STEEL 2050: REVISITED

THE FEASIBILITY OF DECARBONIZATION AND NET ZERO FOR STEEL AND THE ECONOMY IN TOTAL

FEBRUARY 22, 2023

DR RODNEY BEDDOWS
Devonian Ventures Ltd

Steel 2050: Revisited

Prologue

'*No lesson seems to be so deeply inculcated by the experience of life as that you should never trust experts. If you believe the doctors, nothing is wholesome: if you believe the theologians, nothing is innocent: if you believe the soldiers , nothing is safe. They all require to have their strong wine diluted by a very large admixture of common sense.'*

Robert Cecil, 3rd Marquess of Salisbury. British Prime Minister 1855 - 6, 1886 – 92, 1895 – 1902.

This paper commenced as a consideration on the topic of the steel industry's approach to reducing CO2 emissions on the road to a decarbonized economy and society. It has expanded to a wider scope and the many interrelated topics you will encounter if you read on. But where do I start in my prejudices; a word I prefer to assumptions, it reflects the human nature and non-neutrality of assumptions, although they refer to the same things.

I am with Robert Cecil: expertise is valuable and objective, but is expressed by experts who are biased, have agendas and are thus partial; they need to be treated with caution. Expertise is not proven to be useful until it is critiqued by wisdom. Wisdom is uncommon as those who have it are cautious in their claims to it and use of it: expertise is everywhere as those who claim it seek to exploit it widely in pursuit of their agendas.

My task is not to express denial or belief in Anthropogenic Global Warming and its many derivative claims; denial and belief are appropriate to religion not to the sphere of human affairs. I do declare a skepticism regarding all claims of such a magnitude. What I seek is to understand the policies and approaches taken to change in response to claims of global warming and its consequences, and to assess the practicality, reasonableness and feasibility of these approaches and can they achieve their aims. In other words, I seek to apply wisdom and reasoned appreciation to the claims made for policies and actions.

Thank you for reading so far, I hope you enjoy what follows.

Table of Contents

Throughout this paper I use acronyms. Unless they are in common use I use the full phrase in the first instance with the acronym in brackets; after, just the acronym. Also there is a glossary on the last page.

Introduction and Scope

'The eternal mystery of the world is its comprehensibility…The fact that it is comprehensible is a miracle.'

Albert Einstein. From an article in 1936 entitled 'Physics and Reality'.

This paper is a considered reflection on some aspects of my book, released in 2014, entitled: '**Steel 2050. How Steel transformed the world and now must transform itself.'** Whilst released in 2014 it was written over the previous two years and was the culmination of much consulting and advisory experience over many years in the ferrous industry, entailing the whole iron and steel (I&S) making and processing value chain. It seems timely to write this focused reconsideration as there has been much change especially in the broad environment in which the industry operates. I do not intend for this to be a 2nd edition or re-write, rather it is to concentrate on a limited number of topics, ones which are of great importance but which I underemphasized in 2014.

The scope of this reconsideration is broad. The 2014 book included in depth consideration of many aspects of the industry from the prospects for iron ore to finished steel marketing; from service levels to price risk hedging; from internal dysfunctions to externalities such as the drivers of volatility in prices and demand.

I gave little attention to sources of energy even though the basis of all economic wealth creation is energy plus intellectual property. That is the intelligent deployment of sources of energy with increasing effectiveness and efficiency for the achievement of human purposes. My attention was elsewhere as the sources of energy seemed then settled and not vulnerable to great change. Coking coal was the energy source for Blast Furnace (BF) iron and Natural Gas (NG) for Direct Reduce Iron & Hot Briquetted Iron (DRI & HBI). Electricity was the source for Electric Arc Furnaces (EAF) and the major source for rolling mills and other facilities to process semis into usable finished products as desired by customers in numerous applications.

In the last decade the world of energy has been turned upside down and inside out due to the global, though not universal, vociferously held concern for Anthropogenic Global Warming (AGW). This encapsulates a complex of observations, theories and models around the belief that the climate is warming; most importantly and critically, though not solely, due to rising levels of CO2 in the atmosphere; which itself is caused by its release in the burning of fossil fuels. This use of such fuels has been seen for over 200 years, as the bedrock of industrialization bringing rising levels of well-being for the population and the latest stage in the 'intelligent deployment of sources of energy' which I mentioned a moment ago. The clear inference drawn from the belief in AGW is that this use of fossil fuel energy is not intelligent but is in fact stupid and more; it is destructive of the health of the planet and self-destructive of our prospects for survival on it. This belief system started in the late 1960's with the Club of Rome, whose influence has grown despite numerous failed predictions and forecasts and is partially hidden behind its more conspicuous offspring, the World Economic Forum (WEF). I myself have some close understanding of their ideas as I was funded for 2 years in the mid 1970's to study the feasibility of the Club's policy of Zero Growth and its economic and social consequences if implemented.

This AGW, despite CO2 being an essential plant nutrient and signs of more extensive plant growth on the planet, is perceived as having predominantly, indeed overwhelmingly and rapidly developing, negative consequences for the capacity of the planet to sustain human life. The predominant narrative has been of imminent catastrophic tipping points from which irreversible, detrimental and destructive climate change will emerge. These concerns have led to the urgent search, sanctified by institutions from the UN downwards and sovereign governments across the globe, for means to reduce CO2 emissions caused by humans and their industrialization. The direct making of I&S is acknowledged to be the generator of about 8% of man-made CO2 which, on a par with Concrete, is the single biggest industrial culprit. Within the EU it accounts for 14% of industrially generated CO2 emissions.

Hence, decarbonization (D), the avoidance of CO2 generation, or its removal after, is the major topic to be covered in this brief paper. The timing seems doubly appropriate as it is 10 years since my book's release and because enough considered thought and experimentation has gone into finding the solution to this problem in I&S that we can begin to critically assess the routes forward, the feasibility of such routes, their fundability and necessity. As steel making through the EAF and all steel processing, post hot metal and semi-finished product, is a major user of electric power, D is closely tied to the search for decarbonized Green Energy (GE) and thus to the widely held objective – in some jurisdictions legally binding in others no more than a voluntary ambition - of Net Zero (NZ). Whatever the level of commitment, it is enshrined in the resolutions of the various Conferences of the Parties (COP), the supreme decision-making body of the UN Framework Convention on Climate Change, which are now annual jamborees and in their 27th iteration. NZ would be the achievement of a balance between CO2 generation and its reduction by withdrawal from the atmosphere via such as Carbon Capture and Storage (CCS). As the simplest and perhaps best way to NZ is by not generating CO2 in the first place, the greatest effort and excitement is around renewable power using natural resources other than fossil fuels, such as wind and sunlight, and capable of repeated use. It follows that I need to understand and assess alternatives to fossil fuels and their technologies and economics, for energy creation and supply.

