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Topic Insights

Green Processes: Transforming Waste into Valuable Resources

Veena Sahajwalla

Australian Research Council (ARC) Laureate Professor; Director of ARC Green Manufacturing Research Hub; Director of the Centre for Sustainable Materials Research and Technology (SMaRT) at UNSW Sydney, Australia

1. Introduction

Over the next few years, the manufacturing industry worldwide will face intense challenges, as finite supplies of raw materials dwindle and the cheap energy from fossil fuels becomes scarcer. Many conventional manufacturing processes will be outlawed on environmental grounds. For engineers and scientists, these interrelated problems also present an enormous opportunity. Robust new technologies are needed: They must be cost effective and energy efficient, and they must minimize pollution.

A major part of the solution may lie in another global problem—the rapid accumulation of industrial waste, which is sometimes toxic. Research must focus on discovering "green processes"—simple, sustainable ways of converting end-of-life materials into new resources for manufacturing. The machinery to implement these new processes must be easy to construct and widely available. The social benefits of alleviating both problems at once are incalculable; such a solution offers a win–win outcome in the areas of the "three E's"—engineering, economics, and the environment.

2. The science and technology of green processes

Green processes enable a complex waste stream to be transformed into value-added resources, which can then feed an industrial supply chain. One example is the enhanced recovery of rare earth elements from lamp phosphor waste. Belgian researchers recently discovered two green processes that improve recycling yield by 60% and 98%, respectively, and identified the changes in crystalline state that cause this phenomenon (Steff Van Loy et al., this special issue).

Green manufacturing processes may not be vertically integrated in a conventional supply of raw materials, but we can create new supply chains by processing waste to generate alternative feedstock, which can then be laterally integrated. Wastes are packed with useful resources such as carbon, hydrogen, silica, metals, and organic components that would otherwise have to be sourced from virgin raw materials. By working out how to integrate recycled resources into industrial processes, we can address the twin challenges of waste and supply in parallel, creating additional value.

Other researchers are looking for alternative sources of energy for industry. Coal-derived liquid fuels, for example, could be used instead of petroleum-based hydrocarbons. Two options that are potentially more sustainable than fossil fuels are hydrocarbons produced from alternative feedstocks, such as biofuels, and carbon-free energy carriers, such as hydrogen, batteries, and supercapacitors. In the United States, food waste generates 3.4×10^7 t of CO_2 equivalent, and its disposal costs 1.9 billion USD; researchers in Indiana are investigating how nutraceuticals and bioactive compounds can be extracted from this food waste, converted to volatile acids or methane, and sold at a profit (Raymond RedCorn et al., this special issue).

Renewable energy from solar, wind, tidal, and bioenergy sources can all be converted by electrolysis into fuel cells, which may well be more efficient and effective alternatives to internal combustion engines, boilers, and batteries. Canadian and Chinese researchers are examining how a mass adoption of fuel cells could transform the green economy (Junye Wang et al., this special issue).

Another team at East China University of Science and Technology considers the safe extraction of reusable materials from organic waste liquid to be "one of the frontiers of environmental engineering." They suggest a new cyclonic gas-stripping method to separate organic matter from waste liquid, and an airflow acceleration process to classify inorganic matter. These processes would recover substantial quantities of diesel fuel along with the active catalyst used for purification, and would reduce the amount of fresh catalyst needed (Hualin Wang et al., this special issue).

Green technology and research will raise the standards of disinfection, decontamination, recycling, and reuse. They will help to safeguard the environment and cut pollution and costs—not only in the industrialized world, but also in the emerging world, where less energy-intensive technologies are urgently needed.

3. Raw materials and waste utilization

Engineering projects are voracious consumers of raw materials, which need to be affordable, reliable, and fit for the purpose. Consequently, much recent research has been driven by the pressing need to develop products and processes that can use low-cost resources, including those recovered from industrial waste. Many valuable materials are embedded in different waste streams, such as e-waste, automotive and industrial waste, and municipal waste. Two American researchers are working on a hydrothermal

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liquefaction (HTL) process to convert carbon-containing general waste into a basic bio-oil, followed by electrochemical processes to transform the bio-oil into a fuel or chemicals that might act as substitutes for petroleum products (Robert S. Weber and Johnathan E. Holladay, this special issue).

