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# PVC and sustainability

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## Abstract

PVC has been under intense and hostile attack for a number of years, primarily because of its association with chlorine chemistry. It has been argued by some that because of this association it is inherently unsustainable, although much of this argument has been emotionally driven rather than based upon scientific scrutiny. Yet the presence of chlorine imparts a range of unique technical features in PVC that set it apart from many other polymers. A number of these features are well known and documented, and perhaps this uniqueness makes it a fascinating polymer to study in terms of its potential for sustainability. It is durable in use and difficult to break down. This persistence has made it a target by some campaigners, yet this could arguably be one of its greatest strengths from a sustainability perspective. The following report assesses—on a scientific basis—what sustainability means to the PVC industry and the necessary steps that would be needed to deliver a truly sustainable polymer. The evaluation model presented is based on The Natural Step (TNS) framework. The TNS framework is a robust and science-based set of tools that define sustainability in unambiguous and workable terms and helps organisations engage with the practicalities of sustainable development. In particular, the study includes a case history of a sustainable development process leading up to this evaluation involving a number of leading UK retailers. 

*Keywords:* Poly(vinyl chloride); Sustainable development; Sustainability; The Natural Step; Packaging; Norsk Hydro; Hydro polymers

**Contents**



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## 1. Chapter 1

### *1.1. Introduction*

The terms 'sustainability' and 'sustainable development' have increasingly appeared on the radar screens of many businesses and industries over the last few years. A few brave companies such as IKEA, Electrolux and Interface have fully embraced these concepts and integrated them within their businesses, although most companies are currently only at the fringe of embracing such concepts. Yet what such terms mean is often open to differing interpretation and how companies grapple with their meanings, let alone put them into business practice, can be a pretty daunting challenge. The immensity of such a challenge is no different for the polymer industry as it is for any other industry. However, it is the aim of this report to aid those in this sector, and in particular those working within the PVC Industry, to grapple with these terms, in order to form a better understanding and thereby put them to good use.

There have been numerous attempts to define sustainable development; the most commonly cited is that provided by the 1987 Bruntland Commission Report [1] to the United Nations, entitled 'Our common future'. This report defined the term as:

> *Development that meets the needs of the present generation without compromising the ability of future generations to meet their needs.*

When compared to the rigorous requirements of sustainability, the limitations of this definition become obvious. Above all it fails to convey the idea that there are biophysical limits within which society must operate. There are a number of other definitions that have since been put forward as alternatives. For example, Porritt et al. [2] from an organisation in the UK known as 'Forum for the future', uses the following alternative.

> *Sustainable development is a dynamic process which enables all people to realise their potential and to improve their quality of life in ways which simultaneously protect and enhance the Earth's life support systems.*

This definition supports sustainable development as a dynamic process and introduces the importance of social justice and equity for all people. (Forum for the future is the charity in the UK responsible for licensing a sustainability tool known as 'The Natural Step'—which is discussed in detail in Chapter 3).

Importantly, it should be appreciated that there are differences in definition between *sustainable development* and *sustainability*. Where sustainable development is the process or journey we must take to arrive at the destination of sustainability, in other words, quite simply the process of moving towards sustainability.

Sustainability in the context of PVC has been defined in this report through a series of clearly defined science-based constraints and systems and the enclosed case history forms a part of this sustainable development process.

Prior to addressing these constraints and systems, it is instructive to first examine why so much emphasis is now being placed on these issues by the business sector and not just by environmental campaigners. As a growing population places even more demands on dwindling natural resources, so there is more of a pressing reason to address sustainable development. By way of example, global human population growth has increased from 2.5 billion persons in 1950 to around 5.8 billion in 1997, at the same time cities with more than 8 million have grown from 2 in 1950 to 25 in 1997. Predictions for 2050 estimate a human population of around 9 billion.

Such growth places increasing pressures on nature's natural resources, whether this is energy, water, soil or food. In addition, the planet is required to absorb and neutralise the growing amount of waste materials we generate such as carbon dioxide and other gases as well as solid and liquid wastes. These concerns are global, hence the reason for the developments of international agreements such as the Kyoto Protocol to attempt to halt the potential acceleration of climate change and stabilise global $CO_2$ levels by 2010.

So what role could PVC play in a dwindling natural environment? And what are the sustainable and unsustainable attributes that this polymer brings to a growing population? These questions have been addressed in this report through TNS framework and form the basis of a sustainability evaluation. How the evaluation of PVC occurred through the TNS process is an interesting case study and has been described in detail in Chapter 2.

TNS is an organisation founded by Karl-Henrik Robèrt, a Swedish cancer specialist who developed a unique thinking process for scientific consensus in the late 80s. Further details of the methodology of TNS are described under Chapter 3.

PVC has been at the centre of a continued environmental campaign against its use in today's society, with some companies deselecting it in preference to alternative materials. This deselection process carries little credibility in terms of sustainable conduct. For example, few if any of these companies have really addressed how sustainable the alternative materials are compared to PVC in terms of their manufacture, use and ultimate disposal. Yet it would be hypocritical of our industry to challenge the conduct of such companies without undergoing a phased process of sustainable development of our own. A recent report by Everard and Monaghan [3] *PVC: an evaluation using TNS framework* identifies five key challenges that our industry must address to move towards sustainability, and these are discussed in Chapter 4.

Hydro Polymers Ltd is one of two major manufacturers of the polymer poly(vinyl chloride) in the UK. The company is part of the polymers sector of Norsk Hydro a.s. Our company firmly believes it must address these challenges throughout its business activities and beyond to other stakeholders in the supply chain. Consequently, the sector is committed to a sustainable development process throughout its business activities using TNS principles and framework.

The ultimate objective is to reverse the unsustainable practices in our industry and thereby demonstrate to our stakeholders that PVC can play an important role in a future sustainable society. Daunting though some of these challenges may appear, they are not impossible.

### *1.2. Background*

PVC is an interesting polymer since it can accept a much wider range of additives than all other plastics. This is due to the polar nature of the polymer due to the presence of chlorine atoms repeated within its backbone. Consequently, it has been used in a significant number of applications as diverse as blood bags and window frames. Yet this success has not been without some impact on the environment, nor has it been without its detractors. Indeed, PVC continues to be at the centre of an ongoing environmental campaign, primarily headed by the pressure group Greenpeace. Most of this debate has focused around the inclusion of chlorine—'the Devil's element', according to Greenpeace who would like to see the sunsetting of all chlorine chemistry [4]. To an extent, Greenpeace has been right to focus on chlorine chemistry. For example, we have seen the consequences of huge environmental damage of the ozone layer caused primarily by chlorofluorocarbons. In addition, the persistence of synthetic chemicals such as poly-chlorinated biphenyls and the unintentional manufacture of dioxins and furans from industrial processes have caused significant environmental concern regarding the long-term environmental consequences of such chemicals. In some cases, this has led to global phase-out policies. The one common thread is that all these compounds contain chlorine. Similar problems are linked to organic compounds with other halogens like bromine organic compounds (anti-flammables). In addition, despite the significant improvement in modern manufacturing methods, industry remains tarnished with the legacy of past malpractices.

Importantly, before we go on in our analysis, it needs to be stated that there are many benefits that chlorine chemistry can bring to society. For example, over 80% of all pharmaceutical products are derived from chlorine chemistry, and the addition of chlorine to our drinking water prevents widespread disease by the destruction of harmful bacteria.

While questions have been raised about the presence of chlorine in PVC, other issues have since emerged such as the use of heavy metal stabilisers used to protect PVC during processing. In addition, the use of softening agents (such as phthalate plasticisers), have created concerns over their possible hormone disrupting effects. Of major importance are concerns surrounding the ultimate disposal of PVC wastes. This is also on the political agenda including a Green Paper on 'Environmental issues of PVC' [5] at European community level. In response to these concerns, the European PVC Industry has developed a voluntary agreement to address many of the issues raised. This was formalised in March 2000 [6].

The voluntary commitment from industry is commendable and the industry requires leaders to practice a clear demonstration of sustainable conduct. To date, the polymers sector of Norsk Hydro considers itself as one such leader in addressing environmental issues. This includes landmark examples of two published environmental books produced in 1992 and 1996, respectively, [7,8]. Whilst these publications were significant for the industry, they primarily focused on addressing environmental concerns and improving eco-efficiency, which falls short of addressing sustainability, the challenge of the work in this report.

## 2. Chapter 2

### *2.1. Case history*

The following extract details a business-to-business initiative that has had far greater consequences than could ever have been initially perceived. The instigation of this process began with a campaign to ban PVC packaging in the UK, organised by Greenpeace. This section examines the key events of the two UK manufacturers of PVC, Hydro Polymers Ltd and EVC UK Ltd, and some well-known UK retailers—these represent two extremes of the supply chain. This has led to a voluntary commitment from the UK PVC Industry to address important environmental issues. In the process, the retailers have effectively played the role of a pressure group, with the UK PVC Industry responding to their needs. Environmental experts from key UK establishments have facilitated the process. Whilst the majority of the process has been based in the UK, there is growing interest in it from around Europe and in the States.

