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Climate Change and Manufacturing

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Abstract

In 1966, the World Meteorological Organization proposed the term climatic change to encompass all forms of varations in the climate variability on time-scales of greater than 10 years, whether the cause was natural or anthropogenic. When it was realized that human activities had a potential to drastically alter the climate, the term climate change replaced climatic change as the dominant term to reflect an anthropogenic cause. Climate change was incorporated in the title of the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC). Since 1988, the IPCC has produced 5 multivolume reports which collate the consensus of all leading scientists across the globe on all aspects of the science of climate change.

At the Paris climate conference in December 2015, 195 countries agreed to the world's first universal action plan to tackle climate change by limiting global warming to 'well below 2°C'. This historic achievement was just the beginning – now every country must turn their promises into action. We must give serious attention to adapting our processes to mitigate the effects of global warming. This paper reviews the current state of expectations and agreements and explores how manufacturing technology can contribute toward these programmes.

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Keywords: food packaging; electrospinning; anti-oxidant.

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1. Introduction

The term climatic change was introduced by the World Meteorological Oragnisation to encompass all forms of varations in the climate variability on time-scales of greater than 10 years, whether the cause was natural or anthropogenic. In later years when it was realized conclusively that human activities had the potential to drastically alter the climate, the term climate change replaced climatic change as the dominant term to reflect an anthropogenic cause. Climate change was incorporated in the title of the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC) [1].

Since 1988, the IPCC has produced 5 multivolume reports which collate the consensus of all leading scientists across the globe on all aspects of the science of climate change. The most recent of these was published two years ago [2] and it contained components which focused specifically on the mitigation of climate change and advice for governments around the world on action to take to slow and reverse the current trends. In reviewing this vast body of scientific work it is fair to state as many have said that evidence for global warming is overwhelming and is the consensus view of nearly all those engaged in the scientific work. However, it also fair to say to record that the reliability of the predictions of the extent of climate change is unclear in that the range of possibilities cover life more or less as it is to disaster in many areas. The climate models have limitations as to the spatial scale of the predictions partly as a consequence of the sparse nature of the experimental observations and lack of details of the microscopic processes involved in the transmission, reflection and absorption of energy in the atmosphere and the planet surface. So while it is clear that we all need to take action it is not so clear as to the outcomes in later years. However, we know that action is essential to avoid a high risk of disaster.
Figure 1 The cover of the 5th IPCC report [2] which specifically focuses on mitigation of climate change

Article 2 of the United Nations Framework Convention on Climate Change states [1]:

"*The ultimate objective of this convention and any related legal instruments that the conference of Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*"

The 5th IPCC report [2] provides a summary on the greenhouse gas emissions over the last 40 years. Total anthropogenic greenhouse gas emissions have continued to increase over the period from 1970 to 2010 with a rapid increase towards the end of this period. Despite a number of climate change mitigation policies annual greenhouse gas emissions grew on average by 1.0 gigatonne carbon dioxide equivalent which is a 2.2% increase from 2000-2010 compared with 0.4 gigatonne carbon dioxide equivalent from 1970 to 2000. The total anthropogenic greenhouse gas emissions were at the highest ever in 2010 with a value of 49 gigatonne carbon dioxide equivalent. The global economic crisis 2007/2008 led to a temporary reduction in emissions.

In 2010 the industry sector accounted for 28% of final energy use and 13 gigatonne carbon dioxide equivalent emissions. The emissions are projected to increase by 50-150% by 2050 unless energy efficiency improvements are accelerated.

2. Industry

Here industry includes the construction industry.
The report identifies a number of strategies for reducing the emissions and these were [1]:

2.1 Reduction of the energy intensity of the Industry Sector by around 25% through upgrading, replacement and deployment of the best available technologies. Additional energy reductions of around 20% may be realised through innovations.
2.2 Improvements in greenhouse gas emissions through the efficiency of material use, recycling and the re-use of materials and products and overall reductions in product demand.
2.3 Carbon dioxide emissions dominate Greenhouse gas emissions from industry but there are also mitigation opportunities for te reduction of other gases, for example methane, nitrous oxide and fluorinated (key target) gases.
2.4 The applications of cross-cutting technologies and measures can improve process performance and plant efficiency. Cooperation between and across companies for example in industrial parks could include the sharing of infrastructure, information and waste heat utilization.
2.5 Increased attention on waste reduction followed by re-use, recycling and energy recovery. Globally about 20% of municipal solid waste is recycled. In 2010 waste and waste water produced 1.5gigatonnes of carbon dioxide equivalent. Suitable programmes in this area could result in significant reduction in emissions from waste disposal.

Before we start to review actions which can be taken under each of these headings we need to review the landscape of adapting for mitigation.

