A GUIDE TO SUBSTITUTION

AN INFORMATION NOTE FROM THE UK CHEMICALS STAKEHOLDER FORUM

This note provides an easily accessible introduction to the process of substitution. It has been produced in order to influence stakeholder behaviour both at a national and international level in all parts of the supply chain.

It will be of value to all those who, like the Forum, wish to promote sustainable consumption and production

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Introduction

Substitution is a common feature of our daily lives: lead water pipes have been replaced by plastic or copper, chloroform has been replaced by more effective anaesthetics and our vinyl LPs have been replaced first by cassette tapes, then CDs and now by MP3 players. It is therefore not surprising to find that substitution also occurs in the management of chemicals.

Substitution can sometimes be simple and straightforward but it can also be complex and time consuming. Many substitutions are successful, but some are not, especially where unforeseen consequences emerge as a result of not doing a full life-cycle assessment of the proposed change.

This short guide[1] is intended to provide an easily accessible introduction to the subject. It is divided into the following four sections:

A few representative examples of successful substitution are described in the Appendix.

[1] This report was produced by the UK Chemicals Stakeholder Forum and was drafted by a subgroup comprising: David Taylor (RSC) (Chairman), Patrice Mongelard (DEFRA) (Secretary), Amy Mulkern (Wales Environment Link), Piat Piatkiewicz (Non-Ferrous Alliance), Mike Pitts (Chemistry Innovation Knowledge Transfer Network), John Reid (British Association for Chemical Specialities), David Santillo (Greenpeace).

What is Substitution?

Substitution is the replacement of a substance, process, product or service by another that maintains the same functionality. Substitution should aim over the whole life cycle of the replacement to obviate any negative impacts on human health or the environment and improve resource efficiency. It should also be recognised that substitution will only be successful where the socioeconomic requirements of all the stakeholders can be satisfied. Some examples of substitution are given below.

Substance substituted for substance: Polyethylene terephthalate (PET) has replaced glass as the material for soft drink containers. This has dramatically reduced the weight of the package and its associated transport emissions.

Process substituted for process: Caustic soda and chlorine were originally produced by electrolysis of brine in Castner-Kellner cells using a mercury cathode. The process has now been superseded by the use of membrane cells which do not require the use of mercury.

Service substituted for product: Interface used to sell carpet tiles to its customers but subsequently introduced the carpet service concept whereby customers would not buy the tiles but, for an annual fee, would be guaranteed a floor covering of specified quality. In other words the producer is no longer simply selling a product (carpet tiles) but is selling what it does. This change of business model resulted in the company developing more durable and more readily recyclable carpet tiles.

In some cases substitution decisions are simple; however a wide range of factors need to be considered if unintended consequences are to be avoided. This definition describes what substitution **is**, but does not provide any useful information on how it might be achieved. The next two sections discuss how (and why) substitution occurs.

When is substitution needed?

Most processes, products and services are regularly reviewed by technical and product development groups in order to identify improvements that will lead to competitive advantage. In some cases these improvements will involve substitution.

In addition, there are a number of specific drivers that will trigger such a review. These can be related amongst other things to the availability and/or cost of components, changes in stakeholder requirements or changes in regulation. These are covered in more depth in the next section of the guide “Why does substitution take place”

As our definition implies, substitution refers to the improvement of an existing process, product or service. However, many of the techniques used to evaluate possible substitutes are also applicable to the development of new processes, products or services and there is a considerable amount of overlap between the emerging area of sustainable design and the evaluation of substitution. This is considered in more detail in the last section of this guide “A glance to the future”

Why does Substitution take place?

Each individual case of substitution will inevitably have unique characteristics as it will relate to a specific set of circumstances (such as company, sector and product profiles, history of manufacture, marketing and use, etc.) and will be carried out in response to particular opportunities, threats or a combination of both. Substitution may be seen as one element in the management of business risk, but one which specifically supports the overall objectives of reducing or avoiding negative impacts on human health or the environment and improving resource efficiency, while maintaining functionality.

A decision regarding if, when and precisely how to bring about a substitution may be shaped by a diversity of factors, some internal to individual companies and some representing external events, trends or projections in the fields of business, science & technology, policy & regulation and public opinion. Although it is therefore difficult to envisage any form of decision tree which would have universal application to as complex a concept as substitution, it is possible to propose a set of potential drivers for, and barriers or limits to, substitution based on experience to date within both the public and private sector.