In July 1996, an organisation called Media Natura organised a seminar at the request of the pressure group Greenpeace for leading UK business leaders from a wide range of retailers at the Royal Institute of International Affairs, London. Greenpeace's intention was to persuade UK retailers to substitute PVC in all applications whether used in their stores for packaging as well as in building products for future stores. From the PVC industry's perspective, the process was far from democratic, since industry representatives were not allowed to participate at the initial phase.

This was followed by an intense Greenpeace national campaign lasting between August and October 1996, with demonstrations outside high street stores in towns and cities across the UK and leaflets entitled 'Saving our skins' and 'Drink to the future'. The targeted audience included members of the general public, who were handed leaflets before entering the stores, and chief executives of leading retailers who were sent copies in the post. The leaflets called for a total phase-out of PVC in packaging materials and highlighted that PVC packaging could be spotted by looking for a sign saying '3' or 'v' within a triangle on the package. However, Greenpeace failed to point out that this was the recycling logo! The leaflets stated, 'just buy alternative packaging' and listed a range of skin-care products to avoid from specific stores since they were packaged in PVC. It also stated that the first choice of packaging for drinks should be glass bottles, with the words 'it's time to go PVC free!'

Greenpeace had also taken advantage of a potential health scare earlier in the year, when the highly acclaimed journalist Geoffrey Lean published a report in the Independent on Sunday, entitled 'Sex-change chemicals in baby milk' [9]. He made use of a scientific report commissioned by the UK Ministry of Food and Fisheries, MAFF (under their regular food surveillance information sheets, [10]), which had found 'phthalates' in 15 different brands of powdered milk infant formulae—albeit at low levels. (Phthalates are plasticisers used to soften PVC and they are predominantly used in flexible PVC.) The report by MAFF had been published in March of the same year although the article itself was released during a May bank holiday. Coincidentally, a leading expert on reprotoxicity, Dr Richard Sharpe and his co-workers at Medical Research Centre, Edinburgh had published a possible hypothesis [11] linking one phthalate (butylbenzyl phthalate) with reduced sperm counts in men at levels not too dissimilar to those identified by MAFF in its own surveillance report. Lean connected the two reports to devastating effect as far as industry was concerned. MAFFs main conclusions were that it would be prudent of industry to find where this contamination was occurring and reduce levels identified, although there were no immediate risk reduction measures highlighted.

Once the issue of PVC had crossed over from the environmental field into food safety, it became a major concern for the retailers. This clearly helped fuel the fire and provided the momentum needed by Greenpeace to carry forward their anti-chlorine campaign.

Ironically, the follow-up study again commissioned by MAFF and published in December 1998 [12] reported levels of phthalates in infant formulae 10 times lower than those in 1996. According to MAFF, the reasons for the reduction was not clear, however, a spokeswoman from the Infant and Dietetic Foods Association suspected that the original samples were contaminated and that there was a fault with the handling or analysis of the first samples [13].

Richard Sharpe had been working on advice from his co-author Professor Sumpter, Brunel University. Sumpter had found that vitellogenin, an egg protein normally found only in the blood of female fish (roach), had started to appear in male fish in some rivers. Consequently, Sumpter used this protein as a biomarker for oestrogenic contamination of the aquatic environment [14]. Since low concentrations of phthalates had been found in such sediments, it was plausible to suggest that such chemicals may have been responsible for such effects. However, later work in a joint project between Brunel University, the Environment Agency and the UK Ministry of Food and Fisheries [15] strongly indicated that the main culprit appeared to be natural hormones, (anthropogenic—probably excreted by women) found at very low concentrations at sewage discharge effluent outlet sites. Nevertheless, phthalates were now clearly a target, and the fact that a synthetic chemical had been found ubiquitously dispersed within the environment was a cause for serious concern.

As phthalates came under the spotlight, Greenpeace was quick to point out that their main use was a plasticiser to soften PVC. What it did not mention was that baby milk is not packaged in PVC and that little, if any, food contact packaging manufactured in the UK from PVC contains phthalates [16].

The effect of the campaign reached the highest levels and questions were asked about the validity of the Greenpeace claims. Retailers responded in different ways; inconsistencies in their responses varied from one store to another for the same retailers. For example, at one Sainsbury's store the police were contacted and the demonstrator removed, whilst at another, the store manager was proudly photographed alongside the demonstrator [17] and featured in a local newspaper.

Greenpeace's tactics continued, and in September 1996, an ad hoc group of retailers was set up known as the 'PVC Retailer Working Group'. This was formed as a result of a Tesco initiative and the membership included; Tesco, Waitrose, Cooperative Wholesales Suppliers, Body Shop and Lloyd's Chemists, with Greenpeace acting as an adviser. The group's specific objective was to examine PVC-related environmental issues. Other retailers chose not to join the group but sought alternative advice. For example, Great Mills and Sainsbury's both independently visited the Hydro Polymers site at Aycliffe to evaluate for themselves PVC manufacturing practices. Indeed, this led to the development of a Sainsbury's question and answer document on PVC that has since had some circulation [18].

Following the formation of the Retailer Working Group, industry sought to participate at the Group's meetings, but their offer was declined. However, the remit of the retailers was clear: *to firmly establish whether or not there was a case for eliminating PVC*. Globally, at the time PVC world demand in the packaging industry amounted to around 3 million tonnes in 1996 [19].

In October 1996, the Retailer Working Group decided that it did not have sufficient scientific knowledge to make an informed judgement regarding the legitimacy of Greenpeace's claims for a PVC phase-out. Consequently, independent advice was sought from the Chairman of the PVC Retailer Working Group, John Longworth, Trading Director at Tesco's. Mr Longworth approached Jonathon Porritt, a leading environmentalist in the UK, to recommend a suitable academic body to carry out an independent piece of research to evaluate the claims made by Greenpeace. Jonathon Porritt's organisation, Forum for the Future was an obvious choice, since Tesco's had been part of the Forum for the Future's Foundation Corporate Partnership since the forum's existence.

Jonathon Porritt recommended that the Retailer Working Group should approach an academic body linked to a network of universities in the Greater Manchester area known as the National Centre for Business and Ecology (NCBE). The NCBE was appointed to conduct a confidential study on behalf of the Retailer Working Group.

The NCBE was established by the Co-operative Bank, in partnership with: Manchester Metropolitan University, UMIST, University of Manchester and University of Salford. The advantages of using the NCBE were; their independence and their ability to assemble a sufficiently broad-skilled team for the task. This study was commissioned to evaluate both the impact on human health and the environment of PVC used in packaging and in construction materials. (Construction products manufactured from PVC were also considered, on the basis that if harm had been found then this would have been extended not just to packaging but the future construction of retailer sites.) Running concurrently with this project, the retailers also requested PIRA, one of the UKs leading packaging consultancies, to evaluate the economic impact of substituting PVC with alternative materials in packaging. This report was completed but is confidential to the sponsors.

In January 1997, PVC representatives were invited to one of the Retailer Working Group meetings at Tesco's offices in London. Those representatives were asked to follow on from a presentation from a Danish representative working for the Danish equivalent of the UK Co-operative Group, who stated that in Denmark, the more they looked at PVC the more problems it presented. Yet, despite an intensive year-on-year substitution policy, nearly 50% of PVC packaging (relative to the initial phase-out) remained in Denmark, proving far more difficult to substitute than had previously been anticipated. In particular, PVC in waste was singled out as one of the major problems, though, it was conceded that a number of Denmark's municipal waste incinerators were antiquated and that this was a major reason for Denmark's hard stance on PVC. (removing the chlorine source from the incinerator was seen as a cheaper option rather than to construct more efficient incinerators.) A further concern was expressed over the use of phthalates, despite the fact that they are hardly used in packaging, with the Body Shop representatives being most outspoken on this score, although they admitted that 'di-2-ethyl phthalate', had been used as a carrier in certain perfumes included in their range of products.

From an industry perspective, this was a most negative and thoroughly depressing meeting. There was a case to be answered yet the scientific argument had yet to be demonstrated.

During this low period, industry had created its own campaign through a joint initiative between the British Plastics Federation and the Packaging and Industrial Films Association. This involved the wide distribution of monthly mailers in the form of emotional pictures combined with the headline and some text, e.g. a picture of a flexible PVC blood bag with the caption 'Who wants the bloody facts' [20].

In April 1997, the NCBE had completed the report, although this remained confidential to the members of the PVC Retailer Working Group. It was published and finally made public on 10 September 1997 under the heading 'PVC in packaging and construction materials—an assessment of their impact on human health and the environment' [21]. The launch of the report was spearheaded with a spectacular press release from the Retailer Working Group [22] featuring the headline:

Clean up or phase-out, retailers tell PVC makers.

