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Article

Manufacturing a Better Planet: Challenges Arising from the Gap between the Best Intentions and Social Realities

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Abstract: With rising concerns about the social and environmental impacts of industrial and manufacturing waste, scientists and engineers have sought solutions to the burdens of waste which do not simply involve burying, burning, dumping or diluting. Our purpose here is to sketch how social science perspectives can illuminate aspects of the waste problem which are not routinely grappled with within science and engineering perspectives. We argue that if one is concerned about the burdens of waste, it is crucial to understand the way political and cultural contexts shape what happens (or does not happen) in regards to reuse. We sketch some of the challenges facing green manufacturing; challenges that hinge on the gap between the best laid plans and social realities. Rather than imply green manufacturing is simply a post hoc move to hide the excesses of industrial capitalism in the green cloth of sustainability, we hope our discussion can assist those who hope to use green manufacturing as a pre-emptive move to build sustainability into industrial capitalism. We suggest that a socio-political conception of technology can bring greater depth to understandings of the industrial, political and consumer environments into which green manufacturing researchers hope to insert their efforts.

Keywords: green manufacturing; recycling; policy; social science

1. Introduction

Wise commentators have recently said that a desirable future for manufacturing is for it to be ‘smart, agile, and green’ [1]. Reframed as a ‘how’ question: how is it possible to transform our attitudes toward consumption and waste while simultaneously attempting to create more environmentally sustainable processes throughout industry and manufacturing? As social scientists, we are experts in our own fields of inquiry but only informed citizens when it comes to the specific techniques involved in engineering solutions to the burdens of waste. As citizens, we share the ideals of making manufacturing and industry smart, agile and green, and we want our technically trained colleagues to succeed in their sustainability-minded innovation endeavours. However, science and engineering techniques are just one way of interpreting the ‘how’ question noted above. As social scientists, what can we add? We could be critical; following some in bluntly arguing that it is “pure fantasy to pretend that the ‘problem’ of waste can be solved technically” [2] (p. 5). However, we want to be constructive. Thus, rather than assuming that our scientific and engineering colleagues are naïve enough to think technical solutions alone will suffice, we start from the collaborative intuition that we all realize the success of any answer to the ‘how’ question is not exhausted by technical virtuosity. Instead, ‘the how’ is tied up with more broadly framed ‘what and why’ questions. How to

do something is tied up with the politics of why we do it and what is politically, economically, ethically, and culturally involved in doing it. Our contribution here turns on operationalizing that ‘tied up with’ provision. It leads us to suggest that if experts are more reflexive about their own brand of the ‘politics of green manufacturing’, their proposed techniques for solving the waste problem will stand a greater chance of success.

What do we mean by ‘what and why’ questions? What would a ‘reflexive’ practice look like? To address those questions, we need to move beyond the obvious, because we can all agree it is evidently more sensible to reuse rather than renounce most of the by-products of industry and manufacturing. However, we know reuse remains a minority practice, and so we at least need to ask why recycling practices and green manufacturing (or a lack of them) continue to generate political and ethical controversies. Part of the answer must surely be to ask who is being mobilized into such reuse efforts and who is not. Once we acknowledge that mobilization question, it becomes wise to ask what roles should various publics play in how we imagine the development of our future industrial-consumer activities? With these ‘what and why’ questions in view, what would reflexive practice by experts look like in response to such a broad enquiry? For instance, should those experts routinely involved in industry and manufacturing adopt explicit political advocacy with respect to waste and recycling practices? If experts want to do so—which implies that they believe it to be democratically virtuous to clarify values-based positions and social goals along with technical options in public debate—few would disagree. Daniel Sarewitz spoke for many social scientists when he argued that clarifying values and politics alongside technical options is the route to a situation where “science is liberated to serve society and the environment” [3].

We admit such public discourse is often highly constrained and unfortunately not always pragmatically (or professionally) feasible. Values-based discourse can also, unfortunately, be hijacked by those capable of hiding their own politics while decrying the politics of others [4]. The climate change case is instructive here, for, in situations of deeply contested courses of social action, entering the realm of values debates and talking openly of contingencies and uncertainties can fuel misinformation about the reliability and status of knowledge claims [5–8]. Yet, rather than a focus on explicit political advocacy, we are talking about more subtle forms of political activity. Can experts reflect upon the implicit assumptions about the social and natural worlds which are built into their research agendas and design choices? To be reflexive is to not only be willing to interrogate the underlying assumptions guiding our practices, but to be inventive and creative in offering alternatives. Or, as critical realism theorist Margret Archer wrote, being reflexive is about “articulating to ourselves where we are placed, ascertaining where our interests lie and adumbrating schemes of future action” [9] (p. 9). Some attribute rather grandiose ambitions to being reflexive, such as the French sociologist Pierre Bourdieu suggesting reflexivity can help reveal to the researcher the relationship between ideas and cultural and economic structures [10]. The American sociologist Alvin Gouldner came closest to the sense of reflexivity we pursue here [11]. Gouldner argued that being reflexive is about thinking through the relationship between the role of researcher and the values and interests of the person performing the research, transforming one’s relationship to one’s work by breaking down too-easy segregations between our scholarly or technical work and our roles as citizens in ethical, political and environmental orders. Applying Gouldner’s insights to the case of green manufacturing, researchers would be encouraged to reflect on the quantities, qualities and origins of the resources and energy required to produce, distribute and dispose of different products. Researchers would also be encouraged to think more holistically about the likely ethical, political and environmental consequences of following certain design principles and pathways of technological development.

In the hope of provoking such reflexivity about what it is (or will be) to ‘do green manufacturing research’, we sketch a series of examples that allow us to illuminate some of the challenges facing recycling and green manufacturing; challenges that hinge on the gap between the best laid plans and social realities. We frame our discussion around some familiar topics, such as recycling bins and plastic pollution, so that we might focus attention on the moral economies which surround recycling and

reuse at scales ranging from local citizen action to transnational flows. Our intention is to highlight how assumptions about social realities and inattention to social realities both play a role in generating the gap between the best laid plans and successful efforts to socially integrate green manufacturing techniques. Ideally, our discussion can illuminate questions about the choices and visions driving innovation trajectories in the field of green manufacturing, especially as those choices and visions pertain to how the role of publics and governance regimes are envisioned in futures where green manufacturing plays a prominent role in consumer-industrial social orders. We ought to specify that our purpose is to try to articulate questions in need of collective deliberation rather than pretend we ourselves already possess all the answers.