3. The Big Picture

Buildings are a good place to start. In 2010 the residential, commercial, public and service building sector but excluding construction accounted for around 32% of the final energy use and some 8.8 gigatonnes of carbon dioxide equivalent [2]. Our everyday experience tells us that buildings are conservative in design and often rather inefficient. Many buildings are constructed from concrete or brick, both of which are high energy materials

A key component of Concrete is cement. The preparation of cement is a high temperature process and that process also involves the direct production and release of carbon dioxide to the atmosphere. The USA environmental protection Agency [3] has estimated that for every 1000Kg of Portland cement produced between 900 and 1100Kg of carbon dioxide are emitted. 50-60% of these emissions are a direct result of the caclcination of the calcium carabonate raw materials, the remainder is emitted as part of the fuel burnt to achieve the high temperature about 1500C employed in the cement production process. There are developments to use the carbon dioxide emissions in the growth of algae[4] which is to be commended.

Now before we condem cement and concrete to the don't use any more materials bin, we need to consider what will replace these systems. There is a well established supply chain and construction methodology which has served us well from a load bearing point of view. Concrete buildings combine insulation with high thermal mass to make those building more energy efficient. Concrete has a long service life which increases the period before reconstruction and repair become essential. The downside is there are no current pathways to recycle concrete in to high value products as part of the reuse and recycle strands of the mitigation process.

Of course we have to recognize that most building we will use in the future have already been built [5]. So we do not start from a clean sheet. Improvement to building efficiency need to be achieved by retrofit solutions to reduce energy consumption and emissions.

However in terms of new build we can see that enhanced design taking account of the whole life cycle energy consumption and emissions together with improvements to the materials used which could enhance the recyclability.

If we look at concrete, it consists of an aggregate of small stones which are held tgether with the framework of the reacted cement. We need to look at new ways to glue aggregates and sand together with low carbon dioxide emissions and low energy consumption which facilitates recycling. Such a programme is underway in CDRSP.

We will consider one more big picture before looking at the mitigation options under the headings introduced in section 2.

An area which illustrates that to find solutions we need to consider all aspects is food packaging. According to the United Nations Environmental Programme one third of all food produced in the world is wasted [6]. Food waste across the world is responsible for 7% of all Greenhouse Gas Emissions. Despite the fact that most food waste is caused by poor management in the food chain and in the home through overstocking, overpurchase, overcooking and a misplaced sensitivity by consumers to best by dates, researchers look to develop even better food packaging to increase shelf-lives through providing a greater barrier to the diffusion of oxygen through the packaging. Now many of the routes to achieve this involve multilayer films [7] and the use of nanoparticles to increase the tortuosity of the oxygen diffusion path through the packaging material [8]. Both routes make recycling or energy recovery more difficult and with a low economic value. Plastics or polymers are often the principal material employed in food packaging and they represent one of the largest sectors of usage for polyolefins such as polyethylene and polypropylene. Now it is the case that there is considerable societal backlash to plastics as a consequence of the waste in general and the plastic island in the Pacific ocean [9]. It is fair to say that most of the problems with plastic waste arise from poor control and management by members of society. There is little appreciation of the major role played by plastics in delivering clean and safe water, the provision of safe electricity and the positive aspects with regard to food packaging. A recent report focused on the USA and Canada showed that if plastics were substituted by other available materials The substitute packaging would require 80 percent more cumulative energy demand and result in 130 percent more global warming potential impacts, expressed as CO_2 equivalents, compared to the equivalent plastic packaging [19].

One area which has received little attention is the concept of design by function rather than the conventional approach which is design by form. Design by function sets out to optimize the design of an object with regard to its function and that could be lower greenhouse gas emissions as well as enhanced food protection. This is underlined by 2015 study by Denkstat GmbH “How Packaging Contributes to Food Waste Prevention” finds that “packaged fresh goods have a smaller environmental footprint than unpackaged food (even if the packaging is not recycled). The study finds that proper packaging results in less greenhouse gas emissions. Even though more packaging is being used, less food is being wasted, leading to a lower overall carbon footprint”. A key finding was that "Food packaging can make an important contribution to environmental protection, especially if it is the right packaging for the right application.". The possibility of using compostable polymers or biodegradable polymers appears to solve some of the societal pressures. However, neither of these approaches yields any reuse or energy recovery unless suitable municipal systems for composting are developed widely.

4. Definitions

6.1 Sustainability

Article 3.3 of the Lisbon Treaty 2009 states that the European Union “shall work for the sustainable development of Europe based on balanced economic growth and price stability, a highly competitive social market economy, aiming at full employment and social progress, and a high level of protection and improvement of the quality of the environment.” [12].

Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs.’ Brundtland 1987

6.2 Recyclability

Ability of a material to be captured and separated from a waste stream for conversion or reuse

6.3 Biodegradability

EN 13432, the characteristics a compostable material must show are:

•Biodegradability, namely the capability of the compostable material to be converted into CO2 under the action of micro-organisms. This property is measured with a laboratory standard test method: the EN 14046 (also published as ISO 14855 [14]: biodegradability under controlled composting conditions). In order to show complete biodegradability, a biodegradation level of at least 90% must be reached in less than 6 months (Note: measurement errors and biomass production are experimental factors which can make it difficult to reach 100%: this is why threshold is set at 90% rather than at 100%).

•Disintegrability,namely fragmentation and loss of visibility in the final compost (absence of visual pollution). Measured in a pilot scale composting test (EN 14045). Specimens of the test material are composted with biowaste for 3 months. The final compost is then screened with a 2mm sieve. The mass of test material residues with dimensions > 2mm shall be less than 10% of the original mass (Note: also in this case a 10% tolerance is allowed, taking into account the typical error found in biological analysis).

6.4 Industry 4.0

The term Industry 4.0 is often used to refer to the developmental process in the management of manufacturing and chain production [15]. It also refers to the fourth industrial revolution. The concept emerged in Germany where it has been adopted for the 2020 strategy.

6.5 Direct digital Manufacturing

Direct Digital Manufacturing (DDM) is a manufacturing technology widely seen as a key strand to Industry 4.0. It enables objects to be manufactured directly from a digital definition without the use of specific tooling or moulds. 3d printing and stereolithography are examples of the layer-by-layer additive technologies involved.

6.6 Live Cycle Analysis

From the ISO standard 14040 [17]:

A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts direct attributable to the functioning of a product or service system throughout its life-cycle.

6.7 Life Cycle

Consecutive and interlinked stages of a product or service systems, from the extraction of natural resources to the final disposal.

6.8 Life Cycle Assessment (LCA) [17]

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by
- compiling an inventory 2) of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

Stages

- Raw materials acquisition
- Materials manufacture
- Production
- Use/reuse/maintenance
- Waste management

5. Mitigation steps

In light of the previous discussion we propose some priority actions to mitigate climate change based on the recommendations of the IPCC report (Section 2).

5.1 Reduction of the energy intensity of the Industry Sector by around 25% through upgrading, replacement and deployment of the best available technologies. Additional energy reductions of around 20% may be realised through innovations.

One of the digital strands to the 4th Industrial Revolution is the development of Direct Digital Manufacturing [18]. This is a major activity at CDRSP. CDRSP is the lead organization in the Portuguese Additive Manufacturing Inititative It enables an object to be manufactured directly from a digital definition without the use of specific tooling or moulds. 3-d printing is just one of the technologies being developed. There are many advantages to Direct Digital Manufacturing over conventional manufacturing technology and the most striking is that each object which is produced can be different to the last. Previous industrial developments have led to mass production which has enable many complex consumer goods such as cars and household items to be produced at prices that most can afford them. Direct Digital Manufacturing offers mass customization and is therefore particular suited to medical applications. However many believe that Direct Digital Manufacturing will become the predominate form of manufacturing technology. It enables goods to be produced which we need (appropriate design), which are produced when we need them and where we need them. In other words it removed centralization from manufacturing. It changes the structure of employment.

This greatly changes the manufacturing supply chain, it requires no warehousing with large passive stocks, it requires no distribution system and it involves little or no waste. In 2008 the Atkins report from Loughborough University showed that parts produced by Direct Digital Manufacturing involves 50% of the plastic used in traditional manufacturing. This leads to a marked reduction in material energy costs and greenhouse gas emissions. Of course Direct Digital Manufacturing is still in its infancy and there is much to do to optimize to minimize emissions.

Moreover, the approach highlighted above design by function could lead to further reductions in material volumes and in higher performance of the object manufactured leading to further energy savings and reduction in greenhouse emissions It is quite likely that improvments will also come in the development of new materials. One disappointing features of direct digital manufacturing overall is that the material base has not developed particularly rapidly once technologies have been identified in contrast to the rapid development of tailored polymer resins for conventional polymer processing such as injection moulding, and rection injection moulding.

5.2 Improvements in greenhouse gas emissions through the efficiency of material use, recycling and the re-use of materials and products and overall reductions in product demand.

The challenges in recycling mostly take place at the societal interface [20] rather than in the technology. It is clear that the publics view of recycling is that is complex with little real help from producers. It is strange that there is no real move to standardization of policy even within a single country. Why not colour code different types of plastic or different types of plastics to simplify household sorting and also in terms of large scale sorting which have become highly automated in recent years [21]. We have to take a realistic view of recycling and ensure that policy, standardization and the legal requirements make a positive contribution rather than simply relying on berating consumers.