The press release was carefully worded to indicate that certain aspects of PVC production may be harmful to the environment, but if these methods were to be modified then PVC could be a useful product. This now allowed the PVC Industry to demonstrate that PVC could be manufactured to the highest standards, an essential task since, until that time, industry had largely been excluded from the process. The press release indicated that the NCBE report was the basis for this challenge. Consequently it was an important document in the process. Clearly this was not the news that Greenpeace was looking for since it became a 'manage the problem' issue rather than a phase-out strategy. Greenpeace independently produced its own press release that stated that PVC was inherently polluting.

There were a number of key findings from NCBE report, and the important conclusions are detailed below:

> The study team concludes on balance that the careful manufacture, use, recycling and final disposal of PVC products to the highest standards can control the risks associated with the material to acceptable levels but will not completely eradicate them.
> The study team was unable to find conclusive scientific evidence linking the production, use or disposal of PVC compounds where best industry practice is utilised to substantial harm to human health. Likewise conclusive evidence of serious environmental harm resulting from manufacture, use or disposal undertaken to the highest standards was not found, although past and some current production/disposal falls short of those standards. Where there is evidence of harm to human health or the environment, evidence that PVC forms a major factor set against other processes or products was not found.

A range of recommendations subsequently followed: The PVC Retailers Group members should therefore use their position in the market place to:

- ensure the highest possible operational standards from their supply chain—manufacturers, processors and disposal operators
- keep the scientific evidence under regular review in order to ensure that the conclusions drawn from existing evidence in this report remain valid in the future
- reduce the use of all materials to the minimum achievable, in accordance with current best practice
- support appropriate reuse and recycling initiatives to reduce the volumes manufactured and disposed of, in accordance with current best practice.

Following the press release the managing directors of the two PVC manufacturers in the UK, Hydro Polymers Ltd and EVC (UK) Ltd sent a joint letter to the Chairman of the Retailer Working Group. This letter stated that both companies were looking forward to the opportunity to discuss in detail the content of the report, and to assure them of industry's commitment to continuous environmental improvement.

In November 1997, the two UK manufacturers of PVC were invited to participate at the Retailer Working Group with the intention of setting a timetable for action including setting emission targets and deadlines. This would require full transparency of production methods and independent auditing.

At that stage, the Body Shop withdrew from the process. (In fact, the Body Shop did not use PVC in any of its packaging.) Several other retailers who had not been core to the group chose not to participate further, including Lloyds Chemist, Somerfield and Superdrug. IKEA had been involved only at the start of the process since they had previously introduced a PVC phase-out policy of their own prior to the process. Greenpeace, UK then had a difficult management problem on their hands since 'managing an issue' would not be acceptable to Greenpeace International who had called for a 'PVC phase-out'. It was clear that remaining with the Group alongside industry would be untenable, although there were at least two meetings where both parties were present.

Until the publication of the report, John Longworth, Tesco's Trading Law Director, remained Chairman of the PVC Retailer Working Group. Clearly, the signs were that Greenpeace would now 'up-stumps' and depart from the process, and it was important to secure credible environmental leadership for the Group. Consequently, John approached Jonathon Porritt as part and parcel of the Foundation Corporate Partnership with Tesco with a direct request for Jonathon to be appointed as Chairman of the Group. He formally accepted this role on the condition that industry would also be put through a thorough sustainability evaluation. Indeed at the very first meeting that both Greenpeace and the PVC Industry attended, the word, sustainability echoed around the room as tough questions were asked about the sustainability of the alternative materials being mooted by Greenpeace as substitutes to PVC. One of the conditions that Mr Porritt made to his Chairmanship was to ask the PVC industry to go through a gap-analysis process of what measures would be required for PVC to become 'genuinely sustainable' if indeed it could be sustainable.

However, in the first instance there was a more pressing need for the development of an eco-efficiency code of practice. This was required to demonstrate that PVC could be manufactured with a low level of harm to the environment. This would attempt to benchmark PVC producers and at the same time provide the confidence that the retailers needed to demonstrate that the PVC they used had been responsibly manufactured.

Since the NCBE had been instrumental in the evaluation of PVC, the Group was commissioned to draft both a PVC charter and the code of practice. It was decided to rename the group 'The PVC Co-ordination Group' and after its second meeting, despite all attempts to keep Greenpeace on board, they exited the process.

In addition, since the next phase of work would involve a code of practice for the manufacture of PVC, it was concluded that the Environment Agency should be invited to join the Group, as it is the regulatory body for granting the manufacturing licences for PVC production under integrated pollution control legislation.

### *2.2. Charter and code of practice*

Throughout 1999, the main agenda was the development of an industry charter [23] and Code of practice [24]. Both were formally launched on 17 April 2000 by a press release from the PVC Co-ordination Group. The charter itself committed industry to seven key actions:

1. To support the development of, and comply with, an eco-efficiency code of practice for the manufacture of PVC.
2. To regularly review industry operations in the wider social and environmental context, and to explore all possible futures for PVC. The results of these reviews will be summarised and made available to all interested parties.
3. To examine and pursue mechanisms for bringing about environmental improvements in the performance of suppliers and customers in the PVC supply chain.
4. To develop schemes and programmes, in association with other relevant organisations, that radically reduce the potential for end-of-life products containing PVC to accumulate in the environment.

5. To continue to participate in, and finance, research on the environmental and health effects associated with PVC manufacture, use and disposal.
6. To demonstrate compliance with the charter in an agreed manner.
7. To review the charter on an annual basis and update it as required.

Whilst the European PVC industry had already developed a charter for the manufacture of suspension PVC [25], the NCBE believed that this charter should be extended. In particular, the code was developed in order to allow an assessment of environmental impact per tonne of PVC produced. The general tenor for the development of the code established the principle of 'show me there is no harm from the manufacture of PVC'.

The code of practice called for the industry to go further than regulatory requirements by setting challenging targets with defined conditions attached. In preparing the code, it was recognised that manufacturers of VCM and PVC must continually operate at the leading edge of technology in terms of emission controls. Total losses from the factories were already less than, or of the order of, 0.05% of the material processed. Nevertheless, the manufacturers accepted the need to demonstrate to the public that there was no evidence of harm caused by their processes. In this context, challenging targets were established and the code set out minimum environmental standards to be achieved during the manufacture of PVC, together with measurable targets for continuous improvement in environmental performance. In addition, the code incorporated various commitments in relation to the environmental management systems operated by the industry, including an agreement to achieve ISO 14001 compliance by 2002.

Reporting on the compliance with the code by both companies was completed during 2001 and a formal press release by the manufacturers was announced on 26 September 2001 [26]. Press releases were also announced by the Chairman of the Group and by the retailers themselves [27,28]. Both companies had their reports verified by independent auditors, although their approach had differed in detail. Hydro Polymers' Ltd, performance against the code was reported through its EMAS Public Statement [29] for 2000. EVCs performance data were produced as a stand alone document [30].

## 3. Chapter 3

### 3.1. Sustainability evaluation

In accordance with the Chairman's request and running concurrently with the development of a charter and code, a further evaluation was undertaken by Dr Mark Everard and Dr Mike Monaghan, the Director of Science and a commissioned researcher, respectively, from TNS in UK. This process was initially described as a kind of gap analysis, i.e. 'What would it take to make PVC truly sustainable?' and was based on the systems approach of TNS framework utilising basic principles for sustainability as a lens through which the analysis was performed. The 'gap' would be a measure of how far PVC was away from achieving full sustainability. The researchers interviewed, among other stakeholders, both industry and Greenpeace scientists and through this dialogue a report was produced entitled 'PVC: an evaluation using The Natural Step framework' [3]. Prior to reviewing the main conclusions from this work, in the form of five key challenges, it is instructive to first analyse TNSs principles about sustainability and the TNS framework itself.

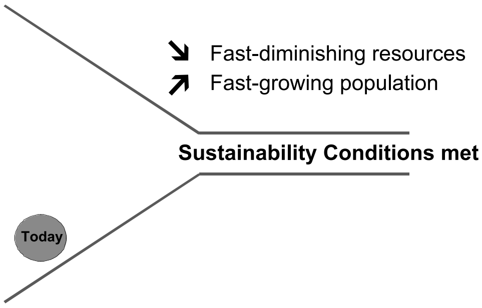


Fig. 1. The TNS funnel.

### 3.2. The Natural Step

TNS organisation was established in Sweden in the late 1980s as a means for tackling the difficulties facing society. Karl-Henrik Robèrt, a leading Swedish cancer expert, in co-operation with physicist Dr John Holmberg, and a network of other scientists from many disciplines elaborated the principles. TNS is now an international charity based in nine countries including; Sweden, UK, USA, Canada, Australia, New Zealand, South Africa, Japan and Israel. The purpose of TNS is:

> To deepen a genuine commitment to sustainable development throughout society using The Natural Step framework.