2. Green Manufacturing: A Theoretical Big Picture

Before discussing recycling and green manufacturing activities, it is worth specifying that our line of questioning is inspired by approaches to technology and social action routinely deployed in the field of science and technology studies (STS); and, in particular, the social shaping of technology. From an STS perspective, it is not possible to adequately grasp the social and political implications of green manufacturing unless it is acknowledged that—like other technological practices—green manufacturing is much more than an interconnected series of scientific practices and engineered artefacts. Technology does not simply consist of material artefacts that are able to perform a variety of tasks. Technology also consists of the knowledge and skills required to create, produce, use and maintain it, and can therefore be better understood as consisting of a network of interlocking and partially inter-dependent socio-technical systems. Different technologies embody different knowledge systems and theoretical approaches about the way the world works, while the capacities of technical artefacts and socio-technical systems to perform different tasks and to be deployed in different socio-economic contexts are shaped, but not pre-determined, by their design features. Technologies are always open to interpretation and reinterpretation with respect to what they are and what they are not capable of doing by different individuals, groups and institutions. This is true of the design, implementation, diffusion and decommissioning stages of technological development. As the sociologist of technology Wiebe Bijker notes, such a reflexive approach to technology cautions against “assuming a single self-evident line of development of a technology” and instead recommends we describe a technology as “resulting from the interactions between different social groups” [12].

We know from numerous empirical case studies that the scale and prevalence of a technology are crucial to understanding its ability to shape, and be shaped by, wider social and environmental processes. The larger and more ubiquitous the socio-technical system, the less open it is to reinterpretation and restructuring, and the more it acquires momentum and the ability to shape its social and natural surroundings to conform to its requirements (often called ‘path-dependence’ in the innovation studies literature) [13–15]. Rather than being some (ontological) thesis about technologies as endlessly and irretrievably flexible, the STS account of technology in society focuses our analytic attention on the relationships between different technological forms and their surroundings, and the ways in which human beings are both liberated and constrained by the technologies that we and our predecessors have created. We know, for instance, that socio-technical systems can explicitly but also implicitly ascribe imagined and actual roles to human users, consumers and even bystanders [16].

The ascription of citizen roles can occur through the most mundane of technologies intersecting with everyday life, such as the way Velcro necessitates bodily practices (constantly adjusting it) to ensure the technology works properly, or the debates engendered by whether Velcro laces deny educational opportunities (the skills of shoe-lace-tying disappear) [17] (pp. 4–9). Such ascription of roles can also occur with much more complex technologies, as we can see in situations in which people cede their judgments to automated systems: a situation, some warn, is inherently dangerous wherever socio-technical systems are highly complex and have tightly coupled interconnecting components (as in the case of nuclear power) [18].

The social actors implicated in such technological ascriptions do not respond to technical artefacts and socio-technical systems as though they are simply rule-governed devices, unfolding and enacting their design and operating principles on their users. Instead, the development and concrete implementation of technologies necessarily involves ad hoc adaptations which can occur at multiple stages in their design, construction, distribution and utilization. How a technology works in the world is therefore not solely dependent on its effectiveness at performing its function. Although all functional technologies are constrained in their capacities by the laws of thermodynamics and the physics and chemistry of materials, they must also be responsive to the evolving practices of ‘surrounding social actors’, whether they are producers, regulators or users [19]. The extraordinarily rapid uptake and technical development of the mobile phone and the proliferation of mobile apps for a vast range of different purposes are clear illustrations of our point.

To understand changes in socio-technical systems, we must similarly understand how any potential change is going to be tied up with the diverse roles that a host of social actors are going to adopt at different scales of activity and in different cultural locations [20]. We also need to understand how potential socio-technical trajectories are constrained or promoted by structures and distributions of power [21].

If we view green manufacturing (and associated sustainability principles) as an embedded component of larger socio-technical systems, we are better able to appreciate its wider relations with surrounding technical infrastructures, knowledges and practices. The social shaping of technology also provides a theoretical framework for understanding how different values and interests not only inform the ‘downstream’ cultural practices of different publics interacting with technologies as users, but also the ‘upstream’ design and implementation of new technologies and technological pathways of development by business, industry and government. Put simply, it provides some sophisticated theoretical tools for better understanding the role of green manufacturing in contemporary industrial societies. This may be especially important for green manufacturing, which if successful is likely to occupy a crucial socio-technical space within a range of infrastructure technologies (such as energy, transport and water), which we already know involve a range of sometimes invisible and mundane services that have evolved substantially over time [22]. The concept of socio-technical systems also illuminates how path dependencies in the development of large technological systems constrain the possibilities for radical technological (and social) change [23–26]. Radical reform is nevertheless not only politically conceivable but achievable through taking advantage of what the Dutch political scientist Hein-Anton van der Heijden has called ‘political opportunity structures’. These are situations of varying duration which provide appropriate social contexts for political intervention [27].

It is also important to understand that, when opportunities for intervention do arise, reformist efforts should involve more than simply holding recalcitrant producers and service providers to account for poor or shoddy goods and services. Public concerns about technology and society go beyond instrumental concerns about impacts and risks and embrace democratic concerns about the need for innovation trajectories to incorporate broader human purposes and visions. Public concerns can be succinctly understood as questions about “upstream driving purposes, about the human ends of knowledge” [28] (pp. 217–218). Crucially, to reject or underplay the image we offer here of technology as an embedded component of broader cultural, political and economic processes is to reject the attendant redirection of attention from simple ‘downstream’ impacts and risks to ‘upstream’ human purposes, ends and visions.

