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The Power of Steelmaking – harnessing high temperature reactions to transform waste into raw material resources

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ABSTRACT

Iron and steelmaking processes present a largely untapped opportunity to transform some of the world's most problematic waste streams into raw materials for production. This opportunity lies in their high temperatures environments, which offer sustainable pathways for utilising chemical reactions to re-purpose waste materials as resources; such as reducing iron oxide to iron and dissolving the carbon in waste materials into metal. High temperature environments can be leveraged to revolutionise the role steelmakers play in globally significant, large scale recycling, *without* making fundamental changes to manufacturing processes. This presentation describes the broad opportunities available to iron and steelmakers to utilise waste streams – ranging from polymeric materials to agricultural wastes -- as raw materials. The potential to implement such novel recycling solutions are not generally available to many other materials industries because they operate at relatively lower temperatures, which may not be suitable for triggering useful chemical transformations.

Recycling waste polymeric materials in steelmaking is one solution for end-of-life products, which currently impose a serious burden on overstretched landfills, as is the case with some plastics. Specifically, the lecture will present fundamental understanding of different plastic wastes -- melamine, high-density polyethylene, polycarbonate and Bakelite, as well as agricultural waste and tyres – and their transformations and chemical reactions at high temperatures. Plant results from EAF steelmaking in Sydney, Australia, where recycling waste is now standard practice, will also be included.

1. INTRODUCTION

Dr Henry Marion Howe is most often remembered for his key role in transforming steelmaking "from an art into a science" through his exceptional powers of observation and deduction. However, another important theme also runs through accounts of his life. That is his boundless enthusiasm for the "possibilities" of steelmaking into the future. As C.D. King remarked in delivering the Howe Memorial Lecture in 1954: "Those who knew him well have said he derived particular pleasure from speculations on the future world of metallurgy[i]." In this year's lecture I hope to honour both Professor Howe's dedication to "doing the science" *and* to thinking creatively and expansively about future opportunities for steelmakers; in light of the particular challenges steelmakers are facing into the 21st century.

My proposition is that today's steelmakers have a largely untapped opportunity, not generally available to other large industries, to make a meaningful contribution to solving the world's growing waste problem. That opportunity lies in the high temperatures we work with. We can use high temperatures to revolutionise the role steelmakers play in globally significant, large scale recycling, *without* making fundamental changes to the way we manufacture steel. We can achieve this by re-purposing major waste streams as raw materials for steelmaking, simultaneously reducing our own production costs and enhancing our sector's environmental credentials. I am not suggesting we burn waste for energy, which is well established. What I am proposing is that we leverage high temperatures to trigger useful chemical reactions to literally re-form waste materials into resources.

At UNSW's Centre for Sustainable Materials (SMART@UNSW) our research focuses on carbon transformation with the goal of realising such commercially viable opportunities to transform waste. In a practical sense that means utilising carbon-bearing waste streams like end of life plastics, used tyres and agricultural waste -- which pose serious problems worldwide -- as alternative sources of carbon. At SMaRT@UNSW, which I head, we have collaborated with OneSteel (now Arrium Ltd) over several years in pursuit of this goal, with good results. Our commercialised Polymer Injection Technology (PIT) allows OneSteel to substitute a meaningful proportion of coke in its electric arc furnaces with a precisely calibrated mix of granulated end of life polymers, as a carbon injectant. The result is a novel recycling solution, which transforms problematic waste and reduces the cost of raw materials for the steelmaker. The new polymer-coke mix also improves the foaminess of the slag, and therefore, furnace efficiency. The incorporation of *PIT* into OneSteel's commercial furnaces over the last five years has achieved a 12-16 per cent reduction in coke consumption, generated significant power savings and absorbed large amounts of waste[ii]. To date, over 1.6 million tyres have been diverted from landfill into value-added steel products.

The concept behind this proven PIT, however, has significant potential beyond this particular case study, which means the opportunity for steelmakers is similarly far reaching. Steelmakers can transform "waste to value". What I am suggesting is a revolution in waste recycling. High temperature reactions offer an important addition to the environmental 3Rs (Reduce, Reuse, Recycle). We are now proposing a fourth "R", that is; RE-FORM. This is a paradigm shift in the way we think about waste materials because they can now be considered as potential raw materials that can be effectively reformed through chemical reactions into resources for industry. This is a novel, industrial scale recycling revolution that the steel industry has the potential to lead – as long as we are willing to take on a leadership role and to recognize that waste offers a manageable, cost effective solution to the some of the challenges we face into a carbon-constrained future. At SMaRT@UNSW we are, in the tradition of Dr Howe, observing various high temperature reactions and then "doing the science" to understand how and why such potentially useful transformations occur. This paper includes fundamental understanding of different waste plastics -- melamine, HDPE, polycarbonate and Bakelite, as well as agricultural waste and tyres – and their transformations and chemical reactions at high temperatures, as well as results from EAF steelmaking in Sydney, Australia, where recycling end of life polymers is now standard practice.