Figure 1 below is an attempt to provide such a list, to identify and outline key generic drivers (Fig 1a) and barriers (Fig 1b) in a manner which may provide useful guidance to those seeking to formulate the most critical questions as part of a decision-making process in relation to substitution.

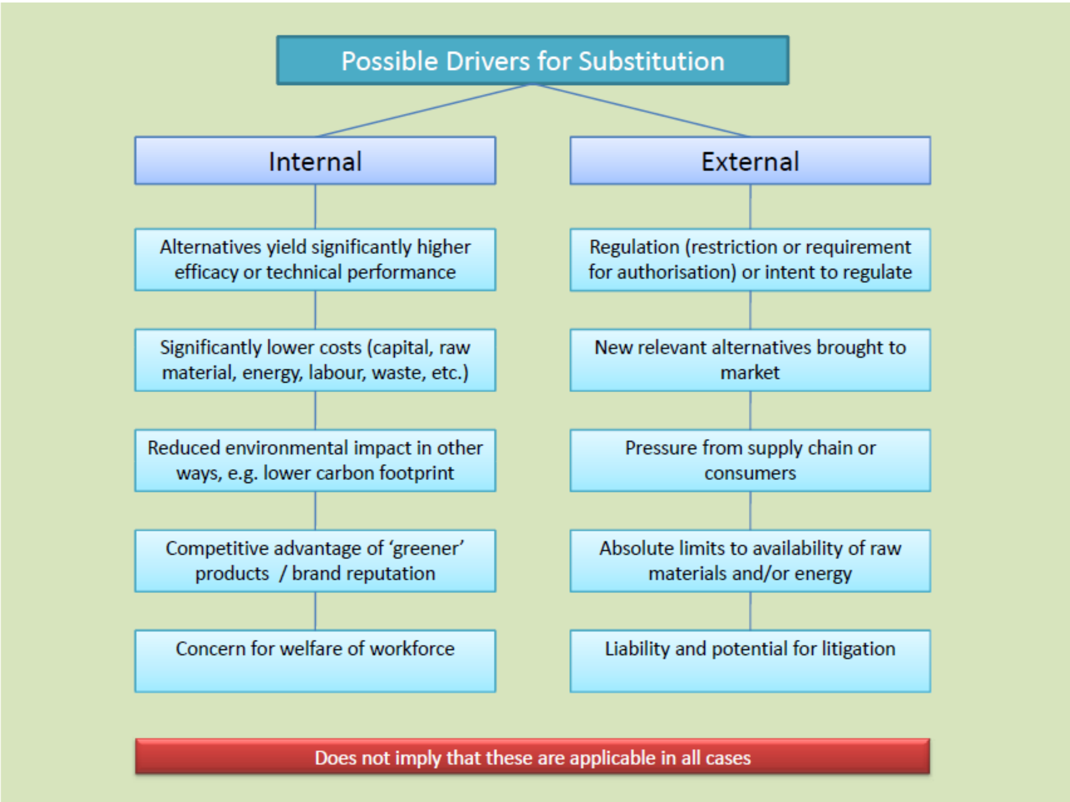

Figure 1a: The identification of potential drivers to substitution

The figure is not intended to provide exhaustive or exclusive lists of factors, or to imply that all factors are important, or even relevant, considerations in any particular case. Rather they are intended as prompts for first consideration and, where necessary, deeper analysis in order to help focus thinking, identify opportunities and address significant obstacles as part of the process of drawing up workable plans for substitution. They also provide a contextual framework for much of the more detailed case descriptions and discussions in the remainder of this document.