The attitude we seek to promote presupposes that any form of deterministic explanation of technological change is inadequate. To explicitly disavow deterministic forms of explanation is to disavow “a key obstruction to diverse, distributed, direction-sensitive, and accountable technoscientific R&D and innovation” [29] (p. 67). Put in an active tense, to what degree will those involved in proposing techniques for green manufacturing think about the surrounding material constraints and enabling factors, public needs and desires, and structures of governance and decision-making that are inscribed in visions of how those techniques will ‘work’? The more one thinks through the

‘surroundings’, the more one thinks through potential obstacles and drivers, and the more one is encouraged to work with broader publics to identify and promote the human ends and visions which lie behind efforts toward green manufacturing.

3. Discussion

If we want to see green manufacturing as an embedded component of broader socio-technical systems, we need to link recycling, reuse and green manufacturing to surrounding practices, publics and institutions. Once we dig below the surface of waste reuse, we discover it is just as complicated at the national and global level as it is at the local level. In the next three sections, we therefore conceptually embed green manufacturing in its surroundings by focusing on waste streams at different scales. First, we outline the global contexts for green manufacturing through a comparison of the levels of waste and recycling across time and in multiple jurisdictions. Second, we then move onto the relatively personal level of municipal solid waste and individualized conceptions of waste so that we might better conceptualize green manufacturing at the local level. Drawing on a case study involving local government monitoring of household recycling practices in the UK, we explore the ways in which ‘a bin is not just a bin’. We will explain how the concrete implementation of a form of citizen monitoring of household waste disposal using the ubiquitous technology of the ‘wheelie-bin’ raises important questions about the ways in which seemingly mundane technologies can be used as proxy instruments of governance. Our discussion then ends with a third section, where we summarize what we have shown and branch out to canvass some of the opportunities for and obstacles to meaningful change.

We suggest that seeing technologies as implicated in how we govern ourselves might inform rather than distract from the design stage of green manufacturing innovation. Our overall intention is to reveal the extent to which contemporary moral economies of waste have de-coupled waste production from waste reuse. In effect, we are sounding a caution to green manufacturing innovators by noting that moral economies of reuse are tied up with social justice issues, basic disquiet about bureaucratic rule, and the net transfer of wealth from citizens to business and industry. We also explore what waste streams—such as plastics and e-waste—suggest about some of the challenges facing reuse ideals. Are our managerial aspirations for waste importantly limited? Do some waste streams point to the need to compliment downstream clean-up efforts with upstream production curtailments? We use the case of plastics to make the point and conclude with a brief critique of the ‘leave-it-to-business’ non-solution which continues to generate globally significant and unsustainable levels of municipal, agricultural and industrial waste.

3.1. Global Waste Streams: Moral Economies

As should become clear from the evidence we cite below, we are losing the battle to sensibly reuse waste. This is primarily because, when we try to implement waste reuse and recycling practices, we tend to run into various forms of non-compliance, here discussed as informalities and illegalities. The informalities and illegalities associated with recycling and waste disposal draw attention to the moral economies which our cultures attribute to and associate with different forms of consumption. It is therefore worthwhile to examine the recent history of waste management from such a perspective. As we will demonstrate below, there is a yawning gap between intentions and actions when it comes to levels of recycling and the quantities of manufactured goods and products going to waste.

Since the mid-1970s, the pressure to ‘reduce–reuse–recycle’ has been inspired by a number of (noble) inter-related environmental and public health concerns, including shortages of appropriate spaces for landfill. Over the last two decades, there has been a move to integrated waste management (IWM) in most developed countries, which is (at least theoretically) guided by four socially useful imperatives: public health, environmental protection, resource recovery and climate change [30]. However, these noble intentions sit within larger—what some would call ‘structural’—forces in our globalized world, which place limits (whether real or imagined) on possible developmental trajectories.

Throughout human history, the structural drivers of recycling efforts have been material shortages, economic constraints and cultural values.

When noble intentions and structural forces collide, it is probably to be expected that obstacles will appear that frustrate those noble intentions. These obstacles might be incumbent political and economic interests, antithetical cultural attitudes, adverse environmental factors, inadequate access to or availability of appropriate resources and/or labour, or the negative unintended consequences of earlier stages of implementation. For example, one of the unintended consequences of the mass production of consumer goods after the Second World War was a growing volume of packaging waste littering roadsides and recreational areas, prompting growing public concern. In an effort to pre-empt efforts by state and provincial legislatures to curb the production of disposable packaging, incumbent manufacturing industries in the United States began lobbying in the early 1950s for publicly-funded anti-litter information campaigns and municipal recycling. This strategy simultaneously enabled American manufacturing industries to appear to be good corporate citizens while shifting the onus of waste disposal firmly onto American consumers and public authorities [31]. When energy prices spiked in the early 1970s, canny manufacturers soon realized that massive reductions in energy use could be achieved from recycling glass, metal and paper, and consequently pushed for greater efforts by municipal authorities to collect these resources on their behalf.

However, as Martin Medina shows in *The World's Scavengers*, the complicated US example of burden shifting, profit-generation and reuse being mixed together for the benefit of manufacturers rather than the environment is not isolated to the US. On the contrary, it has become the model for a broader global dynamic. Medina documents the way informal economies have emerged around urban dumps, with recycling the economic engine, and that reuse tied up with informal economies is one of the most common forms of reuse to this day [32]. Green manufacturing proponents wishing to understand waste volumes as potential resources would be unwise to avoid consideration of the most common form of reuse, which in turn requires adequate consideration of the moral economies implicated in such informal recycling.

The informalities and illegalities surrounding waste recycling play havoc with abstract ideals of best practice. A good example is the recycling and disposal of electronic waste ('e-waste'), which has proven to be particularly problematic in many countries. In a global market estimated to be worth around \$40 billion annually, the UN has estimated that up to \$19 billion worth of e-waste is informally (including illegally) processed [33]. Another example is rubber from automotive tyres, which are not being recycled at anywhere near the levels at which the relevant products are being fabricated and discarded [34].