To more fully explore the subject I decided to add an important application of steel and assess its claims to contribute to D in general. If they are well founded it could have a significant impact on I&S usage and thus its role in D. Thus I review the Battery powered Electric Vehicle (BEV) as a replacement for the conventional internal combustion engine (ICE) automobile. There are three major reasons for this; firstly, the auto sector is a major and technologically important steel sheet and forgings and iron castings market and thus if emissions-free is a major contributor to steel's ambition to be emissions-free and vice versa; secondly, the BEV is a major user of power in various forms as the hard commodities it requires are many and go through the same extended process of provision as I&S. We need to understand what emissions, especially CO2, are entailed in their production and supply. Finally, the ICE auto sector is directly responsible for a great deal of petroleum product use, so whilst at first glance eliminating this fossil fuel use is obviously a contributor to NZ, it needs to be balanced with the emissions generated from the electrical energy generation, if not GE, and delivery to charge and recharge the batteries. The D of steel making and the search for NZ examined here apply to all hard commodities to a greater or lesser degree; all face the same challenges and there are common opportunities or limitations. The automotive sector and the changes being encouraged and often legally enforced there are a comprehensive illustration of the topics and thus I pay special attention to the sector.

Beyond and around the specifics of I&S the climate change narrative and debate is showing signs of shifting and opening up to wider consideration and beginning to be considered in a calmer and more balance and well-reasoned way; which makes it even more propitious and timely to address the D of I&S and NZ generally in such as this paper.

We may be entering a period of reduced hysteria on the topic of AGW. This is a very recent development in the publicly acceptable debate and has also surfaced strongly from the scientific community; it has always been there but has been 'afraid to speak its name' in the famous phrase. Likewise in the commentariat, to question certain 'accepted truths' has been decried. It is clear that this narrative has been dominated by increasing catastrophism and hysteria for the intervening decade since my book was released; at times reaching extreme levels. This is demonstrated by movements in the UK such as 'Just Stop Oil' and 'Extinction Rebellion' and the most extraordinary status given to the opinions of such as Greta Thunberg. The importance and credibility given to her always makes me think of the absurd fantasies and visitations of Christ which inspired the young leaders of the 1212 'Children's Crusade', so called, which was a disaster for many innocent children, ending in their deaths or enslavement, and that of others. I have been hoping for more common sense and a more realistic perspective to break out: it is emerging and I shall seek to show how and why towards the end of the paper. The new head of the UN sponsored Intergovernmental Panel on Climate Change, Jim Skea, a Nobel Laureat, has in his first extensive public statement in that role called for exactly those two things, with a recognition that the catastrophic narrative of imminent tipping points and irreversible changes and such like have been overdone. Simultaneously a group of 1600 scientists have signed a joint statement asking for the same things. They are not saying change is not happening but are questioning responses including NZ and calling for 'adaptation' to climate change not just 'mitigation to eliminate' such change. The latter having been the dominant approach to the perceived changes with adaptation being seen as an avoidance and escapist approach by many such as Greenpeace, other campaigning groups and the likes of the said Greta. The next stage of this realism I expect to be acknowledgement that gainsayers and doubters of AGW are treated seriously and no longer unanimously condemned as 'deniers'. I will return to this topic of realism and balance in the AGW narrative towards the end of this paper, after I have examined the detail of D for I&S and relatedly GE.

We may therefore be at what I call 'peak catastrophism': more balanced opinions and policies will be beneficial, for hysteria and extremism of any kind is not compatible with the search for science-based thinking, reasonable and well-reasoned responses to challenges. Reality has a habit of asserting itself, bringing with it the realization of undue and costly delays, and revealing in the process the misallocation of resources and other deleterious results to the detriment, not benefit, of mankind. I am reassured by these developments; they support the importance of what follows here.

Much has changed in the period since my book was released and I admit to having missed the importance of this critical challenge of D for the Ferrous and hard commodities sectors. To cover this requires me to examine it from the highest levels – those of political economics, and the political acceptability of enforcing behavior change without its democratic mandate - to the economics and technology of I&S making and the industry's structure. I have chosen to start at the bottom and work to the top, so the next section is directly about D in I&S and Ferrous in general. Just as I did in 2014, I shall look across the value chain from the extraction of Iron Ore to finished product use, so extending my attention to the whole Ferrous Sector not just what is commonly thought of as the Steel Industry, the topics and issues cannot be addressed adequately without this approach.

As I have considered this extensive subject long and hard over recent months, I have reached what to me are surprising paradoxes and somewhat unexpected conclusions. I will range far and wide over economic, social and political-economic topics surrounding the industry and conditioning its future. I shall express some words of caution about missing new issues or over-emphasizing what now seem settled answers and responses and what might need to be revisited by 2034.

Decarbonization of Iron and Steel production

The removal of Oxygen from ore is the greatest single D challenge for Steel. Whilst a third of steel is made from recycled scrap and for that no Oxygen needs to be removed, it is still only a third. The melting of scrap in an EAF does entail the production of CO2 directly through the use of carbon electrodes and indirectly in its use of power. I will address the need for power – electricity - shortly. Currently nearly all the processing of virgin iron ore uses coal in the form of coke; approximately 5% of Iron is produced via direct reduction by natural gas NG.

The simplest way to significantly D steel is through the EAF. This process uses scrap, sometimes enhanced by the use of DRI, mostly in the briquetted form of HBI, or pig iron, all used to ameliorate undesirable residual elements in the scrap. This would be ideal except for a major difficulty in the availability of scrap. It is not 'produced', it is collected as off cuts or other unused surplus direct from a manufacturing process or as obsolete material from end of use products. This obsolete material is the vast majority of what enters the scrap market. It is a derived product and cannot be made. The availability will respond a little to price as a higher price will motivate the plethora of local small collectors and suppliers to look more extensively for smaller quantities to collect and feed to large scale processors and shredders, but the supply is determined by forces extraneous to the market. A formula I have always found useful, and used in 2014, is that the available scrap supply is 70% of the apparent domestic consumption in all forms, direct and indirect, seventeen years earlier. Significantly increased demand will be likely to increase price disproportionately, compared to supply over any time scale. In traditional economic terms, scrap has very limited elasticity of supply which makes increasing EAF production useful for D but of limited applicability.