TNS has worked with a wide range of major companies to help them address their sustainability challenges, including DuPont, Electrolux, Tarmac, Carillion, IKEA, Interface, Mitsubishi, Air BP, Nike, The Co-operative Bank, Wessex Water, Sun Microsystems, etc. However, this was perhaps the first time the TNS process had been used in depth to evaluate a single material from a sustainability perspective, rather than to aid a company in using a wide range of different materials to become more sustainable.

### 3.3. About sustainability and sustainable development

Chapter 1 describes the concerns about growing world population, increasing demands upon and depletion of natural resources, accelerating levels of global pollution and concerns about the impacts of businesses on society. These are not new problems, nor are they avoidable unless society complies with basic principles for sustainability. They will increasingly constrain the ‘freedom to operate’ of organisations and society at large. TNS uses the metaphor of ‘the funnel’ to describe the inevitable tightening of these constraints, and the pressures to become more sustainable (Fig. 1). The analogy of the funnel is represented by the increasing narrowness of the walls caused by a fast-growing population combined with fast-diminishing resources. Sustainable development addresses these challenges proactively, based upon a sound understanding of what sustainability means and implies for us.

A sustainable system is one that can continue indefinitely. A sustainable society is one that does not impair or overload the life-support systems that provide for its needs. A sustainable product, process or organisation is one that does not contribute as ‘part of the problem’ in the funnel.

Hypothetically, when and only when all the sustainability conditions are met the metaphor of the funnel could actually ‘open up’ as a restoration phase.

All too often, problems are addressed reactively, using technical means to cure symptoms after problems have arisen. True sustainable development goes a long way beyond merely complying with basic environmental and social obligations, and differs from traditional 'end-of-pipe' solutions to pollution and social problems. It addresses issues 'upstream', in the early decision-making process, such that the pursuit of business does not systematically create the kinds of social and environmental problems that will, sooner or later, harm business performance and reputation.

But how do we move from concept to practice, and begin applying it in the messy world in which we live? If we chase them back far enough, it is easy to see that all businesses ultimately depend upon natural and human resources, including, for example, energy, timber, clean air and water, as well as the ingenuity and labour of people deployed to convert these natural resources into economic goods. The PVC industry, and businesses that use PVC, are no exception, with the extraction of the raw materials (including salt and oil/natural gas) at the start of the process. We all share the same world, and therefore our activities inevitably affect that same world and all those with whom we share it.

Since sustainability challenges are unavoidable, sustainable development is also possibly a great business opportunity. Firstly, it is essential to acknowledge that inherently sustainable ecosystems, upon which we are fully dependent, operate in definite ways—ways that it is possible to define using science—which ultimately determine what is and what is not sustainable. TNSs approach to sustainable development is based upon a systematisation of these scientific principles.

### *3.4. The Natural Step framework*

At the heart of TNS process lies a systems model of the sustainable cycles of Planet Earth, with four associated system conditions that provide the environmental and social boundaries for sustainability. The system conditions recognise that there are limits to the carrying capacity of the Earth in terms of the provision of material resources and environmental services, in terms of the capacity of nature to absorb and breakdown the by-products of society, and the cohesion of society resulting from equitable sharing of those resources. Once these boundaries are exceeded, then society compromises its own and future generations' ability to maintain or improve quality of life. These boundaries act, as the limit within which there is a need to form a sustainable economy, with the economy ultimately being dependent on nature's carrying capacity. If tackled proactively, sustainable development will prevent unsustainable practices and identify the new business opportunities presented by an inevitably changing and more sustainable future world. Continuing on a 'business as usual course' will merely perpetuate the historic habit of industrialised society in responding reactively, at substantial cost and disruption to businesses. A true commitment to sustainable development is therefore about a great deal more than altruism, as it helps deal strategically with the sustainable development pressures that will inevitably define the future business agenda.

The TNS framework presents a set of principles and strategic tools based on the scientific principles governing the Earth's ecosystem, the inherently sustainable system that supplies all our needs. At the heart of the TNS framework is a science-based systems model of this sustainable Earth system (Fig. 2). The framework defines what sustainability means and helps organisations get to grips with sustainable development in their decision-making processes.

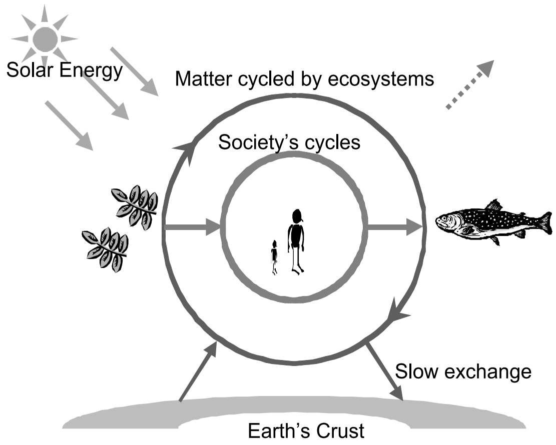


Fig. 2. The TNS systems model of resource cycles.

It can also be used to explore the sustainability implications of today's products and processes, and the measures that must be undertaken to make them more sustainable.

The TNS framework comprises four elements:

(A) *Sustainability awareness*. comprises an understanding of sustainability, or in other words the conditions that must be met in the mouth of the funnel. (Fig. 1).

The TNS framework includes four necessary *system conditions* for sustainability stemming from the science-based systems model. These four TNS system conditions are shown in Fig. 3 and listed below:

In the sustainable society, nature is not subject to systematically increasing…

1. System condition 1: Concentrations of substances extracted from the Earth's crust
2. System condition 2: Concentrations of substances produced by society
3. System condition 3: Degradation by physical means, and, in that society…
4. System condition 4: Human needs are met worldwide

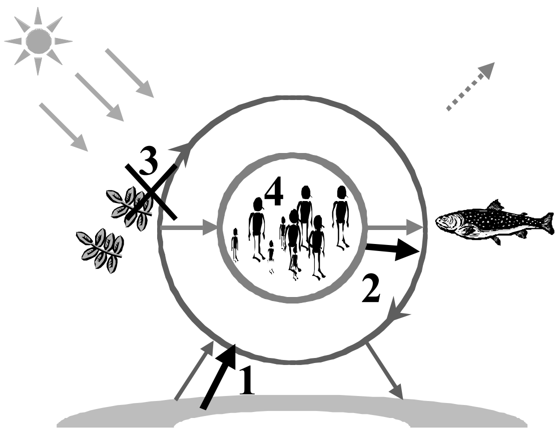


Fig. 3. The four TNS system conditions.

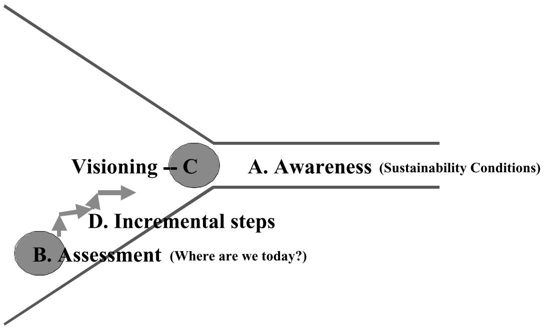


Fig. 4. A, B, C, D and the funnel.

(B) On the basis of these four necessary system conditions of sustainability, it is then possible to make an objective *sustainability assessment* of the present degree of sustainability.

(C) *Visioning*. Having used the system conditions to determine the present state of unsustainability, it is then possible to use the assessment as a helpful tool to create a vision of how we might expect to operate in a fully sustainable future. If based on the system conditions, the scenario-planning is based not merely on possibilities that might be conceived today, but on the scientific realities of the future into which society will unavoidably be squeezed.

(D) *Backcasting*. is a process by which you can determine the incremental steps that we have to take to reach our vision from where we are today. This differs radically from today's more common technique of *forecasting*, which is an extrapolation from today's knowledge, situation and trends to predict the future. Whilst yielding short-term gains, forecasting overlooks the inevitable changes and discontinuities with current trends that will arise through sustainability pressures. Incremental steps derived from backcasting acknowledge current constraints to full sustainability (for example, limits to capital investment or the readiness of the market). However, they also reflect the progressive steps that can be made today, from which further future steps can be taken to lead along a clear path towards the vision of full sustainability.

The A, B, C, D steps for applying the TNS framework are shown in the context of the funnel in Fig. 4. Together, they help define in unambiguous terms what sustainability means, and provide a readily-understandable framework to get to grips with the practicalities of sustainable development. They help the integration of sustainable development into strategic planning, communication of complex ideas, the sharing of these concepts with partners and across social sectors, and making strategic judgements about the steps we need to take now towards a more sustainable future.