Such poor 'conversion rates' ought to be part of any consideration of the moral economies of waste recycling, because they pose the basic question of whether we are truly dealing with the problem we are creating. For example, because there is a lack of uniformity in the kinds of data that are being collected in many jurisdictions, and no international standards for waste data collection, large proportions of the waste stream from mining and agriculture remain uncertain or unknown with respect to their quantities and effects (except to those forced to live and work with those waste streams) [34]. The disposal of hazardous waste from mining, agriculture, transport, sewage treatment, health care and various manufacturing processes is better tracked but no less problematic [35]. In the European Union, around 100 million tonnes (Mt) of hazardous waste was generated in 2012—constituting around 10% of the total waste stream—but only 38.3% was recovered and 13.9% incinerated or used for energy recovery [36]. According to the US EPA, America produced around 38 Mt of hazardous waste in 2011, but less than 4% was recycled [37]. According to the Australian Government, Australia produced 6.2 Mt of hazardous waste in 2011, but only 4% was recycled [38].

The global ubiquity of plastic pollution is clearly one of the signal failures of contemporary waste management and international governance. Plastics made up at least 10% of solid waste by mass in 2005 (based on available data from 61 countries) [39]. It is estimated that only 8% to 9% is recycled [40]. Given the level of noble environmental rhetoric surrounding recycling, this poor conversion rate

for plastics is deeply troubling, because plastics make up by far the largest proportion of the waste stream that finds its ways into creeks, rivers, estuaries and oceans. Such stray plastics pose multiple health and ecological hazards, from endocrine disruption of the reproductive systems of mammals, birds and reptiles [41–44], to choking and strangling hazards for marine life [45], as well as acting as accumulators of other man-made toxins which are consumed by many kinds of animals, including human beings [46,47].

The case of plastics can further deepen considerations about the moral economies surrounding recycling, highlighting the power dynamics, patterns of inequality, and uneven environmental protection built into contemporary consumption patterns. Plastics are cheap, convenient and durable, and it is those very qualities which have led to their dominance in many areas of manufacturing which had once used natural materials. For example, nylon, rayon and vinyl for cotton, jute, hemp and wool; PVCs for ceramics, copper and steel; and PET and HDPE for glass, steel and aluminium. Industrial chemistry laboratories which had developed plastics during World War II were turned during the post-War era to civilian applications, creating a host of affordable consumer items that directly contributed to the exponential growth in economic and political power of the international petroleum and petrochemical industries in the latter half of the twentieth century [48].

With estimates ranging from 4% to 8% of total global oil production being dedicated to plastic manufacturing [49], many goods that had been made from natural substances can now be mass-produced and made available at a price that is affordable even to some of the world's poorest people. Although it is clear that this situation has benefited many, it has also created human dependencies on plastics which have generated extremely high levels of inert waste and logistical problems of substitution. The scholarly consensus is that the end of the Age of Oil is no more than two decades away [50–54], and yet comparatively little consideration has been given to what this will mean for plastic production and the recycling of plastics, most of which end up in landfill, or as roadside, beachside and ocean refuse.

The relevant empirical work on 'the problem of plastics' paints a sobering picture [39,55]. Plastic production has been growing at 5% annually for the last forty years, with around 300 million tonnes of plastic produced in 2013. This represents a 620% increase on 1975 production levels. Western Europeans and North Americans consume around 100 kg of plastic each year, compared with Asians, who consume around 20 kg, most of which is in the form of packaging. The top 20 countries' mismanaged plastic waste constituted 83% of the 2010 total.

The first rigorous study of global plastic pollution was published in the journal *Science* in February 2015. Of the 275 million tonnes of plastic waste produced by 2 billion people living in 192 coastal countries in 2010, the authors found that 5 to 13 million tonnes of this waste entered the world's oceans, or between 2% and 5% of the total. At any one time, they calculated that there is between 6,350 and 245,000 tonnes of plastic waste floating on the surface of the world's oceans [39]. A more recent systematic study increased the lower end and decreased the higher end of the estimate to between 93,000 and 236,000 tonnes [56]. About one-third of this is from China and another 10% from Indonesia [57].

Around 56% of global waste plastic exports have been flowing to China, most of which has been processed by low-tech, family-run businesses with little or no occupational health and safety measures or environmental controls, with low-quality plastics being dumped or incinerated for energy with inadequate air pollution controls [55,58]. With rapidly growing economies and grossly inadequate waste management systems, developing countries make up all but one of the top 20 worst offenders, the exception being the US. There are, therefore, compelling reasons for the public and private sectors to work together with civil society and international organizations in all of these countries to radically reduce the quantities of plastic waste ending up as ocean pollution.

In Australia, the first extensive survey of ocean beach pollution was conducted between 2011 and 2014, and included participation from the CSIRO, Earthwatch Australia, TeachWild and petroleum giant Shell [59–61]. This joint study covered the entire Australian coastline, and involved samples of

175 beaches taken every 100 km. The study found that more than 75% of the rubbish by volume was plastic, while 60% of the total consisted of plastic drink containers. Most of the offending waste was from Australia and had been illegally dumped or irresponsibly discarded by mariners and beachgoers. Around 600 marine species were found to have consumed this waste, ranging from sea birds to turtles, the latter being amongst the worst-affected. It found that 43% of seabirds had plastic in their guts and around 30% of sea turtles.

Jambeck et al. argue that a paradigm shift in waste management is required if the rapid growth of synthetic plastics in the waste stream is to be curtailed. Long-term solutions will need to include “waste reduction and ‘downstream’ waste management strategies such as expanded recovery systems and extended producer responsibility” [39] (p. 768). They also argue that the advanced industrialized countries need to not only provide substantial resources to assist developing countries to improve their waste management infrastructure but must take immediate action to reduce waste and curb the growth of single-use plastics. A crucial point which they overlook, however, is that the issue of waste production needs to become a mainstream political issue that is not just focused on ‘downstream’ issues. In addition, we need to also focus on ‘upstream’ issues of ecologically sensitive design and manufacturing of products and infrastructure, as well as the extraction, use, disposal and reuse of resources by manufacturing, mining, construction, agricultural and other industries, which too often are either ignored or relegated to the ‘too hard’ basket by government policymakers.