The oft mentioned inability of EAF steel to meet the highest quality of sheet product is of decreasing importance as EAF practices and feed mixes improve and now with the probable decline of steel sheet in the automotive sector with the increase in use of aluminum in BEVs.

Various substitutes for Coke from Coal apart from NG for DRI are being developed or proposed as are improvements in Blast Furnace and Basic Oxygen Furnace practices. Bio Carbon is possible but there is disagreement as to how carbon positive or even neutral, that is as claimed by its enthusiasts. It is derived from agricultural product, both virgin and waste; the collection of such is highly dispersed and costly and relevant transport is a big user of diesel fuel, currently. Developments in the use of the BF & BOF route and its fuel feed offer possibilities but this looks only marginal in impact. The use of bio-fuel for example can reduce the use of coke by a few percentage points for the whole industry. The increased use of oxygen and recycling of off gas likewise might reduce CO2 by 10 or 20%. The various optimization options of scrap use plus the range of adjustments in fuel mix plus BF burden mix with high quality ores and pellets for the current BF & BOF steel route could reduce the CO2 generation from 2.0 tons per ton of steel to a range of 1.7 to 1.6. In a world where I&S needs will continue to grow, these are impacts which will be lost after only a few years: something more fundamental is required.

DRI using NG reduces the Carbon emissions from ore reduction using coke by approximately 50% to the level of 1.1 to 0.9 tons of CO2 per ton of steel. This leaves the challenge of handling the residual 50% of emissions. CCS or even CO2 use are possible successful developments; CCS where the geology allows it, but is looking to be very expensive. Under any circumstances DRI looks particularly attractive as the technologies are fully proven and deliverable.

There is limited availability of what is regarded as DRI grade ore capable of producing a product not requiring further processing with its additional cost, except briquetting into HBI to avoid physical deterioration if being transported a distance before charging to a steel furnace. What goes into a DRI module comes out minus the oxygen; it has no refining capability; it is either iron or gangue, a waste product. If the ore has a low Fe content, normally regarded as less than 65%, or a higher than 3% combined alumina and silica, this gangue is deleterious in both economics and throughput utilization for the steel making process and is best removed before steel making. The lower the Fe content in the ore the more the gangue and so the reason for the denomination of DRI grade of ore with high Fe and low residuals of Si and Al. The limitations of lower grade ores can be overcome or mitigated by post DRI melting to remove the unwanted gangue. The source of heat for melting being another generator of CO2. The gas supply for the DRI modules is mostly available in developed regions by mills being located on gas distribution networks. LNG is also available to be linked to networks. Rather than bringing the NG to the established or planned I&S plant, the plant could be located at the source of NG. I look at this shortly under considerations of Mega-Hubs.

In the long term, an ambiguous term but certainly decades, Green Hydrogen (GH) is hoped to be widely available at reasonable cost. The use of GH as the reductant appears ideal as it would entail zero undesirable emissions and the by product could be water. Currently GH being itself dependent on GE is rare; it also has challenges of cost and extreme lightness, the lightest element in the period table, which enables it to penetrate through metal and escape. Electrolysis holds prospective attractions but looks currently too far away to deploy at scale with attractive economics. So the end point for Green semi-finished Steel will be either BOF or EAF using DRI with GH reductant plus scrap and CCS as necessary, using melters to remove gangue as required. As electricity is always required for melters and especially for the EAF this needs to be green. I will come to that below.

All solutions require large commitments of long-term capital; MIDREX DRI modules are currently economically most attractive at capacities of 2.2mtpa of iron make and can cost between $1.5bn and $2bn depending on location and existing infrastructure; there would be additional capital required for the melting to remove excess gangue. The requirement for 1.5bntpa of DRI iron to displace 100% of coke for making pig iron is much beyond the capacity of the steel industry as a whole to fund, being several Trillion $s, perhaps between $3 and $4 trillion; third party funds are required, currently as always with Steel companies, governments are being petitioned. As an example Thyssen Krupp confirmed in January 2024 that it had received pledges of 2bn Euros from German authorities to support, not fully fund, its transition to Green Steel using H and GE. It produces 11mtpa of steel, less than 1% of global non EAF steel. The funds being provided are only part of the capital cost and do not include anything for GE.

The need for adequate capital is compounded by the time challenge for developing and implementing new technology. The steel industry has a long history with many examples of technological change both major and minor, successful and unsuccessful. Since WW2 Oxygen steel making and then continuous casting are conspicuous successful examples. The first BOF of industrial scale and commercial viability came into operation in Linz in the early 1950s, replacing Open Hearth furnaces. The last open hearth in the Atlantic basin, at STELCO in Canada, was closed and replaced by a BOF in 1984. The full adoption and proliferation of the technology took 30 years; longer in the communist countries. A similar time was involved for Continuous Casting to penetrate fully. With targets and sometimes only ambitions for NZ by 2050 we have inadequate time for any technology in the early conceptual stage of development.

The thirty-year rule appears remarkably pervasive across all technologies: the transistor was developed in Bell Laboratories around 1948, likewise, High-Capacity Mobile Telephony, a development the organization and management of which I studied when at Harvard and the original label for mobile phones, had its origins in the same institution of Bell Labs in the 1960s but came into limited use only in the mid to late 1980s. The rule seems sacrosanct for understandable reasons too complex to go into here. Bearing this in mind it is reasonable to assert that any technology which is going to make a significant contribution to meeting the NZ target must be in commercial operation now or imminently. This eliminates GH from making a contribution in I&S to NZ by 2050 and highlights the utility, even inevitability, of NG.

Green Steel Finished Product

Finding an answer to the elimination of CO2 being released from virgin ore processing is only half of the Green Steel (GS) challenge. In addition the whole production chain from ore in the ground to the sheet going into an auto body or a beam going into a building needs attention and change if GS is to be achieved, both in production and over the life of the production units from initial exploration for ore, through construction to eventual decommissioning. The value chain is long, multi-phase and not amenable to totally accurate evaluation for emissions for any individual mine, ore product and finished delivered steel product. For illustration we can detail the steps in the full chain, from beginning in time as well as in supply logistics and product production for carbon steel strip. It involves widespread and substantial use of variable amounts of power produced by variable methods with only partial and limited recording.