Waste to value; converting a problem into an opportunity.

The impetus for researchers and steelmakers to innovate has probably never been greater. Globally, the cost of raw materials continues to rise, while on the sales side pressures for competitive pricing are only intensifying. And despite the world's ever increasing appetite for steel, producers are under pressure globally to reduce the industry's environmental footprint. The steel industry accounts for 3-4 per cent of greenhouse gas emissions worldwide and, on average, 1.7 tonnes of carbon dioxide are emitted for every tonne of steel produced. Meanwhile, various carbon-pricing schemes are due to be implemented in 33 countries and 18 sub-national jurisdictions by the end of this 2013[iii], covering some 850 million people and around 30 per cent of the global economy. These are clearly incompatible trends which, if we persist with business as usual, will only increase tensions for the industry. Consequently, there is an important place in steelmaking for alternative carbon-bearing materials.

Conversely, waste stockpiles – ranging from polymeric materials to agricultural wastes -- are accumulating at a rapidly increasing rate, reflecting the pace of economic activity, shorter replacement cycles for goods and infrastructure and the increasing intensity of global trade and transportation. In the US, the EPA reported over 31 million tons of plastic waste generated in 2011, with a recycling rate of just 8 per cent. In Australia, the total volume of waste generated per capita is about 2/3[rds] that of the US. However, of the 1.4 million tonnes of plastic waste generated in 2010-2011 just over 20 per cent was recycled[iv], with the bulk going to landfill. Used tyres, likewise, are not biodegradable and represent a significant and growing waste burden, with the additional complication of their potential to leach toxic chemicals into the environment. Of the approximately 20 million passenger tyres requiring disposal in Australia every year, only 23% are recycled, 64% go to landfill and the remainder are dumped illegally[v]. In some states in Australia, tyres are now banned from landfill sites due to their toxicity[vi]. Worldwide, about 1.2 billion used tyres are thrown away annually and four billion or so waste tyres are currently in landfills and stockpiles, posing a risk to human health and the environment.

Yet, such waste materials consist mainly of carbon and hydrogen; elements vital in the metallurgical industries due to their role as reductants/carburizers. These long chain hydrocarbons consist of highly volatile matter with generally low ash content. This means steelmakers have an opportunity to use waste streams to source free or low cost raw materials for production. The incentives for local governments and other industries to make such waste streams available for steel production are considerable given steep landfill charges and tight anti-dumping regulations. In NSW, the state where UNSW is based, the gate cost for disposing of rubbish in landfill was $80.30/tonne in 2012 and is pegged to increase $10/year plus CPI to drive local recycling[vii]. One perverse consequence has been the long distance trucking of waste to Queensland in the north to take advantage of lower tip gate fees;

a more desirable outcome would be the provision of useful waste to steelmakers. In the US, tipping fees also vary considerably -- from US$18.43 per ton of solid waste in Idaho to $105.40 per ton in Massachusetts last year[viii]. However, there is one common thread; the cost to disposing of many carbon-bearing wastes, which could otherwise be utilised in steelmaking, is steadily increasing.

To date, the steel industry has adopted various methods for incorporating waste materials, primarily taking into consideration the potential for energy to be released during high temperature reactions. However, plastics have been reported as raw materials in composite iron making pellets. Ueki *et al.*[ix] investigated reduction behaviour during the heating of waste plastic materials and iron oxide composites in the temperature range 1000-1300 °C. Reduced iron was obtained by heating PE/refuse derived fuel and iron oxide mixtures and Ueki *et al*. concluded that higher fractional reduction could be attained by increasing the temperature. Matsuda *et al.*[x,xi] reported the reduction behaviour of iron oxide by waste PE plastics and wood at temperatures of 1200 and 1600°C. The metal yield showed a maximum at C/O ratio≈1 for a PE-hematite mixture while the maximum C/O ratio for wood mixtures was seen to be 0.75. Polymeric materials have been considered in coke ovens as well as in blast furnaces[xii]. Shredded polymer wastes were directly mixed with the burden in NKK Japan[xiii]. Stahlwerke Bremen in Germany has substituted coke, coal and heavy oils with waste plastics since 1996[xiv]. Waste tyres were trialled on a laboratory scale and implemented in industrial production at the Laminés Marchands Européens (LME) site in Trith-Saint-Leger, France where they replaced part of the anthracite. Tyres waste was charged from the top of the furnace into the molten bath at a rate of 1.7 kg tire per kg of carbon, while the off-gas (CO and H_2) levels was seen to increase by 10-20% [xv].