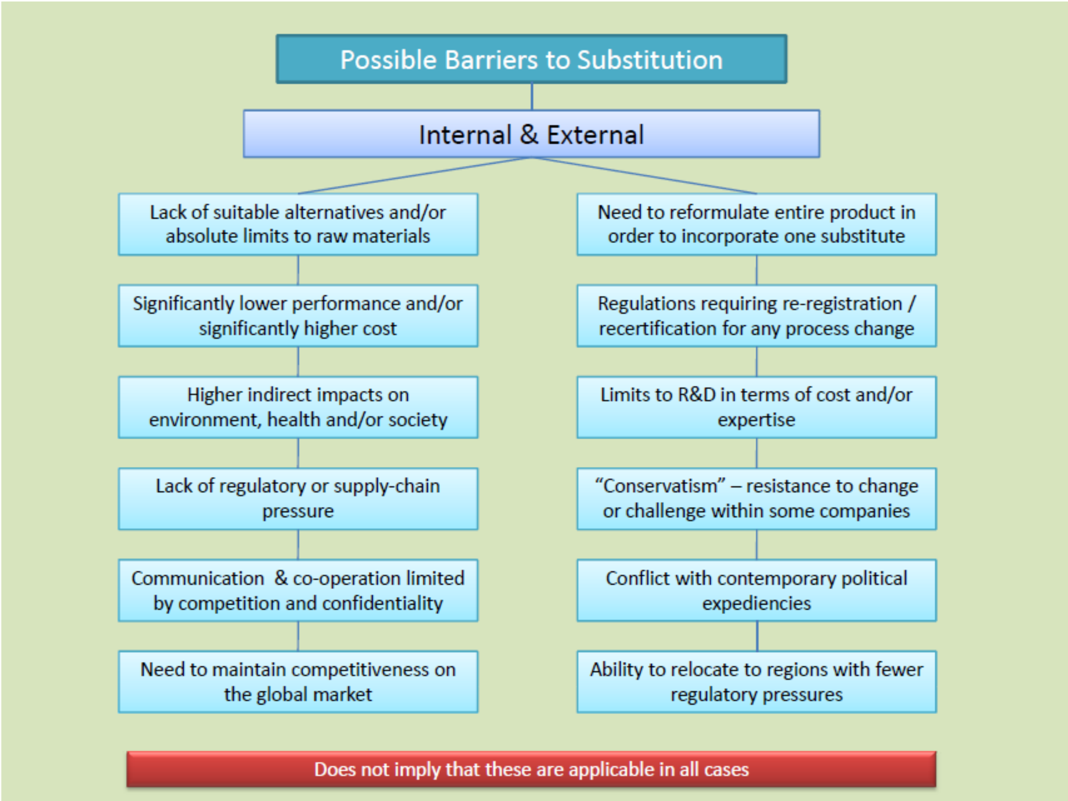

Figure 1b: The identification of possible barriers to substitution

There are undoubtedly many other ways in which the key factors influencing substitution decisions could be categorised and summarised, but the underlying elements are likely to be similar in each case. Furthermore, it may be clear from analysis of Figure 1 that several of the factors identified as being in opposition are, in essence, merely different points on the same spectrum, i.e. they identify elements which can act either as drivers or barriers depending on their absolute and relative magnitude in relation to any specific set of circumstances. For example, factors such as cost and efficacy, availability of alternatives and degree of regulatory or public pressure can all act as either drivers or limitations to the intent, speed and ultimate success of substitution processes. Their relative weighting will vary from case to case.

Making the right substitution can be a complex decision-making process, and one which may need to be applied carefully and iteratively in order to achieve the most progressive and sustainable developments within the inevitable constraints of finding solutions that are workable and not prohibitively expensive. Just as it would be unreasonable to expect innovation to allow immediate substitution in the case of every hazardous substance or process, it is vital that any barriers identified to their substitution are viewed as challenges to be overcome rather than as insurmountable obstacles or as reasons to dismiss the concept of substitution more generically. Substitution is a concept which requires optimism, vision, energy and a commitment to continuous improvement, in addition to the mechanics and resourcing to enable it to happen, whether at company, sector, national or even international level.

How is Substitution managed?

Is the substitute an acceptable alternative?

In principle the proposed substitute (substance, product, process or service) may seem to be a useful alternative, but a number of questions need to be answered before we can be sure that this is the case and that making the substitution will not result in any unintended consequences. A life cycle approach is necessary since there is little point in making a substitution, which reduces one problem if at the same time other problems are made worse or new problems are created.

- **Functionality:** Can an acceptable functionality be delivered?

The alternative does not always need to perform as well as the original, but it must perform sufficiently well to fulfil the required purpose. A product or service that doesn't deliver what the customer wants isn't going to be successful. However, in some cases, it may be possible to develop the customer's thinking. For example, it is not possible to produce a high gloss finish using water-based paint. So, when these were introduced into the domestic market, to replace solvent based paints, the launch was accompanied by a successful advertising campaign to persuade customers that the newer satin finishes were more fashionable.

- **Compatibility:** Is the substitute compatible with all other aspects?

The proposed substitution may deliver the right function but does it have any additional properties that might make it unsuitable? For example tin-based solders are being introduced into electronic circuit boards as a substitute for lead-based solders. However although the tin solder is a good replacement as a solder, it has an additional property, that of spontaneously generating hair like 'whiskers' over time which can and have caused short circuits, which in one case shut down an entire nuclear power plant.

- **Availability:** Is it available in sufficient amounts and is the supply secure?

