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The Grand Challenge on Sustainable Materials

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As we move into the 21st century we face a problem, which I refer to as "The Free Ride is Over!" While at the same time many people in less developed countries desire to increase their standard of living, while those in developed countries are unhappy about the idea of lowering their standard of living, as defined currently in terms of resource consumption. When I write "The Free Ride is Over !" what I mean is that the era when it was acceptable to ignore pollution, occupational disease, overconsumption of resources and other adverse consequences which can occur if through single-minded pursuit of profit, growth or some other advantage. In the past both western capitalists and Soviet bloc communists have taken a view that environmental pollution is an acceptable cost of profitable industrial activities. Unless we are going to depopulate the world and return to living a primitive life we will need large scale processes to produce the things which enable us to have a good life, or even a bad life ! We need to become more sustainable. One view of sustainability defines it as the triple bottom line. Sustainable activities must be sustainable in three ways:

1. Environmentally Sustainable.
2. Financially Sustainable.
3. Socially Sustainable.

This section of the journal is broadly about sustainable resource management and this section focuses on sustainable material which includes the production, investigation, use and disposal of things (materials). To understand the scope of this section we will need to consider some examples. I am an unashamed chemist so my examples involve "chemicals," but I would like to point out two things. Firstly, submissions by people from less chemically orientated disciplines are perfectly welcome. Secondly everything is a chemical or a mixture of chemicals.

It is interesting that back in 1978 David Bellamy (The famous botanist) and Clare Smallman (a biology teacher) pointed out different food production methods such as chicken meat production require the cultivation of a larger area of land for a given amount of food than others (such as grain used to make bread) (Bellamy and Smallman, 1978). They argue we should try to keep food chains short and they point out that a lot of our food is transported long distances thus requiring fuel to be consumed. Steinhart and Steinhart indicate that intensive egg production requires *circa* 2 joules energy input per joule of food, while deep sea fishing requires a staggering ten joules per joule of food. On the otherhand rice production in paddy fields requires <0.1 joule per joule of food energy produced (Steinhart and Steinhart, 1974). More recently an estimate has been made of the number of moles of reactive nitrogen (nitrogen other than elemental nitrogen) which is lost when food containing one mole of such nitrogen is produced (Liang et al., 2016). It is clear that some foods require a greater investment in nitrogen than others. Please excuse the pun but sustainable use of materials in farming might well be a fertile topic.

It was said by William Shakespeare in *Julius Caesar* that "*The evil that men do lives after them; the good is oft interred with their bones.*" Sadly, in this world we are burdened with consequences of reckless, criminal acts and those things which seemed reasonable at the time but with hindsight are clearly inadvisable. We have the problem of how best do we put these things right. We even have

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to ask the question of "should we attempt to put them right or is it better and more sustainable to let sleeping dogs lie?." I used to live in the village of Fåglavik where there was a glass factory, this asbestos contaminated site was finally demolished in 2008 thus reducing the threat posed to the general public. After the removal of the buildings some of the contaminated demolition waste was interred on the site. It has been sealed in, covered with clean soil with the intent that nobody ever digs there or performs another act which compromises the landfill. The great problem is that Fåglavik will never be totally free of the asbestos problem, but if the waste had been packaged up and transported out of the village then it would have to go somewhere else. While landfilling is not politically attractive, for some classes of waste it may be the best method of dealing with it.

I know that many people with an absolutist view of waste and sustainability will be deeply opposed to the idea of waste disposal systems where the waste is buried. Experience with unwanted high activity sealed radioactive sources (HASS sources) has shown that failure to make a robust system for managing them in either a centralized waste store or by their irreversible emplacement in a disposal site has led to a chilling array of accidents. Here, we have a conflict between adverse effects of disposal (maybe people will dig up the waste store 1,000 years later) and the adverse effects of non-disposal of the waste. While I write here about asbestos contaminated wastes from an industrial site and radioactive sources which generate immense radiation fields, there are many other waste management problems where we have to choose the most sustainable management method.

When we consider waste, we need to divide in our minds two types of waste. First, are the existing wastes which we are already committed to. These materials and installations already exist and 1 day must be disposed of. Second, are future arising wastes where we could make the choice not to indulge in the activity which creates the waste.

The morality of a choice can depend greatly on the question of if the waste existing waste or waste which will arise. For example if a national regulatory body was to authorize the transport of goods under conditions which would normally be illegal, then if the dispensation to ignore the law was to enable an act required to protect society from poorly managed waste which already exists then it could be a noble and reasonable act. Such a dispensation could be justified to enable the management of waste which is currently endangering the public due to the abandonment of waste where the transport is only slightly falling short of the standards required in law. But it is hard to imagine a situation where it is acceptable for a regulatory body to issue a similar dispensation to enable a new activity to commence in an area.

