products Association) and TEPPFA (The European Plastic Piping and Fitting Association) are actively working on this. We encourage further dialogue with stakeholders to gain input, build awareness and develop consensus on the progress being made.

As a final point, we view the circular economy as critical to creating a truly prosperous and sustainable society in the long term. Getting there will require a step-wise transition pathway that avoids immediate rejection of recycled materials even if the constituents are not fully compliant with current guidance for substances permitted in virgin materials. The long-term criteria for success (sustainability principles) can guide management options in the present perspective to find the optimal pathway toward the goal. There are clear resource efficiency and intergenerational benefits to society from reusing, for example, PVC profiles and pipes in multiple recycling loops. Furthermore, as we note in the Supporting Analysis, there is even the potential for *lowering the concentration* of legacy additives in the total material flow through successive product and material loops as part of a controlled transition. With large quantities of rigid PVC articles containing legacy additives still in use today, and the potential for further substances being identified for phase-out in future, there needs to be greater discussion about the importance of re-using resources from articles currently in circulation at their end of life and how they can be handled in a safe and controlled-loop system. This also means looking at the consequences from not doing so.

Authored by:

Richard Blume, MSc, BE/BA
Senior Sustainability Advisor
The Natural Step, Stockholm

Dr Mark Everard Associate
Professor of Ecosystem Services
University of the West of England (UWE Bristol), UK.

The authors of this statement are providing strategic advice to the European PVC in the application of The Natural Step's framework and principles. Input and further review has been provided by The Natural Step's chemicals coalition in Europe. Further information is available at www.thenaturalstep.org/chemicals. Inquiries can be directed to chemicals@thenaturalstep.org.

SUPPORTING ANALYSIS

CASE STUDY ON WASTE MANAGEMENT OPTIONS FOR PVC WINDOW PROFILES

Our point of reference for this analysis is the Framework for Strategic Sustainable Development promoted by The Natural Step (often known as The Natural Step Framework)[viii]. According to the Framework, a set of basic principles need to be met in the long term to truly create a sustainable society (hereafter referred to as TNS System Conditions). With this in mind, we explored how to manage rigid PVC waste in such a way that it supports step-wise progress toward alignment with these TNS System Conditions. This takes into account the fate of legacy additives, providing a matrix of considerations to evaluate which is the better resource management option, with appropriate management, from a total system perspective. Table 1 summarizes the analysis of alternative end-of-life strategies for waste from PVC window profiles: (1) landfilling; (2) incineration with energy recovery; and (3) controlled-loop management (recycling and reuse)[ix].

DISCUSSION

From the analysis, we conclude that recycling rigid PVC in end-of-life articles is the best management option to move toward alignment with sustainability principles. This analysis is intended as an example to show how trade-offs can be assessed in the context of a long-term goal of sustainability. The same principles could be used to evaluate different waste scenarios and indeed, these principles should be used across all phases of the product life cycle including in the design of new materials and articles. In this example, the scale of the gains from recycling relative to use of virgin PVC can be quantified through life cycle assessment methods. For example, replacing virgin PVC in window profiles by PVC from post-consumer waste saves around 2 t of CO_2 eq./t of PVC while PVC from post-industrial waste saves 1.8 t CO_2 eq. (the results sensitive to transport distances)[x], with additional savings on emissions to air and water. Given the commonality of the material, similar savings are anticipated for recycled pipes. It is therefore possible that, despite future uncertainty 100-200 years ahead, the overall life cycle benefits from recycling this PVC waste could be substantially higher when multiple reuse cycles are factored in.

Under a controlled-loop scenario, we also considered what conditions should be in place to improve overall performance, trust and accountability. Some requirements that we believe are necessary include:

- *Using the recycled PVC in only approved applications (intentional loops)* - Already in Europe, there are schemes to recycle PVC window profiles and PVC pipes into either the same application or in other profile applications[xi]. This type of controlled-loop recycling should make it possible to keep track of where recycled PVC is being used and is likely to mean that material quality remains high. It also makes for simpler market communication if intended uses for secondary materials are clearly defined.