Manufacturers need to be sure that the supply of any alternative substance or product will not disrupt their business. Any substitution that requires the use of material that is only produced in small quantities by a single supplier in a politically unstable region of the world is unlikely to be acceptable. Some materials that might be very useful in substitute processes or products e.g. rare earths and rare metals fall into this category.

This can also be an issue when attempts are made to replace synthetic materials in major tonnage products with 'sustainable' materials: e.g. Indigo can be sourced from plants, but it takes 80 hectares of land to produce a ton of the dyestuff. Increased use of palm oil has already led to some increased deforestation and habitat loss, and production of bio ethanol has in some situations had a negative impact on food production.

- **Depth of knowledge:** Is the level of knowledge of the substitute at least as good as that of the original?

This can be a major trap for the unwary: the properties of the current material may be well understood and one of those may be undesirable. An alternative may be available that does not have the undesirable property BUT unless the other properties of the alternative are also well understood the substitution may simply lead to a different problem. For example in the 1960s fires were a frequent problem in transformers because the dielectric fluids used were flammable. Alternative non flammable dielectric fluids were substituted but unfortunately these were the PCBs which had other undesirable but at the time unrecognised properties.

- **Human & Environmental Impact:** What are the respective impacts on human health and the environment of the original and the alternative?

The assumption is often made that toxicity to humans and the environment go hand in hand and thus reducing potential human toxicity will provide a similar reduction for the environment. Unfortunately this is not always true and can lead to difficulties. Thus when the environmentally persistent chlorinated insecticides where phased out in the 1970s and largely replaced by the degradable organophosphorus based products there was a considerable improvement in environmental impact. Unfortunately, since the substitutes were much more toxic to humans than the chlorinated insecticides, their impact on human health was much more serious. This situation was then reversed in the 1980s with the introduction of the synthetic pyrethroids, which had minimal impact on humans but were extremely poisonous to fish.

- **Efficiency of resource utilisation:** Does the substitution lead to any changes in resource utilisation[2] including quality and quantity of waste production?

Manufacturing process chemists are well aware that relatively minor changes to process chemistry can have dramatic effects on process efficiency and subsequently waste generation. However, substitution decisions need to be looked at holistically; if the potential substitution results in the overall process efficiency falling drastically or its energy or water consumption increasing significantly it may not be a sensible course of action. In the pharmaceutical industry, for example, water is now used to clean formulation and packing machinery between product runs, which avoids the use of organic solvents but also creates very large volumes of dilute aqueous waste.

- **Socio-Economic Consequences:** What are the socio-economic consequences of the change to the end consumer and to all the other actors in the supply chain?

Substitution may have social and/or economic consequences for the consumer which can be difficult to predict, but are crucial to whether the planned substitution will be acceptable to the end user. The economic case is usually simpler to evaluate; in general terms - increasing the product price whilst increasing its performance could be good business whereas increasing the price whilst maintaining, or decreasing, product effectiveness is likely to reduce sales. However this is highly dependent on the market and each case needs to be considered on its merits.

Engaging with the supply chain(s) should be part of any substitution plan to ensure the market is prepared for the change. Stopping the supply of a given substance to replace it with an alternative will only work if the supply chain is in agreement. Without clear communication and appropriate plans to meet customers' needs, the supply chain may simply seek an alternative source for the targeted substance. As a consequence the proposed substitution may be unsuccessful and result in market losses for the company instigating the change.

[2] Including energy, water and renewable and non-renewable resources

The social consequences are more difficult to predict. As mentioned earlier although water based paints have a significantly lower performance than solvent based paints the end user was persuaded that this was acceptable. It is however unlikely that the consumer could be induced to abandon the oral contraceptive pill in favour of the non-chemical alternative methods of birth control despite the evidence that some components of the birth control pill may be having detrimental environmental effects.

Should the substitution be made?

All of the above considerations involve value judgements rather than being simple black and white decisions and many of the decisions involved in substitution require "trade-offs" to be made between improvements and deteriorations. Consider the following example of a substance/substance substitution:

Substance X has a substantially lower acute toxicity to humans than substance Y. However whilst there is a lot of ecotoxicological information on substance X there is little data available on substance Y. We also know that if we substitute substance X for substance Y in our manufacturing process it increases the carbon footprint by 10% and produces 5% more solid waste. Should the substitution be made?