In the past some journals which have delt with sustainability issues have, wrongly, chosen to only consider arising waste. Here, this journal section will consider wastes which we are both already committed to and those which we are not. After considering committed wastes I would like to consider sustainability issues which relate to current and future activities.

For environmental sustainability we will consider the production of sodium carbonate. Years ago the Leblanc process used salt, sulfuric acid, coal, and limestone (calcium carbonate) to form sodium carbonate in a profoundly dirty process. Firstly, the common salt (sodium chloride) was combined with the sulfuric acid to form sodium sulfate and hydrogen chloride. The hydrogen chloride was released into the atmosphere where it caused dire environmental effects. These were so bad that they provoked the passing of the Alkali Act of 1863.

$$2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl.$$

Next the coal and the sodium sulfate were roasted to form carbon dioxide and sodium sulfide, this would have consumed fossil fuel and released more pollution into the air.

$$2C + Na_2SO_4 \rightarrow 2CO_2 + Na_2S.$$

Finally, the sodium sulfide was combined with the calcium carbonate to form calcium sulfide and sodium carbonate. The calcium sulfide waste is foul as contact with water or dilute acid would have generated hydrogen sulfide. The more modern alternative is the Solvay process. Here, the first stage is to dissolve ammonia and then carbon dioxide in a concentrated solution of sodium chloride (brine) which forms poorly soluble sodium hydrogen carbonate (sodium bicarbonate) according to the following reaction.

$$NaCl + NH_3 + CO_2 + H_2O \rightarrow NaHCO_3 + NH_4Cl.$$

The ammonium chloride solution is combined with calcium oxide (quicklime) which is formed by driving off carbon dioxide from limestone by harsh heating thus forming calcium chloride and ammonia which can be reused in the plant.

$$2NH_4Cl + CaO \rightarrow CaCl_2 + 2NH_3 + H_2O.$$

Equally some carbon dioxide can be harvested from calcining sodium bicarbonate into sodium carbonate.

$$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O.$$

This might have been a rather basic bit of chemistry but if this journal had been operating back in Victorian times then Ernest Solvay's article about his new and more sustainable method for making sodium carbonate would have received a sympathetic reception.

Before we move onto another of the three big areas, we should understand that environmental issues include things than just waste. Consider for a moment the production of taxol (Paclitaxel), if we were to cure cancer using taxol produced by killing pacific yew trees and do so on a scale which results in the extermination of every last pacific yew tree, then we will have harmed the environment in a dire way by causing a species to become extinct. Thankfully it is possible to make taxol by other methods, which enable this lifesaving medicine to be made without killing trees.

Another issue is resource consumption, imagine if we were to use charcoal to fuel the whole of modern society. Then it would be possible that the production of charcoal from wood would result in dire deforestation.

For financial sustainability, an activity must serve a useful purpose to be sustainable. Imagine devising a cheap and effective process for the synthesis of benoxaprofen (Opren) which produced no waste and was very environmentally good. It would never be sustainable as no market exists for this drug. The financial sustainability of a process or product is often linked to society but also needs to be careful of two things. Imagine reacting the methyl iodide with magnesium in ether and then with benzaldehyde, then after treating the product with acid making some very expensive styrene. This would never be a sustainable method of making the styrene needed for many modern plastics on an industrial scale.

But, if this chemistry was used to make the styrene with an isotopic label in a specific position which was then used to solve some problem which relates to the sustainable production, use or disposal of styrenic plastics. Then it would be a paper about sustainability which would be welcome in this journal. Here, while the study might be making some very expensive styrene, the use of the expensive styrene offers an insight which relates to styrene in general. Equally, if you were to use some reagent or device which is deeply troubling to many people on sustainability matters then if it offers information which helps with a sustainability question then it can be perfectly acceptable. One may need to argue a case as to why the "scary gadget it needed." My mind considers the problem in a similar way to how in jurisprudence the defense of necessity is considered. To successfully use the defense of necessity one needs to show that one's breaking of the law was confined to the minimum degree to prevent the greater harm. So, you may have to argue a case for why the normally unsustainable method was acceptable for use, if a more sustainable method existed then your paper might be rejected. For example, one of the best methods of detecting a fire in the early stages is to use an ionization type of smoke detector, these detect the invisible smoke emitted in the very early stages in a fire. Some of the early detectors used radium (^{226}Ra) which is one of the most challenging radionuclides to work with safely. In the west, in modern times, it has been normal to use americium (^{241}Am) while the Soviets in the 1980s were using plutonium as the alpha source as both are safer than ^{226}Ra. Making a measurement using radium as an alpha source would be difficult to justify. It might be interesting for someone to consider the question of what is more sustainable, is it better to use methods of fire prevention which are regarded by many as unsustainable (such as small molecule organobromines such as polybromo diphenyl ether or worse still polybromobiphenyls) or not to use them at all. Clearly, a fire in a house, car, or commercial site will have an environmental (and thus sustainability impact); will it be greater than the impact of the preventative measures used to prevent fires?