Before ore is available to be mined necessary activities include the exploration and drilling to establish the ore body location, size, quality, mining method and other characteristics which go into the bankable feasibility study. If this study shows attractive risk adjusted returns there follows the establishment of the mine including building rail lines, encampments and housing for employees, support facilities and power supply from a grid or, because of scale or remoteness, from new power sources built and perhaps dedicated to the mine. Often the remote location of ore and the scale of its shipments requires extensive port development. Simandou in Guinea is an example of which I have intimate knowledge. This is a most attractive ore body, known and intermittently considered for development since the 1960s. It is many billions of tonnes of high grade, low impurity ore, incidentally suited to direct reduction. Already over a billion $s have been spent on the opportunity and not a tonne of ore has reached the market. Mine development alone will require over $6bn to produce 75mtpa, expandable by phases to 150mtpa, perhaps more. Rail of 552 kms, including many bridges and tunnels, and port developments to take the largest ore carriers are estimated at $18bn. In the context of NZ and D before any shipments reach the market the negative emissions balance from all the activity and products used is already large, incapable of being fully recorded and essentially incalculable.

Whilst for existing mines these emissions deficits from the development can be regarded as the equivalent of sunk costs, the relevant assets can require extension and regular maintenance and occasional refurbishment and updating. Two important observations can be made. Firstly, whilst a product in its direct generation of CO_2 may be NZ it cannot legitimately claim to be so until the production facilities are included and until those facilities are replaced or scrapped. Secondly, to prematurely scrap and make redundant production facilities already in existence is detrimental to NZ objectives even if the replacements are much less CO_2 generative: best to allow the current assets, which are no longer generating development emissions, to reach the end of their natural life.

When built, operating the mine requires blasting, removal and disposal of overburden, extraction and removal of raw ore by truck or conveyor to storage dumps from where the ore is beneficiated as necessary by concentration and increasingly by pelletizing, which improves BF loading and thus reduces CO_2, and is required for DRI processing. Concentration is most likely done at mine site or port involving large scale often long-distance transport by train; for Simandou the distance is 552 kilometers for which there is loading and unloading. All these activities involve millions of tonnes and much energy in both electric power and hydrocarbon form. Pelletizing requires expensive capital investment with the commensurate emissions and again from heat in operation, although cold briquetting is being developed by Vale. The usable product, once at the port of arrival, is often shipped again by rail or barge involving loading and unloading as the ports are seldom close to the steel mills anymore. Eventually, after a number of loadings, un-loadings and shipments over variable distances and most often intermediate processing and blending with other grades from other sources, and combining with coke; the ore is fed into a BF to make Iron. The coke itself is a product of coal which is heated in ovens before feeding into the BF. It is the result of a similarly long, multi-phase historical and logistical production chain as for the ore.

The product from the BF is pig iron. This goes into a BOF to produce hot metal from the pig and usually scrap up to 15% by volume, and some alloying elements such as vanadium, and manganese. This metal has to be cast into semi-finished shapes and cooled. Eventually the semis are reheated, rolled into shapes, maybe rolled twice, perhaps coated, and slit and coiled sometimes painted and recoiled. It is stored and eventually loaded onto a truck for transporting to a customer. I will not pursue the logic into these customer processing stages as we can now regard the steel as finished.   At all the many stages there is a requirement for energy mostly in the form of electricity, to some extent as gas often available as recycled off-gas from earlier processes. When the industry may have reduced or eliminated CO2 in making the raw I&S perhaps by 2050, it still needs the power to be Green for the steel to be Green. This is currently the less considered challenge but is fundamental.

How the power is generated and transmitted to the mines, the transport networks, and the steel plants, helps determine its GS credentials. There is an intense concentration by steel companies on CO2 removal from the BF & BOF processes but as is clear from the prior description this is only half – at best, maybe less – of the problem to achieve GS. Steel as I&S semi-finished production cannot be seen in isolation. I have described only in outline the whole emissions intensive aspects of the before and after I&S production; identifying maybe 20 – 25 separate stages involving power in some form or other. In all these stages the power component is very difficult often impossible to quantify and compare; it is a known unknown. It is the challenge of Green Energy.

Green Electricity

‘ For a successful technology, reality must take precedence over public relations, for nature cannot be fooled.’

Richard P Feynman, Report on the Space Shuttle Challenger Accident, 1974

Leading the response to this challenge are utilities, private or public, through renewable energy technologies. The aim is to reduce the use of hydrocarbons in the form of coal, gas and oil. Many of these technologies are in the early stages of market penetration but already quite mature technically as they are relatively simple. They are also demanding of capital and material in their construction – which takes the question back to the previous sections.

The genuinely CO2 free energy sources, at the point of generation without considering the means to capture the power, but with stability of supply are very limited in scale and availability; namely hydro and geothermal. Wind and Solar are the most favored sources for widespread adoption but are intermittent and sometimes, almost always in the case of wind, very distant from use. They are also environmentally intrusive visually and land hungry. Large scale investments in the grid for transmission and distribution from origin to use are required. In the UK the grid operator has estimated that to meet the government’s planned requirement for wind power and with its location substantially off shore but use widely distributed across the country, will entail capacity expansion costing 32 times all grid investment over the last 30 years. It is reasonable to question both the feasibility and desirability of this commitment of funds; a question I return to in a later section of this paper. This growth in capacity and extension of its reach is already generating intense resistance as it destroys landscape, property values, farming and much else across the country in the case of the UK.

Intermittency is a particular problem for all users and especially for industrial ones such as EAFs as the name suggests, and challenging for mines whose locations are determined by geology not for policy convenience; they are most often far distant from the customer’s use of the mined product, as witnessed by Simandou. A long break in supply to an EAF could be a major disaster if unplanned as it could lead to cooling to the point of solidification of a furnace’s content. For an underground mine the workers could be trapped with ventilation and air flow failing. Those are just two examples of undesirable consequences. Intermittence mitigation requires excess capacity in either supply and distribution to balance volatility in both, and a reserve capacity in hydrocarbon technology or a storage capacity in the form of batteries. To achieve total GE if using hydrocarbon reserve capacity – there is no other option with near 100% security except nuclear - would require carbon capture and storage. The technological innovation and implementation timescales as well as capital requirements quickly mount up and replicate those issues from the previous section. Additional cost is from the established policy acceptance of paying the wind power generators when they produce excess power to not supply it to the grid; effectively paying to waste the energy. The materials required for construction of relevant equipment require to be decarbonized, this is not just steel but concrete and base metals such as copper. The same challenges steel faces are common across much of the periodic table. Beneficiation, smelting, refining and processing into usable finished product requires energy in the form mostly of gas or electricity, the latter because of location often being by diesel generators.