In reality the situation can be even more complex since there may be several alternatives to consider. In this example the decisions are all science based but often the decisions are socio-economic and less amenable to factual determination. Consider the following product/product substitution:

Product A is highly effective and the brand leader in a highly competitive market. Product B is a little more expensive, is slightly less effective but has a significantly lower environmental footprint. Should the substitution be made?

The need to balance dissimilar impacts does not mean that substitution is impossible, but merely indicates that decisions on substitution are often anything but simple and require both a comprehensive assessment of the data combined with a series of value judgements to determine if the proposed substitution is, on balance, beneficial.

How long does it take?

There is no simple answer to this question since each case depends on individual circumstances. In essence the time taken will depend upon how much development and subsequent product testing is necessary before the new or amended product can go on sale. In the case of critical safety components in aircraft several years of testing may be required to gain approval, whereas in other cases minor product formulation changes might be implemented in a matter of weeks or months.

A glance into the future

Sustainable design is designing a product or service or business model to reduce the overall environmental impact, whilst maintaining or improving economic, technical and social performance. It seeks to build the concepts of sustainability into business in the expectation of better long-term economic performance. Sustainable design is about seeking out the opportunities created by market change. Public concerns and regulation on product safety, waste, pollution and end of life disposal are challenging existing products, ingredients and technologies. Thousands of existing solutions will need to be replaced. The sustainable design approach is to look at the whole lifecycle and understand what the downstream users want – what is the effect or property you are providing. Don't just substitute away problem materials, re-think the product. Offer superb technical performance **and** low impact; that's what users are looking for.

This section offers an introduction to the sustainable design approach for substitution. For a more complete guide to Sustainable Design, please see the Chemistry Innovation Sustainable Design Guide on which this section is based.

The process is a three-stage approach:

- First is 'understanding the context' – what are the drivers pushing you to look for sustainable products and processes, and what does the market require? The starting point for this can be the need to substitute a substance – but consideration must be made as to the wider drivers for replacement. The output from this is a clear problem definition.

- From there the second stage is 'identifying and evaluating the opportunities' – what type of innovation is required? Are we simply replacing a substance with an alternative substance or is this an opportunity for a new solution: a better product or service. Here the thrust is to examine existing solutions and define critical success factors.

- The final step is 'delivering the innovation' – what sustainable innovations are possible? What technologies do they require? What are the best options for further development? Here we consider previous successful strategies using lifecycle thinking and areas such as durability, safety, energy use, mass intensity, reusability and servicing[3].

Understanding the Context

The first stage is to clearly define the substitution challenge in its widest context. For this, consideration needs to be given to the external factors to be responded to. In addition to the drivers outlined in a preceding section a good starting point for this is the Global Trends & Drivers document on the Chemistry Innovation website. Other external factors to examine are the market you are working in and the capabilities

[3] i.e. selling the service provided by a product rather than the product itself

and behaviour of competitors. Internal capabilities include the company business plan and strategy, the organisational culture, and its various functional strengths and weaknesses. These are all things that management can change given time and commitment. These should all be assessed in a SWOT analysis: internal strengths and weaknesses, external opportunities and threats to clearly define the wider challenge.

Identifying the Opportunities

The next stage uses the established definition of the substitution challenge to develop a clear description of what is needed in a solution.

Based on the SWOT analysis the first step is to consider the level of innovation required. Four approaches are possible with increasing resource required to achieve:

- *Improve the existing product*. Direct substitution of a single ingredient under pressure is the simplest approach. The product, manufacturing process and functionality remain basically the same but the effort involved effectively leaves you were you started.

- *Redesign the product*. The product purpose concept and functionality stay the same, but the way product is put together changes completely. For example a reformulation with a new mix of ingredients replacing the functionality of the substituted material.

- *Provide new functionality*. Rather than improving the existing product concept, find new ways of meeting the customer needs. For example, by converting the product into a service.

- *Redesign the business system*. Create a new business model in which product, production system, delivery system, supply chain and customer care may all be changed.

Each approach is progressively more complex and more risky. However, there is evidence that the potential environmental and commercial benefits increase dramatically with more radical innovation. As a guideline[4], incremental improvements to an existing product can only deliver a reduction in impact of a factor of 2; whereas a complete redesign of the business system can reduce impact by factors of 20 or more. Examples of these approaches are detailed in the Appendix.