It helps us address the fact that we cannot realistically hope to achieve sustainability immediately in a world that is far from sustainable, but enables us to 'navigate' increasingly towards sustainability through incremental decisions. Importantly, the strategic approach to sustainable development (the journey towards sustainability) enabled by backcasting—at odds from today's more common eco-efficiency emphasis which merely makes unsustainable practice more 'lean'—helps organisations avoid decisions that may represent 'blind alleys' that do not lead on a strategic path towards a clearly-articulated end-goal of sustainability.

## 4. Chapter 4

### *4.1. PVC industry sustainability challenges*

This chapter describes how industry can approach the five key challenges outlined in the report by Everard and Monaghan, 'PVC: an evaluation using The Natural Step framework' [3]. Essentially the systems conditions compliance form part of the sustainability awareness process (A) described in Chapter 3, whilst the enclosed response forms the basis of the (B) (sustainability assessment) and (C) (visioning) processes and the challenges ultimately leading to step (D) (incremental steps) in the above process. In addition, some of the key TNS recommendations contained in the above report are included, followed by an industry response. The order of the response to these challenges is the same as the order that they are defined in the report. An explanation of why these challenges are important and what barriers are needed to overcome these barriers follows.

Importantly, reference has been made to some of the challenges regarding a European voluntary commitment [6] set out by the PVC Industry and submitted to the European Commission. This commitment has been updated both in October 2001 [31] and is now known as Vinyl 2010. These proposals are clearly referred to under various challenges. However, it should be emphasised that this chapter includes other possible options, and that these proposals represent the author's view towards these challenges that are open to the whole of the PVC Industry.

### *4.2. Vinyl 2010, European PVC Industry voluntary commitment*

This is the new name given to an updated European Industry voluntary commitment and has been circulated around the European Commission. It is a 10-year programme, including a mid-term revision of targets in 2005 and definition of new objectives in 2010 to take into account technical progress and the enlargement of the EU. It also includes a strict monitoring process of its implementation through certified annual reports.

A formal legal entity, known as ECVM 2010 (European Council of Vinyl Manufacturers) will be responsible for the management of the voluntary commitment, gathering the whole PVC industry chain and open to a partnership with all interested parties. The PVC industry will provide a financial support scheme, in particular for new technologies and recycling schemes, allowing up to 250 million Euro of financial contribution over this 10-year programme.

*Vinyl 2010* includes the following key actions and commitments:

- Compliance to ECVM charters regarding PVC production emission standards;
- A plan for a full replacement of lead stabilisers by 2015, in addition to the replacement of cadmium stabilisers effective as of March 2001;
- The recycling in 2010 of 200 000 tonnes of post-consumer PVC waste. This objective will come in addition to 1999 post-consumer recycling volumes and to any recycling of post-consumer waste as required by the implementation after 1999 of European Directives on packaging waste, end-of-life vehicles and waste electronic and electrical equipment, e.g. by recycling 50% of collectable available PVC waste of windows profiles, pipes and fittings, and roofing membranes in 2005 and of flooring in 2008;

- A research and development programme on new recycling and recovery technologies including feedstock recycling and solvent-based technology;
- The implementation of a social charter signed with the European Mine, Chemical and Energy Worker's Federation to develop social dialogue, training, health, safety and environmental standards, including transfer to European accession countries;
- A partnership with local authorities within the Association of Communes and Regions for Recycling for the promotion of best-practices and recycling pilot schemes at local level.

### *4.3. TNS challenges*

#### *4.3.1. TNS challenge no. 1*

The industry should commit itself long-term to becoming carbon-neutral

*4.3.1.1. Why is this important?* One of the currently most debated threats to the planet is the burden of increasing quantities of carbon dioxide released into the atmosphere from fossil sources. (Breach of system condition 1 of the TNS framework). The problems associated with this are commonly referred to as 'climate change' and were briefly mentioned in Chapter 1. Clearly, modern developed industrial processes breach this system condition, and PVC is no exception.

PVC consumes quantities of hydrocarbons both in the energy to produce the polymer (process energy) and intrinsically contained within the polymer itself as a repeat carbon unit along its backbone. However, this amount within the backbone is roughly half compared to other polymers since a significant contribution of PVC is also derived from salt as repeated chlorine atoms adjacent to alternative carbon atoms.

The hydrocarbons, which are used in the process energy, essentially form carbon dioxide (and water vapour), that contribute towards climate change and so does the carbon dioxide released from incinerated PVC.

*4.3.1.2. Barriers to the challenge*. Few companies can currently claim that their products are carbon neutral. Some, such as private sector service industries, e.g. Interface, Cooperative bank, and B & Q claim that their services are almost carbon neutral. This has been achieved by these companies mainly through the purchase of 'green' electricity, sometimes at a premium compared to fossil fuel derived energy. Nevertheless, for such companies this can be a significant financial commitment, which raises the profile of the company in terms of commitment towards sustainable development. Clearly the energy's consumed by such service sectors are proportionally lower than energy consumption in materials manufacturing itself.

Consequently, one clear barrier to this challenge is to prevent those companies who are prepared to commit to carbon neutrality not to endanger financial ruin (economic unsustainability) in the process, especially if there is no incentive to do so for competing materials. Nevertheless, it is instructive to assess what opportunities are available to tackle this important challenge over and above legislation and international commitments such as the Kyoto Protocol. In addition, it should be remembered that this challenge is *voluntarily* to progress towards carbon neutrality at a much faster pace compared to any legislative measures.

*4.3.1.3. How could this be tackled?* For some companies, location can play an important factor with regard to carbon emissions. For example, at Hydro's chlorine and ethylene dichloride and vinyl chloride monomer (VCM) plant at Rafnes in Norway, much of the energy used in the conversion process is derived from hydro electric power (HEP), which significantly helps the starting position for reduced carbon emissions. Secondly, at downstream locations that are not geographically located to take advantage of HEP, the move away from burning coal and oil to gas, through purchase of on-site combined heat and power units (CHP), has significantly helped to reduce $CO_2$ emissions, through increased efficiency. For example, at Hydro's plant at Aycliffe, UK, $CO_2$ emissions have reduced from 110 000 tonnes in 1994 to around 50 000 tonnes in 2000; during this period, total production rate of PVC has almost doubled.

The amount of $CO_2$ that is generated in manufacturing 1 tonne of PVC will vary across the European PVC Industry. Typically, Hydro Polymers Ltd emits around 640 kg of $CO_2$ for every 1 tonne of polymer produced [29] in the manufacturing chain, from VCM manufacture through to delivery of the PVC resin to the customer (The reporting of this value has been completed through the voluntary code of practice described in Chapter 1.)

Whilst these processes have not 'solved the problem', they are helpful incremental steps. In addition, across the PVC Industry there needs to be full examination of 'best practice' since there may be obvious gains by benchmarking differing sites and companies.

In addition to the reduction of $CO_2$, it is instructive to evaluate the by-products produced at intermediate sites from the chlorine manufacturing processes and gas cracking processes. Fairly large quantities of hydrogen are produced from such sites, which is currently used as a fuel. Clearly in future years a more appropriate use of this gas could be in fuel cell technology, particularly where purer forms of hydrogen are generated.

*4.3.1.4. TNS recommendations*. The TNS report lists the following targets for challenge no 1:

- Achieve major improvements in energy efficiency in manufacturing plants

Prior to any significant investment in renewable energy sources, such as the construction of wind turbines and solar panels, there may be a number of improvements available at PVC plants around Europe in terms of energy efficiency. Other more significant energy saving projects could be gained from harvesting energy from the exothermic reaction during the polymerisation process; which is currently just lost to the atmosphere.

- Improve generation efficiency, for example by increased use of CHP systems

Stepwise improvements in energy efficiency have clearly been demonstrated by the move from burning coal to oil to gas. This has also significantly reduced acid gas emissions such as sulphur dioxide. This process should be extended across the European PVC Industry

- Develop programmes for a progressive increase in the use of renewable energy sources for generation of electricity

The economics of such programmes need to be carefully considered to ensure there is no danger of becoming 'economically untenable' in the process. However, some companies such as IKEA have chosen to install massive amounts of photovoltaic cells for their roof of their headquarters in Sweden.

This is clearly a massive investment but highly symbolic in terms of their commitment to sustainable development.

- Set targets for substantial reductions in transport energy use by improved efficiency, backloading, rationalisation and selection of optimum mode

To an extent this is already being applied by a number of PVC companies since it also makes good economic sense, although companies sharing payloads and distribution systems could make more use of empty containers.