At UNSW, in developing PIT we focused on using the polymer material as a carbon replacement for slag foaming[xvi]. In 2006, the Australian steel manufacturer, OneSteel, adopted the new technique and began replacing part of the metallurgical coke with HDPE plastic. In 2007, rubber tyres were also considered for commercial reasons[xvii]. A mixed blend is now injected into electric arc furnaces as standard practice in OneSteel's Sydney and Melbourne plants and in an EAF plant in Thailand[xviii]. Our current research is extending our insight into high temperature (1200-1550°C) environments -- with melamine, high-density polyethylene, polycarbonate and Bakelite, as well as agricultural wastes and tyres. Ultimately, we aim to understand the science behind such transformations to assist industry in recognising which waste streams have potential as raw materials and, therefore, represent new opportunities for "waste to value" processing. The research processes and some of the important results and observations discussed below represent the key findings in a much larger body of published work.

4. CONCLUSIONS

Our research to date has generated new knowledge that I believe could prove extremely important in the future of steelmaking. Most notably, the waste streams studied led to better, more efficient furnace operations, when combined with metallurgical coke, than the current standard practice of using metallurgical coke alone. I have outlined only a few of the possibilities, but I believe the potential for sourcing waste as raw materials is as broad as are the range of materials containing Hydrogen and Carbon. That means steelmakers could envisage sourcing waste streams locally, depending on local availability; some steelmakers may have easy access to palm char, others to vast mountains of particular plastics. Industries well understand the commercial and convenience benefits of locally available raw materials as well as the significant environmental benefits of reducing the use of coke, making good use of waste in landfill, reducing transport emissions by sourcing some production inputs locally and the subsequent improvements in furnace efficiency.

However, in the tradition of Dr Howe we need to “do the science”. We do, of course, well understand furnaces and the reactions that occur within them using conventional processing techniques. We have now established the usefulness of various waste streams in steelmaking and have already applied some of this work in developing PIT.

In the in-depth investigation reported in this paper, for waste materials – ranging from polymeric materials to agricultural wastes -- the major findings are summarized below:

The samples considered were seen to have different structures. The rapid gas phase reaction of coke-polymeric blends and agricultural wastes affected the residual particles and significant transformations were observed in the structure of the particles. The gas evolution was investigated and gases were seen to be released from the waste materials. These gases were found to be key factors affecting the subsequent slag reactions.

Slag reactions were investigated and the polymeric blends proved better than coke alone when the blends were optimized, leading to better slag foaming. Rubber blends and palm shell showed an increase in slag volume, compared to coke, allowing for the formation of stable foam throughout the experiment. HDPE blends revealed significantly higher volume ratios as a result of increased gas generation, entrapment and subsequent release. The presence of hydrogen and methane released in the decomposition of polymer chains at high temperatures were seen to participate in the reaction with FeO present in the slag, as a result of carbon/slag interaction, thus increasing the rate of gas evolution and reduction. Iron oxide fine particles were also put in close contact with polymer and agricultural waste residues and a good level of reduction was observed. Investigations into the waste materials at nanostructure levels were performed and the influence of the carbonaceous structures on dissolution into liquid metal was established.

This innovation offers an excellent opportunity to improve efficiency while positively impacting the environment through energy savings and the transformation of waste streams. Such research has established fundamental pathways through which polymers can be re-formed as resources for iron and steelmaking. However, as with PIT, the benefits of waste mixes depend on carefully calibrated proportions; so we need to truly understand these useful reactions to determine how to optimize new coke-waste blends. We are continuing this work with the aim of establishing a solid knowledge base to inform the steel industry. Given the potential to implement such novel recycling solutions are not generally available to other materials industries operating at relatively low temperatures, this is an opportunity which could change the way we think about raw material resources for steelmaking into the future. The building of new knowledge -- in partnership with industry -- reflects Dr Henry Howe's passion for continually deepening our understanding of the science of steelmaking.

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