- *Traceability and verification (traceable loops)* - It will be necessary to put in place transparent procedures in order to build trust and insight into material contents in perpetuity. The industry has already established a chain of custody traceability scheme, but there is also potential to consider what is needed in the really long term for material stewardship in successive product loops, i.e. embedded tracers. This is clearly an opportunity for the industry to further develop under its VinylPlus® Product Label initiative[xii]

- *Preserving the highest possible material value (productive loops)* - Where technically possible, 1-1 substitution of recycled PVC in place of virgin material is the goal. However, where technical efficiency or appearance (e.g. slight colour variations) are at risk, recyclate may be blended or used for other applications that preserve the highest feasible functional value. This should allow additives contained in the recyclate to continue to play a useful functional role. Retention of additive function in recyclate consequently represents more efficient use of feedstocks when blended with virgin PVC. It is no doubt also possible to optimize recycling schemes over time so that the quality and functioning of all constituents of the recycled PVC is preserved or further enhanced.

- *Additional design measures to allow higher recyclate content* - Best Available Technologies (BAT) enable recycled PVC to be encapsulated within virgin PVC[xiii], such as using recyclate in the middle layer of pipes or inner components of window profiles. This allows to include into those articles a high quantity of recyclate without compromising their required aesthetic and long-life performance characteristics.

- *Mixing vs purifying material flows (containment loops)* - Some stakeholders are opposed to combining virgin and recycled materials together in new products ('hybrid' products) from the perspective that this spreads out the contamination of legacy additives and reduces the material value. Our view based on the robustness of TNS framework is that there is a need for closer dialogue to understand the situation for rigid PVC in its major applications. If the above-mentioned control conditions are met, from a long-term perspective, a well thought out approach to blending virgin and recycled PVC can both contain and progressively reduce the concentration of legacy additives in the overall PVC material flow, reducing any potential exposure effects or release to the environment. This positive, progressive approach of working stepwise to a future sustainability goal is consistent both with The Natural Step Framework and the aspirations of a progressive transition to a circular economy.

CONCLUSION

Our long-standing conclusion is that all PVC articles need to be optimised for and managed within a controlled-loop system in order to align with the principles of sustainability advocated by The Natural Step. A closer look at management options for rigid PVC waste from window profiles and pipes suggests that legacy additives are not likely to 'leak out' from recycled materials, and the reuse of this waste stream is preferable to the alternative disposal routes assessed. This assumes risks are controlled through safe use and recycling under approved conditions and is based on the specific circumstances for the PVC industry in Europe. Furthermore, so long as safe handling and ongoing VinylPlus® commitments to achieving controlled-loop management of PVC remain in place, it is likely that the concentration of legacy additives will continue to decline in the material flow as newer PVC formulations enter the recycling stream. Overall, we believe this is consistent with Europe's circular economy strategy, resource efficiency and long-term sustainable development.

This solution also resolves the dichotomy in EU policy between 'cyclic economy' (retaining material value and averting waste) and 'non-toxic environment' (which could prevent controlled loop management due to legacy substances). While this is not resolvable immediately it is attainable through a clear and auditable pathway towards common goals in the longer term[xiv].