Liquid steel production has been the center of attention for the I&S industry as it is the immediate, clearly identified and discrete to the industry, emissions problem. It is also easily understood by governments and public as a clear and punishable target. This is a necessary but insufficient response; much more focus needs to be on reducing CO2 in electricity generation and the reduction of energy requirement. The challenge of GE is common to all economic activity including services. It is rising in importance and gaining prominence in data processing centers, with the arrival and expected rapid growth of Artificial Intelligence and the continuing growth in the internet and telecommunications use, data processing and handling centers will be the biggest industrial users of electricity in the near future and larger than I&S. Already Data Centers represent nearly 20% of Ireland's electricity demand; this raises to prominence the collateral issue of subsea cable vulnerability. The total, global business of these centers is forecast to double by 2031; this lies behind Microsoft's investment into nuclear energy innovation.

Nuclear power is emissions free once the reactor and related capacity for conversion of the generated heat to desirable power or other use has been built. The challenge of construction materials is dealt with above. There is a number of small modular reactor (SMR) and micronuclear technologies under development and small is beautiful in nuclear. Historically the suppliers and governments have pursued scale in the mistaken belief that Nuclear was like other industrial capacity and there were economies from increased scale; the reverse has proven to be the case. The capital for current conventional large-scale capacity is substantial and subject to over runs and delays. The Flamanville facility which commenced generation this year cost 13bn Euros for 1650 MW of capacity. The next similar one to be built is claimed to be costing only 8.6bn. In the Western economies the small number of large reactors which have been built in recent years with constant variations in the technology and thus no settled and replicable design, precludes the exploitation of economies of scale in components and other aspects of construction. Against the scale of investment needed for the mentioned facilities; SMRs will be costing 100s of millions of $s. Micros maybe only 10s of millions for 10MWs of power. The public's fears about potential failures and radiation impacts on populations have led to excessive and astonishingly expensive safety standards based on the precautionary principle; following the precautionary principle is an endless task; there is always another possible danger to be dreamt up and dealt with. The role of large-scale reactors in the future is likely therefore to be limited, perhaps producing a base load underpinning more distributed fragmented capacity.

Small distributed reactors close to centers of use and linked to the current grid so that when capacity is not required locally it can be used elsewhere – and vice versa - would be ideal. In remote places such as the Pilbara or the central African copper belt, which are locations for multiple mines with multiple owners there could be close by reactors. Steel mills could be supported for power in a similar fashion. I think it is fair to say the emissions both of harmful particulates and gases are close to zero and where they exist are from support activities. Nuclear would also fulfil the need for clean electricity across the value chain for mining and manufacturing and for domestic and general commercial use. Nuclear could soon be capable of delivering its promise from the 1950s of abundant low operating and capital cost power.

We cannot end an analysis of nuclear without considering the great objection; the fear of radiation from spent fuel or unexpected crises in operation with its long half-life and therefore long-lived danger to human health and life itself. The images of the atomic bombs used to end

WW2 and the great loss of life are vivid in people's minds across the globe and across generations. Yet the peace time recordable deaths from radiation poisoning are few and far between. Even in the case of Chernobyl which generated extraordinary anxiety and fear, the numbers are claimed to be only between 30 to 50, although information from the Soviet era is not to be given very much trust and this facility was using a very poorly maintained and monitored old technology; the plant had no effective failure containment structure and the core was fully exposed to the elements when it did burn, releasing very large quantities of radiation. The Fukushima disaster was an event brought about not from the failure of the nuclear facility directly but by its flooding as the result of a tsunami, there is little evidence of human health consequences from Fukushima radiation.

There is a risk aspect with other technologies and their deployment which needs assessing and has not been noted and analyzed publicly until very recently and not generally taken into adequate account. I consider this much more relevant and important than nuclear radiation dangers. Now and even more so with the further electrification of the social and economic system, transmission and distribution networks will be attractive targets for saboteurs as they are the social equivalent of the nervous system and blood flow of individual humans. All power systems are vulnerable to sabotage. This can take both physical and cyber form; in the latter case all power generation systems are equally vulnerable and only the same level of protection is available for all technologies.

However, physical vulnerability is especially significant in grid collection and distribution. The Russia/Ukraine conflict has illustrated this in relation to gas pipelines in the Baltic. The supply of gas is largely from remote regions; the exception being with fracking which needs to be widely allowed to reduce this risk and increase energy security. Conventional oil fields have been subject to attack in times of political and military strife as in the Persian Gulf and Middle East region. Similar to gas fields they tend to be concentrated and attractive targets for the disruption of one's enemies. They are under the control of sovereign entities and in times of conflict or severe international stress supplies can be severed to enemies. This is easily understood and can be somewhat planned for or be a threat to in order to bring about constructive negotiation.

Sabotage is different and can be the action of any official or rogue entity. It is seldom predictable. Response to sabotage is not reliably plannable especially as the perpetrators maybe obscure and unclear, and unreliable as co-negotiators. Wind farms, which are increasingly offshore, need extensive collection and customer supply grids which are on the seabed and extremely vulnerable. They are clear and easily accessible targets. Nuclear via SMRs are the opposite. They can be distributed near to users. The destruction or damage to one can easily be compensated for and the threat to many protected against with conventional means in time of strife. There are SMR technologies which are designed to shut themselves down safely if tampered with or damaged so unable to function fully. The anxiety for health has driven regulators to over specify the security and safety of designs for large scale reactors adding greatly to capital costs. The SMR revolution will alleviate these fears, largely eliminate these costs but education will be needed. The anxiety over nuclear is based on ignorance and lack of adequate communication with commensurate vulnerability to exaggerated fears typical of human reactions. There is time to act and educate understanding.

Nuclear has advantages over all other available widely deployable technologies for GE. It is predictable, reliable and non-intermittent in generation; it is distributable by location; requires the least new grid investment; modular so deployable in variable numbers of units to achieve whatever scale is required; is suitable for remote locations; requires the least use of land and other resources; is the least damaging and intrusive to the visual environment; has plentiful supply of fuel; can eventually be fusion, if proven, instead of fission with possibly further advantages.

Nuclear is also ideal for using as the source of energy for the production of green hydrogen; currently very expensive and difficult to distribute to points of use due to its weight, it is the lightest element in the periodic table, which means it escapes through established gas distribution networks using steel or other materials, leading to it being lost. H is also very volatile and explosive. The low operating cost of new modular Nuclear and its ease of location close to H use make it ideal for H generation as it limits the need for distribution.