The examples (above) of the informalities afflicting Chinese plastics recycling, and the illegalities afflicting Australian plastics dumping, reinforce the compliance problems that need to be foregrounded in any discussion of the moral economies of recycling. Indeed, the issue of illicit waste disposal has been deemed sufficiently serious by the United Nations for it to have recently commissioned a report titled *Waste crime—waste risks: gaps in meeting the global waste challenge* (2015). The report points out that the global waste market is estimated to be worth more than \$400 billion annually, excluding the very substantial informal sector [62]. The sheer size and scale of that market provides ample opportunities for illegal activities at multiple stages of the waste chain. Amongst the causes of such activities are the “high costs of treating and disposing [of] hazardous and other wastes, weak environmental regulations, poor enforcement and low environmental awareness” [33].

We admit to being sceptical about bland calls to ‘leave it to business’ to ‘do the right thing’ when it comes to the moral economy of recycling. Despite the growing popularity of government and industry rhetoric about ‘clean manufacturing’, ‘industrial ecologies’, ‘total life-cycle assessment’ and ‘cradle-to-cradle design’—all of which can be seen as forms of ‘ecological modernization’—it is clear from the examples provided that many of the traditional dirty (and often illegal) practices of industrial production continue largely unabated. Even in those countries which have embraced regulatory reforms around cleaner production, whatever advantages these may have engendered for local production, the mobility of late modern capital has resulted in many of the dirtiest manufacturers in those countries simply moving offshore to jurisdictions with lower environmental and labour standards [63] (p. 6).

In those cases where such businesses do not vacate their home countries for ‘dirtier climes’, the illegal disposal of hazardous and toxic wastes within and across national borders continues to present them with ‘cheaper’ alternatives than tackling their problems at the source [64]. Part of the problem here is the ability of industry to find loopholes in standards and laws and exploit them. For instance, EU directives on waste management—which are infused with principles of sustainability and polluter pays—are amongst the most progressive in the world [64]. Yet, differences amongst EU member states over standards and requirements continue to provide loopholes for illegal disposal, some of which involves organized crime syndicates [65–68]. If an illegal waste shipment is detected, it must be returned to its source of origin or legally disposed of, with the waste producer bearing all costs. Recent research has revealed, however, that there is only a 6% probability of an illegal shipment being detected by law enforcement authorities, and that as much as 72% of waste bound for export outside the EU is probably illegal [64–68].

The irony of the current situation is manifest in Germany, because its recycling success has resulted in illegal landfilling and exports to France. Germany has been amongst the most successful of EU nations at increasing levels of recycling and reducing landfill through the implementation of the 'Green Dot' and other recycling and waste minimization programs in the 1990s. Yet, German recyclers have not been able to accommodate the volumes of waste received. Germany's intention to cease all landfill by 2020 will need to take into account the need for more recycling facilities and waste minimization measures within the country's own borders if it is to successfully overcome the problem of illegal dumping [69].

It is clear from these various examples that even the best waste management and recycling policies in the world are ineffective and ineffectual if law enforcement agencies are not adequately resourced to ensure compliance in the short term, and if there is a lack of investment in cultural and institutional change and social learning over the medium- to longer term [70]. In their *Global Waste Management Outlook 2015*, the United Nations Environment Program (UNEP) and the International Solid Waste Management Association (ISWA) argued on the basis of the available evidence that concerted action is cheaper than inaction. If the incremental costs of recycling a much higher proportion of the waste stream at \$5–7 per capita are compared with a likely cost of inaction of \$20–50 per capita or more, they argue that "it is reasonable to conclude that it is much cheaper for society as a whole to manage its waste now in an environmentally sound manner than to carry on dumping." [71] (p. 211). It follows from this that if green design principles were actually embedded in national manufacturing regulations and manufacturers were provided with rewards for compliance and appropriate punishments for non-compliance, much of this waste could be averted at the source. However, even these kinds of measures are unlikely to be successful over the longer term if manufacturers are able to shift their activities to jurisdictions with lower regulatory standards. The need for governments to promote and maintain processes of 'upstream engagement' with manufacturers at both a national and international level is therefore critical in addressing the growing waste problem confronting contemporary societies. Much like the current situation with global corporate tax avoidance, supranational laws and regulatory harmonization within and between national and sub-national jurisdictions will be required.

3.2. Local Waste Streams: Is a Bin Just a Bin?

In this section, we focus on the municipal solid waste (MSW) stream. If it is true that the success of green manufacturing is going to hinge on collaborative efforts to 'reform' waste—reusing waste and end-of-life products as raw materials—what does this imply at the local level? It is a reasonable bet that reforming waste at the local level is going to hinge on municipal collection efforts. However, at that point, we suggest that simple conceptions of the technologies of collection, as mute artefacts performing pre-designed services, should give way to more complex conceptions of technologies—such as recycling bins—as implicated in how we govern ourselves. Put simply, the technologies that form (and will form) the industrial feed-system of green manufacturing ought to be seen as tied up with social practices and governance relations. Innovation in the field of green manufacturing is (by extension) going to be an intervention in such broader practices. We suggest it better that green manufacturing innovators consider such interventions at the design stage of their thinking and practice, rather than trying to play catch-up with socio-political responses.

Such broad concerns derived from seemingly local matters make sense once we admit the centrality of local practices in considerations of waste streams. Contemporary waste management discourse conceives recycling efforts as consisting of three primary waste streams: construction and demolition (C&D), commercial and industrial (C&I), and domestic or residential. The vast majority of residential waste is treated by local governments as 'municipal solid waste' (MSW). Most of the available statistics on recycling pertain almost exclusively to this waste stream. Such local counting operations encourage us to define the problem of waste in terms of volumes, and of course at a local level, static bundles that have been left behind are visible problems. However, as the British anthropologist Mary Douglas

argued in her classic account of waste, to the extent that waste is matter-out-of-place, waste reflects a not-strictly-visible disorder that is in the process of being re-ordered [72].

Rather than conceiving of waste through the lens of static bundles in need of handling, what happens if we conceive of waste as something in the process of being re-ordered? First, waste as something in the process of being re-ordered supports our suggestion above that green manufacturing as a socio-technical system falls within the category of infrastructure technologies. If you see infrastructure technologies as “matter that enables the movement of other matter” [73], green manufacturing participates in the re-ordering (and movement) of waste. Second, the architecture of green manufacturing is going to be relatively unusual amongst infrastructure technologies, because what is being moved is a host of waste streams that represent secondary (i.e., already used) materials. Recycling practices can of course be conceived literally as the source of the materials used in green manufacturing, but in a broader sense are also more like social spaces for re-ordering by-products and unwanted matter. Below, we begin to talk about volumes, but we want our readers to imagine what would be implied if such volumes were conceived as indicating the magnitude of social spaces tied up with re-ordering by-products and unwanted matter.