- Analyse the feasibility and carry out a life-cycle analysis (LCA) of changing feedstocks from hydrocarbons to biomass or other sources

*Biomass technology*. There has been a tremendous amount of interest in polymers derived from natural products in recent years, and a number of companies have developed a range of polymers using this technology. However, it should be remembered that polymers such as PVC could also be manufactured from such feedstocks. For example, about 50 000 tonnes of PVC are manufactured from ethylene derived from alcoholysis of sugar beet in India by the company Sanmar.[1] In addition, there were two plants to derive ethylene from ethanol designed for Sweden and for Pakistan by a company called Kematur, but these plants were never built. To convert the quantities needed to supply the Western economy is rather daunting, but at least this process could be examined to evaluate from a LCA perspective the impacts from both feedstocks. In future years, no doubt, this will be much more significant than today, although one argument could be that oil/gas should be reserved for plastics manufacturing, with future conservation demands on the bigger oil guzzlers such as electricity, heating and transport. Of course, introducing such technology to eliminate one system condition, might in its own right, run the risk of introducing contributions to other system condition breaches. The replacement of oil with biomass is a good example, since biomass grown specifically for ethylene would require vast areas of intensive farming and this may, for example, risk contributing to breaching system condition 3 (SC3).

*Feedstock recycling*. This is a new technique developed for the recycling of 'PVC-rich' plastic waste such as PVC-coated fabrics, automotive interior trim, cable harnesses, floorings and other composite structures. It is anticipated that feedstock recycling will be far more attractive to the PVC Industry in the short and medium term than biomass technology, and there are no less than four feedstock recycling projects underway across Europe. The feedstock process essentially breaks PVC down to syngas and hydrogen chloride (HCl) that can be reused in PVC production.

The technologies of feedstock recycling plants and their subsequent breakdown products are as follows:

(i) Tavoux Pilot Plant, France—this is a slag bath gasification process, where PVC compositions lead to the production of syngas + hydrogen chloride
(ii) Dow/BSL Project, Germany—a rotary kiln process that recovers hydrogen chloride and energy
(iii) Stignaes Project, Denmark—this is a two-stage thermal hydrolysis process yielding sodium chloride

[1] www.sanmar.com (India).

solution, followed by gradual pyrolysis to recover hydrocarbons, fillers and heavy metals for reuse.
(iv) REDOP Project, Holland—this is a dehydrochlorination of mixed plastic from municipal solid waste.

More details can be found from the European PVC Industry voluntary commitment, Vinyl 2010 [31]. Importantly, such technologies feed into ethylene/VCM plants rather than PVC production plants. This will have implications on where such large-scale plants should be constructed in the future.

- Develop co-operative programmes to substantially increase the recycling of waste products including a major effort to work with other agencies and users

This is discussed in more detail under challenge no. 2.

- Agree specific targets for adopting carbon sequestration schemes

There is continuous debate about the potential for carbon sequestration, with some NGOs completely against such schemes. As an initial proposal, it will be important to establish what realistically can be achieved by energy efficiency projects within the PVC Industry and over what time scales. Carbon sequestration can also be achieved through various technologies; one route is the plantation of trees, which has been claimed to offset $CO_2$ emissions. Some companies have utilised these schemes, but these are probably largely symbolic than truly sustainable solutions. In addition, other more pioneering techniques have been developed, for example, those that involve the reintegration of carbon dioxide back into the lithosphere by means of pumping liquefied $CO_2$ into under-sea strata using off-shore oil installations.

*4.3.2. TNS challenge no. 2*

The industry should commit itself long term to a closed-loop system of PVC waste management.

*4.3.2.1. Why is this important?* Currently up to 90% of waste PVC is landfilled across Europe. This primarily contributes to breaching system condition 3, but the indirect effects of wasting PVC in this manner may contribute to all of the system conditions. In addition, despite all industry's efforts to demonstrate that such disposal routes are safe, questions will always remain. In the words of one European Commissioner, "Landfill is like sweeping our waste under the carpet, even if you cannot see it, it still remains and would not go away". Future legislative measures across all industries are anticipated to drive much more activity towards finding solutions to the growing mountain of waste. Such measures have already begun in the form of European legislation such as the 'End of Life Vehicles Directive' [32] and the proposal for a directive on waste electrical and electronic equipment [33]. The European Commission's Green Paper on PVC [5] is a direct result of the Commission's interest in resolving waste arising from PVC products.

In the *short to medium term*, the option of landfill will become even more restricted in some member states. There is impending German legislation to prevent the disposal of plastics in landfill sites, and in 2000, a specific tax on certain PVC products was introduced in Denmark for the purpose of funding the additional costs of incineration of PVC in this country. Using the metaphor of TNS regarding the 'funnel effect', the entrance to the funnel will be narrower or wider on a country-by-country basis regarding the option of disposal to landfill. This is an important consideration since this will also affect the economics of what can and cannot be achieved, although in all cases the sustainability challenge must be grasped in the long term.

*4.3.2.2. Barriers to the challenge*. In today's society, it will be very difficult to collect all material back for recycling even if bold benchmarks are used. According to one report by Prognos [34] (undertaken by the European Commission as part of the 'horizontal initiative' on PVC), there will be limitations on the amount of PVC that can be mechanically recycled. For example, this study predicts a maximum 18% of PVC that could be handled by mechanical recycling by 2020. Therefore, alternative emerging technologies such as feedstock recycling and other novel technologies such as Vinyloop [35] will require large-scale production sites particularly for the more-difficult-to recycle products. Industry must also consider the emerging importance of Product Stewardship, taking a responsible attitude towards the fate of additives no longer used by our industry but contained in existing PVC products in use. For example, should these products be recycled and if so how can we prevent them from being diluted into other recycled products and thereby spreading contamination? Such exercises should not be done in isolation, but must be undertaken with a broad range of stakeholders such as recycling organisations, legislators and environmental bodies.

The economics of recycling remains the biggest barrier to this challenge. Unlike metals, plastics carry a much lower economic cost per tonne of virgin material. This means that, when collection, reclamation and washing costs of used products are taken into consideration, the economics of recycling can become restrictive particularly during a downturn on prices of virgin PVC.

Other barriers are beginning to be overcome. For example, by working with the various standards institutes, restrictions on quantities of recycled product in finished goods are being withdrawn through demonstration that the functionality of the product has not been diminished by the inclusion of recyclate and that recycled material is able to conform to the same specifications as virgin PVC compounds.

PVC is not alone regarding the relatively poor recycling rates of plastics compared to metals, although such rates are predominantly due to the economics of recycling lightweight products. Importantly, from a technical perspective, PVC can be recycled a number of times without significant loss in technical properties. This has been clearly demonstrated by Hydro Polymers Ltd for pipe fitting mouldings and computer housings that were recycled across 10 thermal histories in total without the inclusion of any additional ingredients. The physical properties of these PVC products remained largely unchanged [36]. Examining this in terms of the sustainability of a building product, would yield a hypothetical 250-year usage of a material assuming 100% recycling at periods of 50-year usage. Clearly, this begins to open up a new realisation that perhaps PVC can play an important role in a future sustainable society of growing population. Its persistence is actually a strength in terms of sustainable development, enhancing the amount of service to society that may be delivered by a pool of atoms. In addition, nearly 70% of total PVC usage is in construction applications with long-term service life, such as in windows and pipes.

*4.3.2.3. How could this be tackled?* The European plan for the development of an integrated waste management approach has been formally prepared within the industry voluntary commitment outlined in Vinyl 2010 [31] The main thrust of this is to examine how recycling schemes are already operating in some European countries (e.g. the German scheme for recycling window frames as well as several schemes for pipes) and a commitment to recycle specific targeted quantities of PVC by given deadlines.

Ideally, PVC products should be recycled back into the same application or within controlled loops (e.g. building products recycled into new building products), this is often termed 'closed-loop recycling'. Importantly, fresh thought should be given to formulation consideration at the design stage and within the supply chain of the industry. Sometimes the term precycling has been used, i.e. designing products so that they are easy to dissemble and recycle. Often the PVC industry is accused of 'down-cycling', this is where the new application of the recycled product is considered of lesser value than its original application. A number of recycling schemes in place today have been accused of down-cycling. There needs to be a shift to 'high quality' recycling which, according to Prognos [34], could contribute as much as two-thirds of the recycled quantities by 2020.

However, there may be some applications where the original application is of less value than the recycled application. One example of this could be recycled packaging which if used in a building application could be considered as 'upcycling', i.e. from a short term application to a longer life product such as a building application.

From an environmental perspective, the waste hierarchy is worth reviewing, which states that for end-of-life products, the following options in order of environmental preference:

(i) Product reuse (most favoured)
(ii) Product recycling—mechanical, chemical
(iii) State of the art energy recycling (incineration with energy recovery)
(iv) Landfill (least favoured)

It should also be remembered that recycling is not without its own environmental impacts and consumption of resources. The need not to be obliged to recycle more than is required must be given careful consideration, although this should not be an excuse for doing nothing.