For social sustainability we need to consider several things. A product, process or activity must be something which society will tolerate or even better encourage. Also, the product, process, or activity should not be harmful to society. A two-way street exists between public opinion and the creation of law, if an activity is sufficiently reviled then sometimes it becomes illegal which it is the ultimate in social unsustainability.

De jure legal activities can be become *de facto* illegal when local governments or other bodies oppose them. This can happen when lower tier of government creates a regulatory environment or performs an act which makes it impossible to engage in a legal activity. My personal opinion is that seeking to obstruct or undermine law by acts such as misusing planning law, setting unjustifiable standards or other acts is wrong. Instead of banning or discouraging an activity a government can through subsidy and other means encourage an activity. An extreme example of this is the Renewable Heat Incentive where the subsidy on renewable heat was so large that it lead to a political scandal sometimes known as "Cash for Ash." If too much public money is consumed by a subsidy scheme, then it may be a threat to sustainability.

Governments both national and local, corporations, public bodies and even individuals sometimes attempt to increase sustainability by making a change. One of my PhD supervisor's favorite phrases was "The road to hell is paved with good intentions," it is very possible that a change made with the best of intentions can make the world a worse place. One could write "The road to X in Brighton is paved with weeds." In recent times in Brighton the local government have chosen to stop using glyphosate and other "chemical weedkillers," the Green party in Brighton and Hove have cited the IARC's classification of glyphosate (IARC Monologe 112) as "probably carcinogenic to humans" putting it in group 2A. Since the use of "weedkillers" has stopped unwanted plants (weeds) have sprouted out of the pavements creating a trip hazard.

Thankfully the 1962 film "day of the trifids" is not a documentary but there are other troublesome plants like Japanese Knotweed (*Reynoutria japonica*) which can cause devastation. Even if some herbicides such as paraquat (Gramoxone), diquat, cacodylic acid and 2,4-D are harmful to human health and the environment, I argue that a total ban on herbicides could render us unable to deal with the worst of the worst of weeds.

The case for glyphosate being a carcinogen is weak when compared with large doses of gamma rays from ^{60}Co sources, in dogs exposure to gamma rays is clearly carcinogenic (Benjamin et al., 1991). While in animals studies with glyphosate sometimes show it is carcinogenic, also in genotoxicity tests glyphosate typically comes back as "non mutagenic" (Kier and Kirkland, 2013). Before we move on there is something interesting about the environmentalism movement, they do not trust UN bodies equally. While they tend to trust IPCC and IARC they do not normally trust the IAEA. I have a possible answer, many people decide what they want "the answer to be" and then search for evidence and arguments which support this "answer" just like one UK judge did.

What the judge did wrong was he would hear the facts of a case, make up his mind on what he thought the outcome should be based on his own personal opinions. Then he would search the law libraries diligently for an excuse to give the ruling he wanted to give. What a judge should do is to hear a case, then maybe consult the literature and then decide how to rule. His behavior is the opposite of what a judge or a scientist should do. Please when you are doing your work which leads toward papers in this section or elsewhere do not emulate his method

of working. Now regardless of how weak or strong a carcinogen glyphosate or even if it is non-carcinogen, we should ask the question of was an assessment made of the benefits of ceasing the use of "roundup" against the harm. I think that a scientifically sound (defendable) assessment of the risks to workers, the general public and nonhuman organisms of using glyphosate should be made and weighed up against the injuries caused by people stumbling on weed infested pavements.

The journal welcomes submissions from jurists and related professionals who consider how the use (and abuse) of law affects sustainability issues. A lessor effect is when the general public make purchasing decisions based on how they perceive how sustainable or "eco friendly" a product or corporation is. Sometimes the public gets it right while sometimes they make incorrect judgements. Papers exploring these issues are welcome.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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