Innovative Structural Implications for Iron &Steel

In **Steel 2050** I spent much time and argument on the poor quality of service delivered by steel producers in all their products. I highlighted and explained the potential beneficial changes in the marketing of finished steel products, particularly through price risk hedging mechanisms. There has been some progress in this area but much still remains to be done. Here I will focus on a potentially beneficial change in the structure of the value chain not considered in 2014. At that time it was not something I could imagine to conceptualize.

As I write this Tata Steel Europe (TSE) has announced a long-anticipated restructuring of its steel making at Port Talbot, its BF and BOF site for flat products in South Wales. It will replace the current steel making with EAFs. No mention is made of other changes such as DRI production which could utilize LNG imports through Milford Haven only 75 miles away and already with the relevant infrastructure as currently utilized for such imports from Qatar for the gas distribution network. Of course it could use UK gas if fracking was allowed but it is another piece of dysfunctionality to think it better to import gas even though that produces more CO2 than using a local gas. The DRI as HBI could be used in the EAFs to mitigate the impurities likely to be present in the scrap. It could also have the same function at Scunthorpe, 325 miles from Milford Haven, a plant not owned by TSE. But the structure of UK rolling assets owned by TSE suggests another option which could bring lower cost and be more effective in reducing emissions.

TSE has galvanizing lines at Shotton in North Wales and welded tube mills at Corby in Lincolnshire: the EAFs could be sited at those mills. The capacities are commensurate with EAF economies of scale and such a process route could facilitate increased capacity and shipments at Shotton; the UK has a deficit of 1m tonnes of galvanized sheet, currently met by imports, partially for the reason of poor service itself partially due to a fragmented process route. Integrating the process route at Shotton would facilitate improved service and reduce transport costs by eliminating hot rolled coil shipment from South to North Wales. Reducing shipment steps also reduces CO2 emissions further, as would reducing imports. The transport of steel and its raw materials is seldom a subject of comment and analysis yet it is a major factor in cost and emissions due to the energy expended. As a rough rule of thumb every time a steel product such as a coil is picked up or put down it costs $10. Every movement requires one or more machines with consumption of energy and labor and generation of cost. Much of the structural change in the industry has been driven by the elimination of these costs and the optimization of integration. TSE has new structuring options as it moves to EAF steel making, maybe they have considered these; I am unaware although I have tried to speak to them.

The industry in total, internationally, has a major new option as it moves to DRI production. This can perhaps be best understood by considering the availability of the scarcest resource available in this transition to NZ; resource location and availability have always been prime determinants of steel mill location and the scarcest resource today is money – capital to fund the changes.

Developing an industry-wide DRI capacity will need massive amounts of capital; in the order of $1.5bn per 2mtpa at a brownfield site with established infrastructure, $2.0bn at a greenfield site, which given the growth of steel consumption by 2050 implies the total capital required is likely to be $3 to $4 trillion. With their low returns and constant need for other investments, only a few steel companies can provide the funds for their required modules and their governments would much prefer to avoid it given other demands on funds. The only alternative sources of such quantities of capital are the Sovereign Wealth Funds (SWFs), fortunately they have strong incentives to provide it on terms acceptable to both parties.

SWFs have the funds from their Oil & Gas (O&G) revenues and they have the desire to deploy it elsewhere as the prospects for O&G are expected to atrophy. Furthermore, O&G have a negative PR image in the age of AGW. The atrophying has brought a need for alternative sources of long-term wealth creation thus the SWF owners as sovereign countries wish to diversify their economies for long term growth and employment using the funds in their 'banks'. These forces for change provide the opportunity to construct profitable business models around these pools of capital, in attractive locations for sources of reductant and energy. Thus has been born the concept of Mega-Hubs. There are a number of locations where there is ample space at little cost, a plentiful low-cost source of NG, good port infrastructure possibilities, good logistical coordination between Iron Ore suppliers and Steel off-takers; which all together provide a most attractive location for producing DRI/HBI or going further in the value chain to semi-finished steel; and doing this at a scale of 10s, maybe many 10s, of millions of tonnes a year.

At such locations ore from whatever source could arrive, be blended as necessary, processed into HBI, the form of DRI suitable for transportation, or even further into steel where customers desire it. The output could then be transported to steel rollers and processors overseas who could close their I&S CO2 generating assets. Developing countries with neither the volume of demand for large integrated facilities nor the appetite and capacity to deploy capital and accept the risk in those investments could start with smaller scale rolling and finishing capacities suited to their markets whilst taking semi-finished steel from a Mega-Hub. Facilities for DRI/HBI would be greenfield initially so optimally configured but expandable on a modular basis. The scale could be open-ended. The capacity would be capable of using different sources of ore and blends. Surplus gangue from lower quality ores could be removed by post DRI melting. The electrical power could be provided by appropriate means depending on location. In the Gulf, the sunlight and space might justify solar, otherwise Nuclear would be suitable.

This structure of NG and DRI with good capital availability will facilitate the development of GH technology eventually able to supplant the NG. MIDREX DRI modules are already tested for use of H rather than NG and will need minimal adaptation. Thus, if suitable CO2 neutral fuels can be used for the vessels transporting ores inwards and product outwards to customers, the whole value chain is potentially NZ. By employing hedging mechanisms and margin sharing the SWF could deploy its capital to good effect with low financial risk and create employment in the host country. With multiple steel companies as partners and off takers there would be an incentive to balance supply and demand in periods of volatility. I have already discussed TSE's plans as they are currently understood for steel in Port Talbot. The supply of material from a Mega-Hub is an alternative and probably would have more attractive economics. The Mega-Hub, if in the Middle East region, could also support Tata Steel's Indian operation or ones they might want to develop in other countries.

A value chain restructured in this way would also facilitate more balance in industry-wide management of capacity and expansion of steel production and use in developing countries. A follow-on consequence to Iron Ore producers could be profound as their ore might eventually be displaced as the benchmark price setter by a DRI product with melter or by HBI or the semi-finished steel. Ore producers may want to participate in the Mega-Hub capital structures as these could become the dominant influence on the ore market's pricing over time. This structure offers some very interesting and innovative funding formulas which I mention briefly towards the end of the paper.

The Automotive sector and Decarbonization.