*4.3.2.4. Voluntary commitments—Vinyl 2010. Pipes and windows.* The European PVC Industry voluntary commitment made by the windows and pipes federations goes some way in supporting this challenge. For example, TEPPFA (European Plastics Pipe and Fitting Association) and EPPA (European PVC Window Profile and Related Building Products Association) have committed to setting up collection and recycling task forces around Europe. This will ensure that over 50% of recovered pipes and windows will be recycled into new pipes and windows by 2005. In addition, EPPA is currently undertaking research on the most effective methods to increase post-consumer window frame recycling.

*Flexible PVC including cables/tarpaulins/flooring*. A new emerging process (already discussed) that has been developed by Solvay is known as Vinyloop [35]. This technology takes scrap PVC that is first dissolved in a solvent. This is subsequently filtered and precipitated and the solvent recovered for future use. It is best suited for composite materials. Currently, there is a scale-up process being developed at Ferrara, Italy, taking the small-scale development plant of 70 kg a day to a potential 25 000 kg per day. Anticipated volumes for the Italian plant are expected to be around 10 000 tonnes per annum. In addition, a further project (Ferrari) examining PVC-coated fabrics is being developed in France using the same technology. A business concept to evaluate the relevance of this technology to flooring is under review by the European PVC flooring group EPFLOOR, who have committed to recycle increasing quantities of PVC flooring at end-of-life. This commitment is to recycle at least 50% of the collectable available quantity of PVC flooring waste by 2008. The roofing membrane sector represented by ESWA (European Single Ply Waterproofing Association) commits to recycle increasing quantities of PVC roofing membranes at the end-of-life application; this commitment is to recycle at least 50% of the collectable available quantity of roofing membranes waste by 2005.

In addition to the Vinyloop process, the alternative feedstock process can be utilised for these materials. This process essentially breaks PVC down into syngas and HCl that can be reused in PVC production. There are various other emerging technologies being developed around Europe that are described under challenge 1.

*Design for recycling*. New products entering the market need to be assessed for their suitability for recycling. For example, concerns have already been expressed about the ability to recycle PVC/wood composites. This is not to say that they are not recyclable, it is just that there appears to be little work done on evaluating the potential to recycle such products. Meanwhile, the market continues to expand. By way of example, if such products prove difficult to recycle, then what do we as an industry do? Clearly, products which are hugely problematic to recycle may come back to haunt our industry.

TNS recommends that, to be effective, any recycling scheme will have to involve many stakeholders including processors, customers for the product, local and national authorities. In the UK, landfill tax credits (Government-funded) have just been obtained to help support a British Plastics Federation task force charged with the task of evaluating the amount of waste PVC entering the waste stream from applications such as cables, tarpaulins and other difficult-to-recycle PVC-rich products. There will always be some products that will require disposal by incineration because of the potential for contamination and biological infection such as disposable PVC medical devices. Such products are unlikely to gain acceptance to be recycled because of the health and safety risks. However, such products yield a very high social value that may offset incineration costs.

In summary, the specific targets for action to move to a 'closed-loop' system as recommended by TNS include:

- Enhance joint efforts with stakeholders to increase the amount of recycling and reuse of PVC products including investigation of obstacles and infrastructure necessary to overcome them

  Various European schemes are now underway.

- Set specific targets for the above increasing progressively over time

  Industry-wide targets have already been set through the European voluntary commitment.

- Continue investigations into the potential toxicity problems arising from PVC in landfill and, where required, ban substances from landfill

There is a continued dialogue with academia and trade associations following a three-year landfill study commissioned by industry [37]. Landfill will remain an important waste disposal option for PVC and other waste arisings in the short term, but landfill is not a sustainable solution and must be phased out in the long term.

- Analyse the sustainability implications of the extent of continued use of landfill and alternative waste disposal routes, including incineration

This is currently being tackled through the waste management group of ECVM.

- Develop the pilot plant for PVC feedstock recycling to full-scale production

Such plants are under construction and the most successful of them will be scaled-up.

*4.3.3. TNS challenge no. 3*

The industry should commit itself 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.

*4.3.3.1. Why is this important?* Organochlorine compounds exist as products or by-products of PVC at all stages of the process. They are seen as possibly the most controversial part of the PVC industry. Some of these chemicals are highly toxic, and when released can cause harm or accumulate in nature under certain conditions where they may have long-term effects (Examples include furans and dioxins). Other chlorinated compounds break down fairly readily but may lead to localised acidification (for example, VCM). However, major reductions of dioxins have been achieved by the PVC industry in recent years. For example, at Hydro's Rafnes plant in Norway total dioxin emissions are of the order of around 40 mg TEQ dioxins per annum. To put this into perspective, the annual emissions from a marine engine on a deep sea tug are estimated to be around 70 mg TEQ per annum [38], i.e. nearly double the emissions from the Rafnes plant.

*4.3.3.2. How could this be achieved?* The TNS methodology is satisfied when emissions and all kinds of leakages of persistent organic compounds are eliminated. From a scientific process it could be argued that values may already be reduced to levels where these releases do not exceed the capacity of natural systems to break down and reintegrate these substances and their breakdown products. However, in the absence of such a threshold concentration then the precautionary principle would suggest a commitment to 'zero emissions' as a prudent goal. Further research may be helpful to establish maximum levels consistent with reintegration in natural systems, to enable fair comparisons to be made with other substances many of which may be considered 'safe' in the absence of such data.

Some key activities in this process will be:

- Identify sources and emission/leakage levels of persistent organic pollutants across the whole life-cycle

Values now exist as published in the latest Hydro Polymers Ltd EMAS statement [29] for most of the production phase of the life-cycle, including all fugitive, accidental and by-product emissions of organochlorines in plants as required by the UK code of practice for the manufacture of suspension PVC [24].

- Define mechanisms for achieving emissions to a level that results in no systematic accumulation in nature

This is important since it may be possible to operate at near-zero levels for some contaminants and at higher levels for others if it can be scientifically demonstrated that the capacity of natural systems to break down these levels and reintegrate such substances. Establishing threshold levels could be important but will always carry a higher risk compared to elimination.

Other persistent chemicals

- Refrigerants and fire fighting chemicals

Like any industry there are a number of alternative refrigerants used within the PVC Industry. (Some of these refrigerants are known as ozone-depleting substances.) TNS methodology requires the same approaches described above.

- Mercury emissions

A number of European chlorine plants still rely on mercury cell technology. Whilst significant reductions of mercury emissions have been achieved at these plants in recent years, elimination of this technology will be required to prevent its accumulation in the environment. For Hydro this is relevant to the Stenungsund plant in Sweden, and Hydro has given a commitment to phase out this technology by the year 2010.

*4.3.4. TNS challenge no. 4*

The industry should review the use of all additives consistent with attaining full sustainability, and especially commit to phasing out all persistent compounds foreign to nature, as well as chemicals for which there is reasonable doubt regarding toxic effects.

*4.3.4.1. Why is this important?* PVC is one of the most versatile polymers due to the fact that it can accommodate a wide range of additives and at significantly high levels, in some formulations exceeding the mass of the resin itself. Therefore, it comes as no surprise that all such additives contribute towards the sustainability implications of the PVC life-cycle. The two types of additives to which we must pay attention are stabilisers and plasticisers. The continued use of heavy metals and the debate surrounding phthalates remain contentious. From a TNS perspective, the escape of heavy metals from our products from either original manufacture, degradation of products in use, or ultimate disposal in landfill, incinerator gases or ash, is a cause for concern. Although TNS does recognise that such heavy metals are used in other industries, the issue remains whether or not the PVC industry contributes towards the systematic accumulation in nature of such heavy metals. In addition, the use of phthalates raises a number of issues regarding the principles of TNS; they contribute to breaching system condition 1 since they are derived from oil, and they may contribute to breaching system condition 2 since, under the right conditions, they can accumulate in the environment under anaerobic conditions (Although phthalates under aerobic conditions are generally considered to be biodegradable.) In addition, their ability to cause toxicity and reprotoxicity effects in rats and mice raises concerns, as does their potential endocrine disruption effects although there is no evidence for these effects in humans. However, it is important to emphasise that the debate surrounding hormone-disrupting chemicals is a highly controversial area of science, and may pose a threat to industry far bigger than some of the other challenges. Therefore, we need to be mindful of all kinds of potential low-dose effects on biological systems in order to prevent the emergence of major future issues. There are also a number of other additives of potential concern including chlorinated paraffins, tin compounds, antimony, etc. When we contribute to the release of persistent compounds into nature, and once such effects are validated, it's too late to rescue the situation.

*4.3.4.2. Formulation development*. Prior to new formulations being developed, consideration should be given by the industry to all additives used with regard to their suitability, using the TNS methodology. New formulations should be free from lead with calcium/zinc systems the preferred option on the short time period (zinc is problematic in the long run) as well as emerging organic-based systems (OBS). The OBS stabilisers were developed at the request of Hydro Polymers, that led to a joint partnership between Hydro Polymers, Ciba Additives GMbH and the pipe manufacturer, Wavin. Such decisions of course need to be put into perspective of economic constraints. Ironically, this is where regulation can help to set a level playing field, since all players would need to conform to the same principles and standards.