Even though more radical innovation can deliver deeper cuts in environmental impacts, the apparent extra time, cost and risk will push many people to think about incremental changes. This can be a false economy. The costs and risks of shallow, incremental innovation can be as high as deeper, more fundamental innovation. Shallow innovation still appears to be an attractive strategy; particularly where a specific ingredient is a cause for concern and needs to be substituted. A fast reformulation project looks cost and time efficient. The EPA in the US and in Denmark have collated tables of known substitutes for materials where the environmental or health and safety profile have caused concern. This approach is particularly widely used for solvents, where it has been very effective (for more information see: Chemistry Innovation Sustainable Technologies roadmap).

However, the cost of simple substitution and shallow innovation can be substantial. REACH regulations are expected to result in a large number of chemicals that are

[4] From 'Dynamics in Eco-Design Practice' Brezet (1977) Vol 20 p22

currently freely available to vanish from the market. Formulated commercial products such as inks, adhesives and paints can contain up to 60 individual chemicals in one formulation. If one of these is withdrawn as a result of REACH, the potential costs of reformulation can be very high (for an example analysis see here).

It is important to try and decide where the project is likely to lie on the innovation continuum. Factors to consider will come from the challenge description you have described:

- How much time do you have? If the substitute must be delivered quickly, that will tend to push towards shallow innovation.
- How much resource do you have? If money and manpower are constrained you may not be able to invest in deep innovation.
- Do you have the technical capacity for deep innovation? Do you have access to technologies that can take you far outside existing solutions?
- What are the drivers for the innovation? Your market analysis can tell you whether the market is looking for an incremental change or something more radical.

Assessing the current product or process can help identify opportunities for improvements and innovation. A key part of assessing existing solutions is to evaluate their impacts across the whole lifecycle. In principle, any lifecycle tool can be used, and a qualitative rather than a quantitative answer will allow comparisons between potential new solutions and the incumbent. Lifecycle information will reveal where the impact hotspots are in the current lifecycle. As a minimum a SWOT analysis of each stage of a product lifecycle (raw materials, manufacturing, distribution, use and end-of-life) should be completed. Opportunity should be taken to implement a new solution that reduces the main impact.

All of the considerations so far, taken together will define a set of minimum standards to be met for successful substitution; the critical success factors. Some of these are external and some internal.

External factors may include:

- Technical specifications that must be met or exceeded
- Compliance with regulations or standards
- Product form
- Compatibility with existing technologies - the 'drop-in' replacement
- Price

Internal factors may include:

- Fit with the corporate strategy
- Projected market size
- Projected return on investment
- Fit with technical capabilities
- Cost and time to bring the product or service to market

A detailed innovation description should now be clear and should cover:

- What is the market opportunity?
- What is driving this opportunity?
- What benefits does the product deliver to the user?

- What are the strengths and weaknesses of the existing solutions?
- Where could innovation have the most impact?
- What are the critical success factors?

Deliver Innovation

With a detailed description of the innovation required for substitution in hand, potential solutions can be examined. For successful sustainable design, mindset is as important as technical expertise. There are some common assumptions which need to be challenged, and common areas of opportunity.

Assumptions that need to be challenged about sustainable design include:

- *“Environmental issues are just an overhead”* - some companies may see environmental issues as a threat rather than a chance to create competitive advantage. When an external pressure is applied, the tendency is to ‘circle the wagons’ and attempt to fight off the perceived threat. The company becomes stuck in a defensive posture where they cannot consider alternatives. Other companies see environmental issues as an opportunity and when an existing product / solution is under pressure believe that there is a business opportunity in solving the problem.

- *”Just fix the problem”* – it may be tempting to fix problems when they occur rather than to eliminate the source of the problem. End-of-pipe or end-of-life solutions are superficially attractive because you don't have to go back and repeat work which has already been done. However, this approach is not sustainable in the long-term and is often both environmentally and financially inefficient as technical fixes are piled upon technical fixes. Deep innovation thinking is more demanding but offers much more chance to leapfrog competition.

- *”Waste is inevitable”* - once you have developed a waste management strategy for your product or process, you have designed waste into the system. It is better to start with the assumption that there is no waste. Any material left over from your products and processes is a feedstock for another technical process or a biological process. The goal should be that every material is in as close as possible to a closed loop. This approach has been championed by the William McDonagh and Michael Braungart ‘cradle-to-cradle’ concept instead of the more usual ‘cradle-to-grave’.

- *“You cannot simultaneously achieve reduced impact and higher value”* - a common assumption is that reduced environmental impact must be paid for by higher prices or lower profit margins. This is a dangerous assumption because it reinforces the idea that environmental issues are a problem and cost. With good design you can achieve reduced impact and higher value at the same time.