First, however, a cautionary note about literal waste volumes: due to inconsistent statistics, definitions and data collection, it is difficult to provide definitive figures for global waste production and recycling. We should not respond to this fact by concluding that this is simply an artefact of incomplete accounting, a problem of knowledge-acquisition. We should, on the contrary, see it as possibly fundamental to the technological application of science. The sociologist of science Jerome Ravetz once argued non-knowledge can result from science. Because we have limited abilities for anticipating all of the consequences of our science- and technology-enabled interventions in the world, we are constantly expanding our ignorance at the same time as we are expanding our knowledge, making ignorance endemic to our commerce with the modern world [74]. Ravetz defined this kind of ignorance as “an absence of necessary knowledge concerning systems and cycles that exist out there in the natural world, but which exist only because of human activities” [75] (p. 217). Waste streams depicted as well-known might attain such governance visibility because of institutional dynamics to construct waste as a manageable object [76].

With that caution in mind about not ignoring the less-visible, we can begin to build our account of a bin not being just a bin by noting that the most counted form of waste stream is ‘municipal solid waste’ (MSW). In two recent international studies, one reported that 3 billion people living in urban areas produced 1.3 billion tonnes of MSW in 2010 [77], while the other reported that the 6.4 billion people living in 192 coastal countries produced 2.5 billion tonnes in the same year [39,78]. Some estimate this constitutes a tenfold increase over the past century, and if we take 2010 as a semi-random reference year, the scale of our collective waste problem is clearly expanding. This is reflected in the fact that the total volume of global solid waste—generated from urban households, commerce, industry and construction—is estimated at being between 7 and 10 billion tonnes, or between three and four times the quantity of municipal solid waste [79]. Based on current trends, this volume is expected to triple by the end of the century as western-style consumption habits and urbanization become more widespread [77,80,81]. Clearly, current levels of waste production are in no way sustainable and literally threaten to engulf humanity and our fellow species in mountains (and seas) of garbage.

What happens if we return to our proposed imaginary above and think of these estimates not in terms of volumes of waste but as pointers to the magnitude of social spaces tied up with the re-ordering of waste? What emerges is a picture of a vast series of ongoing political contestations, with attendant practices of making some social practices visible and others invisible. What emerge are opportunities for intervention in how to re-order geopolitical spaces, at scales ranging from the local to the municipal and the national to the global.

Such incipient political contestations are unearthed once we move away from abstract populations and tonnes and make our analysis of volumes more personal. At the personal level, we find that recycling waste is always tied up with moral economies that have geopolitically framed degrees of

visibility. Take residential waste in industrialized countries, for example. For many, seeing beyond volumes is difficult because our green ways are apparently pre-defined by coloured bins into which we sort our waste. If we exceed our quota, we can drive down to the local recycling centre, dropping off a designated amount of garden waste per visit or deposit other recyclables (such as plastics or e-waste) per volume (for which we pay, per volume). More than half of the residential waste in industrialized countries consists primarily of paper products and biodegradable substances such as food and garden waste, with metals, glass and plastics making up a significant proportion of the remainder. Consequently, the main emphasis in the domestic waste stream has been on recycling paper, glass, metals and a handful of plastics.

In the relatively-privileged 'Global North', what is most visible is thus the downloading of recycling responsibility from manufacturers onto the due diligence and sorting capacities of ordinary publics, assisted by municipally organized collection services. For the most part, this is a series of formal operations, modelled on throw-away practices, where citizens dispose in controlled ways and municipalities collect according to rates-based social contracts. Observing the visibility of these throw-away practices is nothing new; Vance Packard's classic *The Waste Makers* analysed them as an effect of over-consumption [82]. However, the sheer volumes alluded to above can easily become invisible to urban and rural disposers of waste, a kind of civic fallacy of composition whereby waste is quietly and smoothly transported to recycling bins and lodged regularly in the drive-way to be collected, often without further thought to the implications of everyone doing the same.

Green manufacturing proponents can infer from such relatively thoughtless disposal that the attitudes and behaviours of households ought to be a key target for policy-making about recycling. However, do arguments exist which point beyond individual behaviours and attitudes as the focus of policy and thus beyond individual behaviours and attitudes when setting R&D agendas for green manufacturing? If single technologies are regarded as embedded components of larger socio-technical systems, the recycling technologies involved in capturing the future resources for green manufacturing need to be seen as not just artefacts fulfilling some pre-designed purpose, but as surrounded by other practices. Put simply, a (typically coloured recycling) bin is not just a bin. Indeed, diverse perspectives on the way technologies, choices and governance strongly interact suggest that a bin is, indeed, not just a bin.

Recalling our earlier articulation of the social shaping of technology perspective on technology, one can explore the way technologies are implicated in social governance practices without assuming a deterministic account of technology [83–85]. Instead, one only needs to highlight the way technologies are rarely if ever neutral, and can thus form part of power structures operating either over or through citizen-subjects. For example, a bin is still not just a bin even in libertarian conceptions of contemporary social life. Thus, Richard Thaler and Cass Sunstein's bestselling *Nudge*, advertised as a libertarian-paternalist way of nudging citizens toward better decisions, discusses 'choice architecture' as involving anyone who "has the responsibility for organizing the context in which people make decisions" [86] (p. 3). Crucially, choice architecture is said to be ubiquitous and inevitable; structured choices abound: there is no neutral design of user and product relations. From their disciplinary positions in economics and law, Thaler and Sunstein conclude—whether playfully or seriously is open to interpretation—that it is in fact irresponsible not to nudge. Closer to our concerns is the way power can act through deployments of, or engagements with, technologies. For example, the sociologist Mitchell Dean's *Governmentality* focuses on how state and non-state actors "try to shape, sculpt, mobilize and work through the choices, desires, aspirations, needs, wants and lifestyles of individuals and groups" [87] (p. 20). Technologies figure prominently in such sculpting, as they can facilitate indirect modes of governance that turn on target setting, monitoring and evaluating.