Future formulation chemists could apply their skills to this important area of research to formulate 'away from the walls of the funnel'.

*4.3.4.3. How could this be achieved? Legislation*. The European Commission Green Paper has already highlighted concerns about the continued use of lead and cadmium stabilisers, and the final communication on PVC from the European Commission is still awaited. A resolution from the European Parliament [39] on the Green Paper stated that lead stabilisers should be phased out, but did not indicate a specific timetable. Some member states have already implemented a lead phase-out policy such as the Swedish chemicals policy and Denmark's proposed ban on virtually all products containing lead. Furthermore, the recent development of a European Community Directive on drinking water quality [40] has already highlighted that lead stabiliser will not be approved for use in PVC pipes after 2003.

With regard to phthalates, the temporary ban on the use of PVC toys intended to be sucked or chewed is an example of 'hitting the walls of the funnel', described in Chapter 3. Phthalates are also highlighted in the Green Paper and the European Parliament Resolution. Industry awaits the findings contained in the final communication. Importantly, five phthalate plasticisers are nearing completion of an 'Existing Substances Regulation' (EEC/793/93) which evaluates risks to both human health and to the environment from exposure and use of these chemicals. The publication of the conclusions in the European Official Journal from the risk assessments for the main plasticisers used in PVC compounds, di-2-ethylhexyl phthalate (DEHP), DINP, and DIDP are anticipated during 2002.

In addition, The European Commission issued a White Paper on a strategy for a future community policy on chemicals [41]. The main objective is to ensure a high level of protection for human health and the environment, while ensuring the efficient functioning of the internal market and stimulating innovation and competitiveness in the chemical industry. It remains to be seen what effect this will have on the chemicals used in the PVC industry.

*4.3.4.4. Voluntary commitments*. With regard to European wide voluntary commitments, The Vinyl 2010 report emphasises the importance of the following commitments:

*Plasticisers*

- The plasticiser industry will continue to conduct research in order to provide scientific studies and expertise to help policy-makers develop well-informed decisions with significant funding on research.
- The sector will continue to improve the already sizeable scientific database of its products consistent with Responsible Care® principles, and use it to propose improvements based on the results of

European risk assessments. If warranted by the results, appropriate risk reduction measures will be taken by industry.
- Industry supports the concept of life-cycle inventory evaluation of materials in order to highlight possible improvements. An eco-profile report was published in 2001 for the manufacture of plasticisers.

*Stabilisers*

- The use of cadmium in all stabiliser systems placed on the European market has been phased out as of March 2001.
- ESPA have committed to performing initial risk assessments on lead stabilisers under the CEFIC and ICCA programmes 'Confidence in chemicals' by 2004.
- ESPA members continue to research and develop alternative stabilisers to the widely-used and highly-effective lead-based systems.
- ESPA members will produce yearly statistics showing which stabilisers are purchased by the converters and in which product category.
- ESPA and EuPC commit to replace lead stabilisers to achieve the following reduction targets, measured on the basis of 2000 consumption levels:
  15% reduction in lead by 2005
  50% reduction in lead by 2010
  100% reduction in lead by 2015.

Areas for action suggested by TNS include the following:

- determine in which applications it would be prudent to review the use of plasticised PVC, and other potentially problematic additives

Hydro Polymers Ltd took a decision 20 years ago not to support the use of flexible PVC for use in teething rings [42]. This was primarily based on the fact that the standards set up for toys were inappropriate for organic contaminants in terms of measurement for migration. In some applications, further consideration may be needed in view of pending risk assessments on phthalates (particularly for DEHP).

- where there is reasonable doubt about the safety of phthalates, research alternative plasticisers and other additives that do not result in systematic accumulation in nature or toxic effects. It is important to note that alternatives should not be assumed to be more sustainable than known problematic substances in the absence of a sustainability analysis.

Hydro Polymers Ltd is participating in a project with the Danish Technical Institute and a number of Danish medical converters and the Danish Environmental Protection Agency to evaluate a range of plasticisers that may be suitable for use in medical device applications. Currently formulations are being developed at Hydro's compounding plant in the UK to support this project following a two-year review of alternative plasticisers. However, it must be emphasised that phthalates such as DEHP have been safely used in medical device applications by Hydro Polymers Ltd for 47 years [42], whilst such alternatives have no proven track record.

*4.3.5. TNS challenge no. 5*

The industry should commit to the raising of awareness about sustainable development across the industry, and the inclusion of all participants in its achievement.

*4.3.5.1. Why is this important?* This is of fundamental importance in supporting the other challenges. A clear strategy for raising and achieving awareness of sustainable development across the industry can only lead to more sustainable business practices and improved market opportunities. Significantly, many sustainability challenges can only be addressed by partnerships of organisations involved with PVC across its whole life-cycle. The Vinyl 2010 process is the beginning of such a strategy that is uniting the European PVC Industry from raw materials suppliers to end customers. However, this does not prevent pioneers from within the industry innovating their own novel solutions to existing challenges ahead of the game. One of the recommendations from the TNS report was to increasingly engage in an awareness campaign such that all those directly involved understand what sustainability means in practice, and can participate in the process.

*4.3.5.2. Engaging stakeholders*. Whilst Chapter 2 described an interesting case study of stakeholder engagement in the UK, there have been several other voluntary commitments across Europe. For example, a recent study was published in Germany [43]. It was funded by AGPU—the German PVC trade organisation and was directed by a steering group involving a wide spectrum of interests from environmental lobbyists, academics, politicians, representatives of industry and the media. The study focused on four product areas: windows, pipes, cables and packaging film. Sustainability indices were defined covering social and economic as well as ecological areas, the so-called triple bottom line perspective. The study assessed the short, medium and long-term impacts of PVC products and compared them to alternatives. In general terms, PVC was considered on the basis of LCAs to be more sustainable than alternative products for most applications in the short to medium term. However, in the longer term, less sustainable, principally because of PVCs dependence on oil/natural gas feedstock. However, it did note that this could be improved and was highly dependent on the feasibility of recycling product after use. Clearly, this result also emphasises the long term importance of alternative feedstock to hydrocarbons.

From Hydro Polymers' perspective, the company has already made a commitment from senior management to address the above challenges. This is an essential element for any company wishing to take forward a sustainable development agenda.

*4.3.5.3. Socially beneficial products*. Future attention to products in the market will also be measured by their social contribution to society. This is required to satisfy the fourth of the TNS system conditions: that resources are used fairly and efficiently in order to meet basic human needs worldwide. This was included in the German study [43] and it is envisaged that—on the condition that the five challenges are appropriately dealt with—PVC can have an increasingly important role to play in meeting such needs. For example, on the theme of protection, PVC plays a key role in delivering clean drinking water to our homes, insulating high voltage cables, storing of blood and plasma, acting as buoyancy floats, helping us to avoid many problematic heavy metals like copper on tubes, help provide cheap materials in the developing world.

## 5. Chapter 5

### 5.1. Conclusions

The work outlined in this report demonstrates that PVC could be considered a sustainable material provided that the industry can deliver on five key challenges. It is important to recognise that these challenges on their own are huge, and at the very least, rather daunting. Nevertheless, through a series of stepwise improvements such challenges can be broken down into flexible platforms that would permit the industry to drive towards sustainability. Indeed the systems framework can be applied to almost any material or process as a guide to what would be required to take steps towards a sustainable future. Furthermore, these challenges are probably not too dissimilar to the challenges faced by competing materials, should they be scrutinised to the same degree as PVC has been in this report.

In recent years, the PVC industry has witnessed some materials specifiers taking the easy option and deselecting PVC in preference to competing materials. In other words, the ostrich approach towards sustainable development. Such substitutions have rarely been done based on any rigorous scientific scrutiny. For example, such scrutiny could include the examination of the sustainability footprint of one material versus the other, and opting for the least unsustainable product and encouraging further sustainable practices for such a product. Or, by opting for a particular material and driving out all unsustainable practices throughout its life-cycle.

In future years, the easy option of materials deselection without thorough scientific scrutiny must be questioned if we are to base our future on scientific arguments and principles. Similarly, the PVC Industry will no doubt be judged on its ability to become sustainable as the consequences of unsustainable practices continue at their present rate. However, provided that the industry is able to deliver on these challenges, then it's future looks positive. The durability of PVC combined with its resistance to degradation are essential components for long-term product applications. Equally, PVCs ability to be recycled in controlled loops back into similar applications is fundamental to the principles of sustainability. It is only a question of time before alternative materials are assessed with the same degree of rigour as PVC has been. Ultimately, I would like to think that this might well lead to a better understanding of the importance of PVC in its role to the well-being of mankind and to the environment.

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