The key areas for finding new opportunities are:

- *Think service not product* - companies tend to think about products not the service that the customer is buying. Forcing yourself to think about it from the customer perspective, focusing on the service or functionality required to meet their needs, opens up new innovation space. If you concentrate on the product, you will improve the product, upgrade the product, or redesign the product. If you think about the service, completely new business opportunities will open up.

- *Think lifecycle* - thinking about the entire life cycle of a product allows many new opportunities for improved performance to be identified. It is essential that environmental, health, safety and socio-economic aspects are all taken into consideration at each stage of the life cycle to be able to take an informed decision on the best way forward. Companies need to look at what is going on upstream of their factory as well as downstream.

- *Look for benefits downstream* - companies often miss opportunities downstream of their own operations. Whilst most would recognise the need to understand the business of their customers, looking further downstream and trying to understand the needs of their customer's customer can prove challenging. However, if your materials can reduce energy consumption or waste production in a final product, you reduce the costs further downstream and potentially change the value distribution across the entire supply chain. If you understand how your products are used downstream, you can share that value with your customers.

Previously successful commercial strategies can be found on the Chemistry Innovation Sustainable Technologies Roadmap along with case studies using lifecycle thinking and eco-innovation directional thinking. The website also contains numerous case studies categorised by end market, technology applied and the problem solved and can be accessed here.

Once a series of potential innovation opportunities have been identified, these should be assessed based on:

- What technology capabilities are required to deliver the innovation?
- Does the organisation have these technologies already?
- Can the organisation access technologies through partners?
- Can the organisation acquire the technologies?
- When are the technologies likely to be ready for deployment?

These opportunities need to be evaluated on a risk/reward basis and the chosen projects integrated into the organisation's innovation project management system. Sustainability should be just the way you do business, and therefore sustainable innovation projects are just projects you are working on. They should not, and must not, be a special case.

APPENDIX – Examples of successful substitutions

The following examples demonstrate, in their own words, how a number of companies have approached different types of substitution. They also illustrate the range of drivers perceived by the companies concerned.

These examples are merely intended to be illustrative and their inclusion does not imply any endorsement of the products by the Chemicals Stakeholder Forum or its members. They are taken from a database published by the Chemistry Innovation Knowledge Transfer Network (CIKTN).

Process for process

GlaxoSmithKline – Green Process for an Antidepressant

"GlaxoSmithKline (GSK) is developing a chiral functionalised morpholin-2-ol as an antidepressant. The (S,S)-enantiomer has the therapeutic effects, whereas the (R,R)-enantiomer has undesirable side-effects. The final drug must contain very low levels of the (R,R)-enantiomer. Current methods for the asymmetric synthesis require low temperatures, toxic materials and production of waste

Multi-column chromatography (MCC) was used to resolve the racemate. This has a very high solvent recycle efficiency, and allows easy recovery of the unwanted isomer. This can be epimerised and recycled, improving the overall efficiency. The process also requires only relatively small quantities of the chiral stationary phase, further improving the atom efficiency."

Thomas Swan & Schenectady Pratteln: Alternative Thymol Synthesis

"Thymol is used as a menthol intermediate, disinfectant, perfume and medicinal compound. The traditional industrial synthesis uses Friedel-Crafts alkylation of m-cresol with isopropene. This reaction uses a number of toxic intermediates and solvents, and produces a large amount of waste. In collaboration with the University of Nottingham, a much cleaner Friedel-Crafts alkylation was developed using a solid Lewis-acid catalyst in supercritical carbon dioxide."

Substance for substance

Low Toxicity Wood Preservatives

"Increasing amounts of timber are being used around the world for housing construction, decking, walkways, fencing, and play areas. Traditionally most of this wood was pressure treated with chromated copper arsenate (CCA) as a preservative. Environmental groups and regulators began to challenge the use of this preservative because of the arsenic content. Over 90% of all the arsenic used in the US went into CCA. As a result CCA was progressively banned for domestic applications and where children could be exposed (play areas etc).

Chemical Specialties Inc (now Viance) developed ACQ Preserve, replacing CCA with alkaline copper quaternary (ACQ). This combines a bivalent copper complex with a quaternary ammonium compound dissolved in ehtanolamine or ammonia. Although a 10% - 15% higher price than the older CCA system, it meets the required safety standards, and allows cheaper softwoods to be used where otherwise only hardwoods could meet durability requirements."

Low toxicity pigments

"Traditionally the yellow to red range of colours have been provided by pigments based on heavy metals such as lead, chromium(VI) and cadmium. These metals have been under increasing regulatory pressure and there is a need to find safer alternatives.