The long-term boundaries between steel and other materials - who gains and who loses - are questions without definitive answers. It is too early to see or even to guess if a decarbonized future will change the markets for different materials; it is possible we shall witness a fundamental industrial revolution. The most advanced and conspicuous frontier of such change is also one of the most important markets for steel and iron; the automotive applications. There are approaching 70 million vehicles of all types produced annually with the numbers growing; we would expect that to continue for the foreseeable future with the worldwide development of the middle class. The applications of iron and steel in this sector for internal combustion engine (ICE) vehicles are several in the drive train, body, engine and elsewhere; they are regarded as premium sectors for quality specification and potential margins. They span forgings, castings, bars and especially strip. These products' markets are already being impacted by Battery powered Electric Vehicles (BEV). The benefits in reduced pollution, especially emissions, seem generally accepted; the battle between the ICE and the BEV is often declared to be over and the victor is on the podium. Is it so? Have we decided prematurely? Should we, as the protesters wish, 'Just Stop Oil', of which the ICE would be a major casualty?

The core of the EV is the battery, hence the acronym BEV, which currently is a lithium iron technology. This is a motor power device with no emissions at the point of use, unlike the ICE, and that is the basis of enthusiasm for BEVs; instantaneous CO_2 reduction, an obvious and indisputable contributor to NZ. The electricity generation issue has been dealt with earlier in this paper and is the first source of doubt about the real contribution to NZ. The second source of doubt and the biggest, most complex and difficult to assess, is the production of the battery which requires a multi-product and multi-stage process generating copious quantities of CO_2. Firstly, the battery weighs 12 times the fuel tank it replaces, with only the power capacity of 80 pounds of gasoline, such weight reduces the range a great deal but we must assume this will improve in time as technology improves. Secondly, it requires a combination of metals – lithium, nickel, cobalt, copper, graphite, manganese, aluminum and steel – as well as non-metallic materials. Each of these metals requires a complex and highly variable supply chain requiring much energy, generated disparately depending on the available grid and source of electricity or by diesel for remote and off grid sites of production. Because the mine origins are many and grades highly variable in many aspects, containing differing amounts of valuable and waste elements and product, it is fair to say no two sources are the same as to their CO2 generation. Whilst this is true of iron ore the variations are within much narrower ranges, the average grades are very much higher, the mine scale average is much bigger and relevant data on emissions is more readily available and reported. It may seem surprising that the mined ore, not including the over burden, is not greatly different to produce 20mtpa of copper cathode as for the global demand of virgin iron; copper bearing rock grades average little more than 1% and Fe grades about an average of 50%. For the ICE of a particular model the fuel consumption is known and for that vehicle varies little irrespective of the way it is driven or the gradients it drives over. The steel and other materials in the ICE construction are likewise well known, vary only within narrow and transparent limits. None of these facts are true for the BEV.

All claimed knowledge on each non-ferrous metals' CO2 and other emissions is assumptive - a guess or wide estimate - currently an unknown knowable. However, we need best estimates which can be derived from extensive analysis in papers from many sources. Any analysis must start with energy intensity for each metal to reach a state of usability. This in itself must start with the amount of mined material required to produce the usable metal. This then can be used to derive some measure or comparative scale of the 'hidden energy' or estimated power required for the processing.

An average battery currently weighs about 1000 pounds and contains, in pounds, 30 of Lithium, 60 of Cobalt, 130 of Nickel, 190 of Graphite, 90 of Copper and 500 of steel, aluminum and various plastics. The weight of ore in pounds required to be processed given the global average content of the mineral in active mines is respectively; 20,000, 60,000, 10,000, 2,000, 6,000. In total just short of 100,000 lbs. In addition there is overburden of indeterminate weight and scale but certainly more than the ore. In addition must be added the emissions from production and use of chemicals used in the processing. The energy required to produce any of the metals in a battery is 2 to 3 times per pound that of steel, rather more for iron which is used for castings; the ferrous metals in an ICE vehicle constitute up to 85% of the weight of the vehicle, at much less energy intensity. Substantial energy is required to fabricate the battery from its constituent metals and other parts; it takes the equivalent of 300 gallons of gasoline to fabricate the average battery capable of storing the energy equivalent to 1 gallon of gasoline. The fuels used to generate the energy cannot be calculated as there is far too little specific information and therefore no calculation can be made of the emissions involved for a specific BEV. It can be useful in this wilderness to start with the IEA's reports on these energy minerals which includes their work on mining and fuel use. This world of energy required for battery material sourcing and manufacturing is a mine field – no pun intended! It will take a great deal of time and effort to get near to full analysis.

The IEA has produced an answer to the question of the life cycle emission comparison of ICE and BEV, which involves the above and the fuel use of the vehicles. To go into detail on their work would involve more than this paper is attempting. It is fair to say that the assumptions, variables, and uncertainties which they use are both largely hidden and, where transparent, highly debatable. Individual car companies who have 'skin in the game' could be regarded as more reliable sources of information; a report by Volvo showed that the BEV is superior in total emissions but only after 90,000 miles of driving. Volvo have recently announced a scaling back of the plans for BEVs. Toyota, the world's largest car company have been deliberately slow and limited in their participation in BEV's; selling only 15,000 in the US in 2023. They seem to be reaping good financial results from their circumspection. The jury is still out on the emissions from driving and not yet as advanced in its considerations as it is for the materials in the construction.

I think it reasonable to deduced that the NZ status of each metal is very unclear and highly variable but is substantially more negative than Steel. This must be factored into the NZ status of EVs but is not in the minds of the public and is little considered in the policies of regulatory authorities, politicians and others promoting the BEV as the vehicle of the future. For them it is too complex and difficult to assess.

The story for BEVs is not limited to these considerations as the use of the vehicle requires electricity, as dealt with previously. The performance of the batteries is conditioned by weather as well as power availability and in the recent extremely cold conditions in the Northern US there are plentiful stories of failure to start and unpredictable performance. We can leave the

BEV story here perhaps except for recent developments in the market place. Early enthusiasms are cooling with experience. Hertz Car Rental, after setting ambitions to purchase 100,000 BEVs for its North American fleet, has announced the early disposal of 20,000 and further purchases are in abeyance. Insurance premia in the UK for BEVs are twice those for similar ICEs and sales of BEVs have disappointed to the point where distributors are seeking the reinstatement of subsidies via a halving of the rate of VAT on sales.

The Political Economics of Decarbonization and Net Zero

'Insanity is doing the same thing over and over again and expecting different results.'

Attributed to Albert Einstein.