In their book, *Mundane Governance*, sociologists of science Steve Woolgar and Daniel Neyland argue similarly, noting that understanding contemporary governance involves understanding how our lives are regulated through the intermediaries of everyday objects and technologies [88]. So-called 'wheelie bins' are ostensibly ways of regulating household rubbish, but such mundane objects also

“participate in governing our lives.” [89] Woolgar and Neyland thus tell several stories about the roll out of wheelie bins in the UK [88]. One story involves the monitoring noted above, in which residents were outraged to find microchips in the bins to weigh and evaluate household rubbish. A bin was not just a bin, but a tool for information collection for some and a bureaucratic intrusion into private domains for others. A second story involved a woman who was fined by her local council for (allegedly) using the wrong bag for her rubbish. Woolgar and Neyland note the context for the fine was a broader battle between those concerned about the intrusions of a nanny state and those concerned not enough was being done to either encourage citizens to be more responsive, or to direct attention to manufacturers of waste rather than citizens dealing with waste. However, Woolgar and Neyland’s main point is not to invoke that context to explain the dispute, but to show how the context itself was constitutive of the objects, i.e., how the meaning and significance attributed to the wheelie bins and rubbish bags was a product of the values and interests of the actors involved.

Woolgar and Neyland’s discussion highlights an important sense in which a bin is not just a bin. In the conflict outlined above, the political overtones of the conflict are sustained by the contrast drawn between the council and the fined-woman, with each in pitched battle over apparently the same object. If the interpretation of the meaning of an object is stable, different individuals or groups can construct their actions towards it as ‘normal’ and ‘appropriate’, and thus as politically legitimate. For example, when the fined-woman stated that ‘a bag is just a bag’, she was asserting that her recycling practices were based on conventions about what were generally considered to be legitimate practices, while the council’s demands were a bit odd (given the apparently ordinary character of bags) and therefore illegitimate. Woolgar and Neyland are not so much concerned to be ironic (each social combatant is responding to a different object). Instead, they want to highlight the way struggles over ordinary objects like bags are simultaneously struggles over what are appropriate or inappropriate actions with regard to what the object actually is, and who can say what about it. Technologies are like focal points for imputations of moral orders of accountability, and by extension, social power. The lesson that Woolgar and Neyland’s story of the bag holds is that, if we enlarge their discussion to the general category of recycling bins, such civic collection points for recovering waste are not mute objects around which politics will swirl. Rather, politics is being created as we attempt to achieve closure about the character of the objects in our surroundings; different social actors will construct a bin as ordinary to facilitate political claims about how people should behave in their presence.

Woolgar and Neyland’s brand of ontological politics will appeal to those who are inclined to think a technology can become the battle ground for creating political action, but who are also inclined to think incoherence, uncertainty and complexity will follow from a creative reworking of rules as mundane objects get sucked into messy governance endeavours. For green manufacturing innovators, can these insights help inform how ‘noise’ in the waste stream is conceived, how community engagement about recycling practices is structured, and how much orderliness is expected in and around technologies for re-ordering waste?

A final observation—or provocation—for this sub-section is to note that Woolgar and Neyland’s conception of bins as not just bins is closer to the ‘power through’ than ‘power over’ spectrum of positions on technology. Although a recycling bin can certainly be conceived as embodying ‘power over’ residents and businesses, in the sense that the regulations and conventions in which it is embedded are intended to compel (or at least, encourage) compliance, bins arguably embody a much wider set of social relations and assumptions. Here, we recall Langdon Winner’s argument, cited above, wherein technologies can either contingently carry aspects of social order (they can be built to perpetuate the privilege, power and authority of some over others), or be inherently political (either require or be strongly compatible with particular social relations and political arrangements) [85]. Recycling bins can certainly be placed into one or the other of those categories if one considers environmental psychologist Cindi Katz’s argument that to “focus on the scale of individual recycling . . . often serves to efface the much broader realm wherein environmental problems are produced and to lull people into a problematic sense of security . . . While we recycle frantically . . . industry . . . can

pollute . . . with abandon . . . it also represents a net economic transfer from individuals to businesses. Corporate responsibility for dirty production is individualized" [90] (p. 52).

Katz' critique should not be read as an expression of opposition to recycling efforts per se. She is instead suggesting that business and industry should not be let off the hook for continuing their dirty and wasteful practices and socializing the costs. In other words, consciousness cleansing (by citizens, business or industry) should not be encouraged as a substitute for effective environmental action.

The nub of the issue is that, while recycling can be good for the environment, the development of recycling efforts in most industrialized and advanced industrialized countries during the post-War period has been driven by what is considered good for business. Recalling the recommendation from earlier in the paper about the virtues of articulating value judgments in public, strictly avoiding the 'business case' can look like a form of greenwashing of corporate profit motives. As Katz quipped, "with so much green, I start to see red" [90] (p. 52). There are, as discussed in the previous section, issues of moral economies tied up with recycling, so that a recycling bin wrapped in a green cloth of environmental concern might seem like an act of obfuscation to some. For those who choose to interpret the meaning of a recycling bin in this way, we might well expect its presence in their lives to generate the kind of disruptive behaviour discussed by Woolgar and Neyland. A bin, then, is not just a bin, even if it is constructed as completely ordinary and simple.

In his *Tools for Conviviality*, Ivan Illich argued that tools were convivial when they could be easily used by anyone at any time for the accomplishment of a purpose intimately chosen by the user [91]. Convivial tools are thus accessible, flexible and non-coercive. Bins for materials recycling and organic waste can be thought of as deceptively convivial to the extent that their ease and flexibility of use mask the fact that the user might be a delegate of governance control over what goes into the bins and what might otherwise remain invisible (the masking of continued dirty production?).