Engelhard has developed a wide range of safe to use azo-pigments under the Rightfit™ brand. These are manufactured in aqueous media avoiding the use of toxic solvents. They are also made without the use of polychlorinated intemediates. They are low toxicity, and low migration, and have been qualified for food use."

Mechanism for mechanism

Ship Hull Antifouling

"Ships lose sailing performance and develop damage due to fouling through organisms such as barnacles settling onto a vessel's underwater hull. The usual approach is to coat the hull in a biocidal paint.

Intersleek® provides a slippery, hydrophobic, low friction surface onto which fouling organisms have difficulty settling. Any that do settle normally do so only weakly, and can usually be easily removed by simple wiping/washing, or by the vessel moving through the water at speed. Intersleek is a unique patented fluoropolymer foul release coating that allows all vessels above 10 knots - including scheduled ships, tankers, bulk vessels, general cargo ships and feeder containers - to benefit from foul release technology."

Fire Safe Epoxy Resins for Electronics

"Epoxy resins are widely used in electronics as encapsulation materials for integrated circuits and in producing the substrate for printed circuit boards. To control the risk of fire, flame retardants are usually added; typically brominated compounds. These materials are under a lot of pressure from regulators because of concerns about their intrinsic safety and the toxic substances that can be given off when they burn

In collaboration with Sumitomo Bakelite Co Ltd, NEC developed a new resin that does not require any fire retardant. The resin contains an aromatic epoxy resin and a phenol derivative hardener. After curing the resin forms a network with a low cross-link density leading to high elasticity at high temperatures. When exposed to a potential source of ignition, ingredients in the resin form pyrolysis gases that expand in the elastic matrix, producing a foam layer on the surface of the resin. This slows oxygen penetration and heat transfer. As a result, the resin is self-extinguishing. The resin itself has a high resistance to thermal decomposition making the foam thermally stable. The product is successfully used for encapsulation and production of printed circuit boards."

Product for product

Cold Water Laundry Detergents

"Full lifecycle analysis of the Proctor & Gamble laundry range showed a dominant hotspot in the heating of water for washing machines. 75% of the impact comes from heating water for a hot wash. Low temperature detergents have to overcome consumer preconceptions and potential misuse.

P&G launched Ariel/Bold Gel laundry detergents that work at 15 ºC. The enzymes in the formulation allow complete cleaning at low temperatures but must not deteriorate in performance at higher temperatures or consumers will lose confidence. A strong advertising campaign was required to persuade consumers to use the lower temperatures. The problem of the user dosing the correct amount was tackled by the formulation and packaging. Over-dosing of laundry powders and liquids is common and customer surveys suggested even tablets were broken up to increase dose due to a consumer perception this would improve results. In fact correct dose is important to achieving good results. Liquid capsules went some way to ensuring this, and the gel detergents with their integrated dosing cap don't provide leeway for mis-dosing. P&G looked at 5 million possible formulations to achieve the desired product qualities - only 30 met the success criteria for this redesign."

Dow Sentricon™ Termite Colony Eliminator

"Each year in the US more than 1.5 million homes will face a termite problem and need some form of defence. Traditionally this has done by using insecticides in the soil around a property to create a barrier that the termites cannot break through. However, this approach uses large volumes of insecticide and creates both human toxicity and eco-toxicity risks.

Dow has developed the Sentricon™ Termite Colony Eliminator. This delivers targeted bait directly into the areas of termite activity. The hexaflumuron bait is significantly less toxic than conventional products, and because it is delivered directly to the right location much less active material is used. Only 1/1000th the same amount of active material is required for Sentricon™ treatment. Since the active ingredient is contained within the applicator and is buried below ground, there is no risk to children, pets or other animals."

Product for service

SafeChem closed loop solvent recycling

"Chlorinated solvents are extremely efficient cleaning agents. Unfortunately, significant toxicological and environmental hazards have caused many companies to stop using them altogether. SafeChem, a subsidiary of Dow, has developed a handling system for chlorinated solvents that allows them to be used in closed loop degreasing systems. The Safe-Tainer system uses two dedicated double wall containers; one to hold fresh solvent and the other used solvent. The containers are connected to the cleaning equipment with zero dead volume, leak-free connections that prevent spills, leaks or vapour emissions during use. Used solvent is collected for recycling and professional disposal of any residues.

However, this is not just a safe container. It actually switches the business model from sale of a chemical to management of a chemical process throughout the lifecycle. SafeChem is fundamentally a service company."