Fundamental changes in global attitudes to resource management and waste mean that all industrial processes should be systematically reassessed to determine their sustainability. Researchers in South Africa argue that industrial plants and machinery should be routinely subjected to an asset life-cycle management (ALCM) program [1]. They believe that the optimum value from physical assets over the lifetime of a facility is best achieved by operational reliability and systems engineering.

It is also important to avoid wasting costly resources. In recent years, engineering and/or environmental management tools have been integrated into many industrial processes. Several are covered in this special issue, including automation, information technology, digital and artificial intelligence, and multidisciplinary technology, which can be an effective route to cleaner production and sustainable development. One study proposes an online, real-time, non-contact monitoring method for a large quantity of a complex liquid. This process replaces expensive and time-consuming lab testing of samples with intelligent optical analysis, and could be applied to many other manufacturing processes (Ning Duan et al., this special issue).

Another study illustrates how intelligent, unmanned control technology can be used to operate an underground metal mine (Jian-guo Li and Kai Zhan, this special issue). If environmental considerations are coupled with engineering processes, recyclable materials can be selected for use, while unusual or hazardous ones can be avoided, removed, or safely transferred to other feedstocks—probably reducing damage to the environment. For example, goethite is a metals-rich residue that occurs during zinc production. Recovery of the metals is possible but not financially viable, so the goethite is usually consigned to landfill, which is costly and environmentally hazardous. In this special issue, researchers explain an innovative valorization strategy that liberates the zinc in the goethite, producing a clean byproduct that can be used as a novel building material (Andrea Di Maria and Karel Van Acker, this special issue).

When recovering resources from waste, it is vital that the processes employed do not have side effects that are harmful to human health or the environment. Carbon dioxide (CO_2) foam is commonly used in enhanced oil recovery and its operation can be made more efficient by various additives; researchers in North Carolina are aiming to develop biodegradable and non-toxic foaming agents (Jennifer A. Clark and Erik E. Santiso, this special issue).

4. Green chemistry at the SMaRT Centre, UNSW Sydney

Our own work at the SMaRT Centre focuses on discovering innovative ways of treating waste streams sustainably to create valuable resources. Our electronic arc furnace (EAF) process, in which used automotive tires replace fossil fuels in "green steelmaking," has already saved over 10 million tires from landfill. We have created "microfactories" (as small as 50 m^2) for local application in both advanced and developing economies, where metal alloys and a range of nanoparticles suitable for use in industrial ceramics are recovered from e-waste. The plastics from computers, printers, and so forth can be transformed into filaments for use in three-dimensional (3D) printing applications. Our future projects include research into new ways of recycling batteries, and always incorporate consideration for the environment. Like medical doctors, our first concern is to "do no harm"; however, our green processes must be good business as well.

5. Conclusion

The challenges faced by humankind are enormous and unprecedented. The industrialized world can no longer rely on its ability to draw new resources from the earth and the oceans. It is no longer safe to exploit those resources without regard to detrimental, potentially disastrous effects such as climate change or catastrophic damage to water or food supplies. Traditional sources of energy are no longer environmentally acceptable. A radical new approach is urgently required.

There is ample evidence in this special issue that scientists all over the world are rising to these challenges: Green processes are being developed in many areas, entrenched attitudes to waste and conservation are being overturned, and we are learning that sustainability is key to prosperity. Science alone is not enough. The many innovative technologies from research labs need to be understood, accepted, and then applied. This can only be achieved in close collaboration with our colleagues, the engineers, who have the skills required to scale up the many new discoveries of green chemistry and apply them in real-world situations. There is a strong synergy between the "three E's." We must preserve our environment and improve our economics—for which we need a wholehearted commitment from engineering.

Reference

[1] Schuman CA, Brent AC. Asset life cycle management: towards improving physical asset performance in the process industry. Int J Oper Prod Manag 2005;25(6):566–79.