3.3. *Where to Now?*

Once we accept that green manufacturing is an embedded component of broader socio-technical systems, several important considerations for fully understanding that socio-technical system arise. One, that while green manufacturing is (thus far) a small component of modern industry, the wasteful practices it seeks to ameliorate are conditioned by contingent political, cultural and economic considerations, many of which are entrenched and systemic. Two, governments, policy-makers and waste producers need to carefully consider how recycling and waste recovery agendas mesh with on-the-ground industrial and social practices, as well as broader environmental concerns at the national and international level. Three, to fully understand recycling practices and the associated ways those practices have the potential to form a feedstock for green manufacturing, we need to pay attention to the various scales—individual citizen, municipal, regional, national and global—at which reuse practices occur.

We also advocated the virtues of subtle forms of reflexive political advocacy, in recognition of the fact that the technical mastery of green manufacturing techniques and processes is not going to be sufficient to drive meaningful change. Widespread social change depends on the way our techniques are incorporated into our practices and often on the way our social practices lend legitimacy to certain kinds of technical interventions in them. We thus encourage green manufacturing researchers to take note of social science research on the factors relevant to meaningful social learning. For instance, the sociologists Marcus Hadler and Max Haller (2011) found that whereas private behaviour is primarily shaped by local contexts, public behaviour tends to be similar across countries. They argue that, whereas the global context for environmental awareness has been driven by international treaties, transnational social movements and government and non-government organizations, national awareness has tended to be driven by issues that have become the focus of local and national social movements [92]. Especially important to our concerns here is Hadler and Haller's finding that "[t]he institutionalization of environmental protection by—for example—establishing environmental ministries, protected environment resorts, availability of recycling and so on, will shape individual

behavior in all polities" [92] (p. 320). Can scientists and engineers involved in green manufacturing therefore reliably avoid getting somewhat political about their ideals, if social science research demonstrates that citizen uptake of recycling practices is intimately affected by various forms of political organization and governance regimes?

The targets of scientists and engineers' overtures will of course have to be specific. Handler and Haller found that private environmental behavior is influenced more strongly by governmental linkages, while public behavior is influenced more strongly by non-governmental linkages [92] (p. 318). Polities which place a strong demand on individuals to act as public agents result in a high level of public environmental behaviour, while the stronger the institutionalization of environmental protection, the more prevalent are both public and private environmental behaviours [92,93]. Or, put differently: if in effect we are asking citizens to act as public agents to usher in green manufacturing, is it too much of a stretch for scientists and engineers to also act as public agents (with the implied greater advocacy than normal injunctions to be 'apolitical')? Of course, we do not mean to imply that the burden of change should all fall on citizens as public agents (scientists and non-scientists included). Hence, we have also argued for the importance of attending to the structural issues of socially-embedded values, norms and practices, along with the peculiarities of various institutional and regulatory regimes, if we are serious in our commitment to driving the requisite social and economic changes.

Ultimately, there are several courses of action that our analysis suggests are good candidates around which to build a green manufacturing and recycling agenda. First is the need to focus on the reduction, capture and recycling of plastic waste: it is deeply disturbing that the plastics and packaging industry has been given such license to pollute our oceans and marine life. Second is the need to focus on the reduction and recycling of e-waste, which is becoming a growing problem due to the rapid obsolescence of many electronic devices. Third is the need to rethink the way recycling efforts are actually monitored and enforced once the relevant waste is collected: non-compliance and illegal dumping remain attractive alternatives for unscrupulous businesses and industries. Fourth is the need to admit that corporate voluntarism is inadequate to the task of making industrial production accountable to public scrutiny. Instead we require waste and energy auditing and regulatory work to establish sufficient monitoring and enforcement procedures. The fact that whole industries in the US and elsewhere are not subject to any requirement to keep records of their waste or energy use is an invitation to pollute with impunity.

4. Conclusions

Unfortunately, in Australia and internationally, there are a number of pressing issues around waste, recycling and industrial production which are generally given little to no priority by governments and industries primarily focused on economic growth and increased profits. Given the volumes of waste that continue to be produced by industrialized countries, and the compliance and conversion issues noted above, a key question that needs to be addressed is whether current attention to practices like green manufacturing reflect a tinkering at the edges of an unsustainable mode of production, or a fundamental rejigging of industrial production? In our judgement, there is little evidence that recycling practices in developed countries constitute a social movement strategy aimed at challenging industrial capitalism (thought of as a wasteful and unsustainable socio-economic system). Green manufacturing is instead, at least at this point, a modest attempt to tinker at the edge of that industrial capitalist system. Those concerned to develop a 'circular economy' suggest that one of the main challenges for industrial capitalism in the 21st century is going to be whether it can decouple waste generation and energy consumption from economic growth [94]. Whether this is a feasible goal remains hotly disputed, but in this article we have highlighted the currently delusory nature of claims for 'green capitalism'.

To conclude, while notions of 'green capitalism' recognize the importance of behavioural change, they tend to avoid any serious consideration of direct regulatory measures as a means of driving 'green' innovation in the manufacturing sector. Providing sufficient incentive to improve industrial capitalism according to principles of environmental and social justice will necessarily involve making concerted

efforts to refashion popular tastes and attitudes. However, we also need to revisit our images of proper governance. Corporate voluntarism is the idea we arrive at when we fail to be critically reflexive about the limitations of political ideologies (such as neoliberalism) that make a virtue of cutting ‘red tape’. Our refusal to acknowledge that ‘good regulation’ is not synonymous with ‘no regulation’ or ‘self-regulation’ will undoubtedly leave our societies facing the prospect of literally swimming in our own waste. The sciences and the arts are sometimes represented as two cultures engaged in mutual misunderstanding. But in the green manufacturing case both professional ‘cultures’ share an interest in ‘upstream engagement’. Green manufacturers’ desire to reduce waste at the source is the right way to go, and our (social scientist) contribution to such efforts is to flag the necessity of coupling technical solutions to deliberation about the driving purposes behind knowledge formation and the desired ends of knowledge application. We hope this overlap of aims, a shared interest in forms of upstream engagement about the kinds of societies we are all building, can help produce constructive exchanges between social and natural scientists and engineers about how to manufacture a better planet.

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77. Hoornweg, D.; Bhada-Tata, P. *What a Waste: A Global Review of Solid Waste Management*; Urban Development Series Knowledge Papers, No. 15; The World Bank: Washington, DC, USA, 2012. This translates into 430 kg per person in 2010.
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