In a sustainable society: / Post-use Management	System Condition 1 **… nature is not subject to systematically increasing concentrations of substances from the Earth's crust, e.g. heavy metals and fossil fuels.**	System Condition 2 **… nature is not subject to systematically increasing concentrations of substances, produced by society, e.g. NOx, EDCs, CFCs, dioxins.**	System Condition 3 **… nature is not subject to systematically increasing degradation by physical means, e.g. overfishing and destroying habitat.**	System Condition 4 **… people are not subject to structural obstacles to health, influence, competence, impartiality and meaning-making[xv].**
Scenario 1 – Landfilling waste rigid PVC In this scenario, we assume that virgin PVC is used to produce new rigid PVC products rather than recycled PVC.	Rigid PVC is believed to behave rather like stone. Heavy metals are firmly bonded in the PVC in landfills, with no significant evidence of release of scarce metals. However, over millennia there is always the potential that these bound metals could migrate out as the PVC slowly degrades. Fossil fuel consumption and other emissions result from extraction and production of virgin PVC, with none of this embedded energy / material recovered but instead residing in the landfill.	Over a timescale of millennia, PVC polymer would eventually degrade and release its constituents and breakdown products into nature, some of which may systematically accumulate in concentration. Uncontrolled burning of PVC waste mixed in landfills has the potential to generate dioxin, furan and other potentially problematic emissions.	Physical displacement of nature results from landfill space taken up by PVC waste. Physical displacement of nature is likely to result in future if we assume that articles made from virgin PVC are also landfilled at the end of their use phase in the absence of recycling systems.	Not making use of available waste streams perpetuates the linear economy, is a waste of a useful material that can be reused to meet human needs, and landfilling PVC may create health impacts. Hence, it generates both direct and intergenerational equity questions.
Scenario 2 – Incineration of waste rigid PVC with energy recovery In this scenario, we assume that virgin PVC is used to produce new PVC products rather than recycled PVC.	Energy recovery from burning PVC waste releases energy embedded in chemical bonds, with ash concentrating other elements (particularly metals such as lead, zinc, cadmium, titanium) that may comprise of toxic waste. Energy recovery from incineration today can be seen as the most eco-efficient for difficult-to-recycle PVC and is consequently preferred relative to landfilling, though the self-quenching nature of chlorine liberated during incineration means that lower efficiencies are achieved. The carbon content of PVC is emitted to the atmosphere as carbon dioxide.	Incineration of PVC under controlled conditions limits the generation of dioxins and other pollutants, as specified in the EU Directive 2000/76/EC. Controlled incineration of PVC destroys the additives. Residual waste from burning can be collected and some may be reused as, for example, input to building materials such as breeze blocks. However, ash tends to accumulate metals and other potentially hazardous materials so may require disposal as hazardous waste.	Significant residual waste is generated from PVC incineration, which is likely to require landfilling. Landfill sites not only displace ecosystems directly but can have secondary effects such as interfering with aquifers. Note that, whilst it may be possible to find alternative uses for residual waste from incineration, where significant concentrations of problematic contaminants are present this will lower or eliminate its value and options for reuse.	Even with energy recovery, incineration destroys 'structure' and value of otherwise useful materials, depriving future generations and other beneficiaries. Failure to make best use of available waste streams perpetuates the linear economy, is a waste of a useful material that could otherwise be used to meet human needs and may create health impacts. Hence, incineration generates both direct and intergenerational equity questions.
Scenario 3 – Controlled-loop management of waste rigid PVC window profiles. In this scenario, we assume that recycled PVC is used to produce new PVC products, combined with a proportion virgin PVC.	Reusing materials avoids impacts from sourcing virgin resources. The carbon-based energy saving can be substantial, both of embedded energy and in the material itself. Studies indicate that that metal compounds embedded into PVC matrices as additives are not biologically available, as they remain immobile in recyclate. Metals such as lead and cadmium are no longer used as additives in virgin PVC formulations. The overall concentration of legacy additives will therefore be gradually reduced through blending of recycled and virgin PVC.	Production emissions from sourcing virgin resources are avoided. Emissions from recycling processes need to be counted but will be at least an order of magnitude lower than that of virgin material production in the case of physical recycling. Use of recycled PVC averts any releases of additives relative to landfilling and incineration In product use, PVC recyclate is generally encased within virgin PVC in multi-layered design, serving as an extra precaution against migration of any legacy additives.	Reuse and recycling avoids physical impacts from sourcing virgin resources for new articles, e.g. water (see note below). It also avoids physical impacts from landfilling PVC or disposal of residual waste after incineration.	Legacy additives are not likely to have health effects if they are immobile during the recycling process and in recycled articles. Encasing recyclate within virgin PVC can increase recycling volumes without loss of aesthetics or functional benefits. Reuse and recycling retains the value of the material to meet future human needs and supports a progressive transition from the linear to a circular economy model. In order to secure market trust, safeguards need to be built into the recycling and reuse of PVC with well-founded documentation and communications of safety and other sustainability benefits.