It is clear that worrying about recycling after products are produced is considering the problem back to front. The design of new products should support, reuse and recovery programmes. These are simple policies which will change the balance between consumers and other end users and producers. The authorities need to take account of the fact that this is not a static situation, and best practice will change with time. Any design must take account of whole life cycle assessment and there is a case for making it a responsibility of producers to provide best practice information and advice to endusers about end of life aactions.

5.3 Carbon dioxide emissions dominate Greenhouse gas emissions from industry but there are also mitigation opportunities for te reduction of other gases, for example methane, nitrous oxide and fluorinated (key target) gases.

The development of green materials will be a critical activity here. The Centre for Rapid and Sustainable Product Development has in the last two years launched a major strand of research work titled FAVAM, Forests Added Value Advanced Materials [21, 22, 23] which seeks to develop new materials using the resources of the forests. Forests are under threat around the world and this is the case in Portugal. Lack of effective management can lead to a loss of biodiversity and a loss of forest area, maintenance of these is critical in the mitigation of climate change. To stabilize forests and their rural communities we need to increase the economic value of the products of forests and this is the immediate target of FAVAM.

The major anthropogenic source of nitrous oxide is agriculture. There is a clear need to review agriculture policy and the mass transport of food produce around the world. A recent report focuses on the lack of activity on the livestock industry. It is the case that the global livestock industry produces more greenhouse gas emissions than all cars, planes, trains and ships combined [24]. However a worldwide survey by Ipsos MORI in the report finds twice as many people think transport is the bigger contributor to global warming. Cattle are a major source of methane, the other is methane leakage from gas supplies [25]. Although it has been suggested that the diet of cattle could be varied from the normal corn to alternatives which would reduce methane output [26], cattle are a high energy sourse of food and consume large volumes of water. We may be reaching the point where we need to agree to reduce the number of cattle used for meat productions. Some progress has been made in growing meat in an artificial environment [27]. Cultured meat is not the only development which would radically alter land use which will reduce Green House Gas emissions. Hydroponics coupled with LED lighting is particularly suited to mass indoor agriculture and placing food production where it is needed. [28]

5.4 The applications of cross-cutting technologies and measures can improve process performance and plant efficiency. Cooperation between and across companies for example in industrial parks could include the sharing of infrastructure, information and waste heat utilization.

The Centre for Rapid and Sustainable Product Development is seeking to establish a Science and Technology Campus to support industrial development. Consideration has been given to sharing high performance computing resources and large scale materials characterization equipment and facilities. By providing geographical clusters of industry there are opportunities for waste to become input for others. For example coal-fired power stations produce large volume of fly ash which could become a useful source to reduce emissions in the production of concrete. The development of an intelligent industry infrastructure to share and harness common problems could do much to reduce emissions from transport. There is clearly n important role for regional and local government.

5.5 Increased attention on waste reduction followed by re-use, recycling and energy recovery. Globally about 20% of municipal solid waste is recycled. In 2010 waste and waste water produced 1.5gigatonnes of carbon dioxide equivalent. Suitable programmes in this area could result in significant reduction in emissions from waste disposal.

From the matters discussed above our central strategy is to reduce waste by design and method of manufacturing and to build in the functionality of re-use, recycling and energy recovery through the design. We can the reuse and recycling of waste by forming industrial clusters in which expensive facilities can be shared and the waste of one company can be the input material for others. Coding the mterials used in the product appears to be straightforward and just needs governmental action.

The author was involved in an EU project Focused on the production of high performance composites using nanocellulose fibrils as the filler [29]. The nanocellulose fibrils were extracted from clean waste in the form of pulp from juice production from carrots, sugar beet and the like. This is a good example of a pipleline from waste to valuable added value material. CDRSP is exploring the use of nanocellulose in the FAVAM programme so in the future we may have a sustainable high performance composites made entirely from forest products.

6. Conclusions

We have identified a multiscale strategy to climate change mitigation in the zone of industry.

1. We need to develop industrial clusters to minimise energy use and emissions associated with transport and to facilitate the sharing of facilities and services and to couple waste to input;
2. We should review agriculture and replace meat production through cattle with cultured meat;
3. We need to add value to natural resources to ensure the stabilization of those natural resources, rural communities and biodiversity;
4. The development of Direct Digital Manufacturing needs to be accelerated and used to reduce waste and minimize energy and emissions;
5. We should colour code materials used in multimaterial products to facilitate ease of recycling;
6. We need to develop design by function as a routine design tool for all new products considering the whole life cycle in the design and the ease of reuse, recycling and recovery as objectives.

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