Table 1: PVC window profiles End of Life scenario comparison evaluated using sustainability principles

BACKGROUND

THE NATURAL STEP AND SUSTAINABILITY ANALYSIS OF PVC

The Natural Step has a long history of analysing the sustainability challenges and potential for PVC in Europe, starting with a study and multi-stakeholder process commissioned by the UK Environment Agency in 1996-2000. The result of that analysis was a summary of sustainability challenges for the industry to address:

The five 'TNS Sustainability Challenges for PVC' initially published by The Natural Step[xvi]

1. **Carbon Neutrality:** Commit long-term to becoming carbon-neutral.
2. **Controlled-loop:** Commit long term to a controlled-loop system of PVC waste management.
3. **Organochlorine emissions:** Commit long-term to ensuring that releases of persistent organic compounds from the whole life cycle do not result in systematic increases in concentration in nature.
4. **Additives:** Review of the use of all additives consistent with attaining full sustainability, and especially commit to phasing out long term substances that can accumulate in nature or where there is reasonable doubt regarding toxic effects.
5. **Value chain collaboration:** Commitment to the raising of awareness about sustainable development across the industry, and the inclusion of all participants in its achievement.

In the years since this study we have advocated for sustainability improvement across the industry, coached business leaders and trained hundreds of chemical industry professionals in the principles of sustainability. In 2009-10, we challenged the PVC industry to increase its ambitions and acknowledge what it will take to truly address the key sustainability challenges of PVC. As a result, we were invited to help the industry to establish a new 10-year industry roadmap to 2020, VinylPlus®, building on an earlier voluntary commitment.

While further progress and speed is needed in all sustainability endeavours, VinylPlus® should be seen as part of a long-term roadmap for the industry to move step-wise toward the circular and sustainable management of PVC. The Natural Step aims for VinylPlus® to make progress on its roadmap and for stakeholders to hold the industry accountable for its promises. The Natural Step also provides critical expertise to VinylPlus® and is currently helping a number of its Task Forces integrate the principles of sustainability into their work on additives, labelling and the design of the controlled loop management system.

This particular statement is produced in response to a request from the VinylPlus® controlled loop management task force to help develop science-based proposals for managing the legacy additives in rigid PVC waste. It is intended as advice to VinylPlus® and is shared publicly as an opportunity for stakeholders to review the conclusions we reach when looking at the issue of PVC waste through the lens of a strategic framework and science-based sustainability principles.

---

[i] Stichnothe, H. and Azapagic, A. (2013). Life cycle assessment of recycling PVC window frames. *Resources, Conservation and Recycling*, 71, pp.40– 47.
[ii] Leadbitter, J. and Bradley, J. (1997). *Closed loop recycling opportunities for PVC*. Current Trends in PVC Technology Conference. Institute of Polymer Technology and Materials Engineering, Loughborough University; 3–4 November 1997
[iii] Recovinyl is the main system for recycling PVC http://www.recovinyl.com/. VinylPlus® Annual Report includes verified volumes of recycled PVC in Europe. https://vinylplus.eu/uploads/downloads/VinylPlus_Progress_Report_2017.pdf
[iv] http://www.thenaturalstep.org/pvc/
[v] https://vinylplus.eu
[vi] See VinylPlus® Annual Reports for industry statements and projects on legacy additives. See also European Commission: Study To Assess The Possibility Of Granting A Derogation Given To Specific Types Of Plastics And Rubber Waste In The EU Waste List, Reference: No 374/Pp/Ent/Ima/14/11917 – BIPRO Final Report, 8 May 2015
[vii] https://vinylplus.eu/progress/annual-progress/2013-2
[viii] Research about the Framework for Strategic Sustainable Development promoted by The Natural Step is most recently the focus of a Special Issue of the Journal of Cleaner Production in 2017 http://www.sciencedirect.com/science/journal/09596526/140/part/P1?sdc=1
ix Here we have considered mechanical recycling only.
[x] Stichnothe, H. and Azapagic, A. (2013). Life cycle assessment of recycling PVC window frames. *Resources, Conservation and Recycling*, 71, pp.40– 47.
[xi] http://www.rewindo.de
[xii] http://label.vinylplus.eu
[xiii] EPPA video: How are window profiles recycled - https://youtu.be/j3SrSkkmXOw
[xiv] Everard, M. (2014). Stepping towards sustainability. *Materials World*, December 2014, pp.27-29.
xv For simplicity, the social dimension of sustainability is addressed under this one principle. In more recent research each of the five factors noted here are presented as distinct principles of social sustainability.
[xvi] Everard, M., Monaghan, M. and Ray, D. (2000). *PVC: An Evaluation Using The Natural Step Framework*. The Natural Step, Cheltenham.