The BEV is a consumer product; when it is a private purchase it is the largest in a person's life after a property and perhaps an engagement ring! This is where the process of D impacts economically most strongly on the individual. Steel on the other hand is a commercial purchase and market place; it does not impact directly on the private purse and the impact and economics of D are somewhat hidden. Energy purchases are ubiquitous and both private and commercial, they have become conspicuous by their volatility; when a private purchase they are much smaller and more regular than the purchase of a car. They have become conspicuous and tendentious recently by their volatility and rapid increase. Governments wish to influence citizens in their behavior regarding D and AGW and in this changed environment of increased prices and volatility have taken an approach, here in the West, of coercion, indoctrination, legislative edict and enforcement and when they have sensed resistance they have resorted to subsidy and price manipulation, all of which has distorted the free market to the point of its suffocation. As I came to understand this I was surprised, then shocked and now admit to be baffled.

Only recently has the world witnessed the total failure and economic destructiveness of these very same tools of influence and change in the largest experiment in the manipulation and forced direction of personal choice, at a total society scale, ever attempted – the Soviet Union and its satellites. Thus we have in living memory the demonstrated success of the democratic, free market disaggregated model of economic choice, reflected in aggregate in the price mechanism; and the total failure of the socialist model of centralized decisions driven by experts and imposed on individuals with prices determined by fiat. Despite this demonstration of success and failure governments in the West - the EU, UK, USA and others - to varying degrees, had chosen the failed model to implement their Green Agendas of D and NZ.

I found and continue to find this a puzzling almost incomprehensible paradox with the inevitable prospect of immense economic cost and failure, as before, unless the direction is changed quickly. As the actions of individuals taken separately but in the mass will determine the success or failure of NZ and D, as they do with any social, economic or political policy either sooner or later, I needed to explain and understand this paradox of the political economics of AGW.

Back in 2013, more than ten years ago when I was finishing **Steel 2050,** the steel industry's context meaning the environment of geo-political, social, ideological and economic conditions, which provided its operating environment - its political economics - were quite settled. The West had won the Cold War, peoples across the world were looking to better lives through democracy and capitalism, liberty from tyranny was widely sought and authoritarianism was in retreat. The human aspirations to health, economic development, freedom, wealth as in the opportunity to own and dispose of assets as we wish, and to seek happiness with responsibility each as he wished without unreasonable legal restrictions, seemed shared and growing in their popularity: the American Dream was looking like becoming the Universal Dream.

The governing elites and their cheer leaders and acolytes across the multitude of varying sovereignties and with differing degrees of development were aspiring to democracy: the frontiers and bastions of autocracy were crumbling. The virtues of the nation state, whilst not without its limitations and its opponents recommending various forms of globalism, were recognized and the success of the West in the Cold War was seen as a vindication of its virtues and qualities, heralding its continuation and a future of peace and prosperity. Dr Francis Fukuyama had declared the 'end of history' and as fatuous as this was it had a certain resonance with the moment's zeitgeist: as so often in times of total success and its following condition of excess confidence and enthusiasm: hubris was lying in wait.

What had brought the positivity and hopeful conditions prevalent still in 2013 was the fall of communism. Over the few years from 1989 to 1992 the Soviet Union collapsed comprehensively in all dimensions and aspects. This came as a surprise to many, perhaps the great majority, of people and institutions, so doubling the impact of its ending. It had been a seventy years experiment in ideologically driven state control. Its economy had been centrally planned and the plan had been seen as a success, even romantical hopeful in the perceived idealism of its incarnation, by many intellectuals and others: it had gradually become dysfunctional, sclerotic, very effective at misallocating resources with decaying infrastructure and physical assets, devious and dishonest in its planning and reporting throughout its institutions, etc. Its central planning paradigm was shown to have failed and was gradually then quickly seen to be so: it had experienced the classic process of bankruptcy - happening at first slowly and then ending suddenly. The decentralized fragmented wisdom of multitudes of individuals making their own economic decisions, the free-market capitalist democratic model for all its limitations, had succeeded elsewhere and been denied to Soviet citizens with their increasing penury and social disintegration.

Even more had been proven. The Soviet system was explicitly Marxist. Marx was no doubt sincerely motivated and in modern parlance had a 'lived experience' which gave him opinionated strengths. Engels, his colleague and follower in theoretical political views, and his funder, certainly had the lived experience of industrialization through capitalism in his own family's mills, which informed his views and underpinned them with a sincerity. It matters not if this had much correspondence to reality. The importance of the idea of 'lived experience' however fatuous – it is nothing more than a tautology – probably applied to Lenin and might also have applied to Stalin in their explicit adherence to Marxism. The central tenet of Marxism was that the dictatorship of the proletariat would be a peak political system, to be followed only by a withering away of the state as humanity achieved a state of perfect interpersonal harmony, and this dictatorship was to be pursued at whatever cost to other objectives or values. Indeed other social and political groups, as exploiters of the overwhelming majority of society who are the proletariat, required suppression and elimination; effectively extermination in the Soviets. A process of physical eradication which once started could not be stopped.

Freedom was not a right but a legislated benefit if it existed at all. Expression in any mode, verbal, written, musical and in other ways was suppressed or at best tightly circumscribed and monitored as only 'valid' ideas, inoffensive to the prevailing ideology and authorities must be allowed to avoid the development of 'false consciousness'. Political opponents and those who disobeyed were executed or sent to the Gulag. The death of Soviet Russia would be expected to see the end of this kind of ideological fantasy with its cruelty and destructiveness, and the long-term dominance of the multi-polar fragmented form of democratic politics and capitalism.

The fantasy that legislation in its benign or malevolent and even violent forms could defy economic logic; that bureaucrats however knowledgeable and expert could fulfil the aspirations of millions of actual producers and consumers; that innovation could be planned; that all these experimental ideas could lead to outperformance was seen to be absolutely false, even absurd. In other words; ‘the end of history’ as conflict between ideologies and ways of life had arrived, there was no longer a need for such: one side had won.

My shock came at the revelation of the parallelism of this failed experiment in socialism with a new experiment of even greater scope and ambition, that this end of history was not the case and a new ideological chapter of even greater magnitude had gripped the West in particular. In fact almost simultaneously with the death of Sovietism there had arisen a new ideology; that of ‘Anthropogenic Global Warming’ and its social and political reactions which in summary can be labelled; ‘Global Climate Catastrophism’.

There are numerous parallels. The world was no longer needing to succumb to revolution to save the proletariat from exploitation by capitalists, the bourgeois or the kulaks. The world itself was the equivalent of the proles. It needed saving from its degrading exploitation by the whole of humanity in order to save the world and humanity from themselves. The false consciousness that needs eradication is that of materialism and economic growth, defined in material terms.

The equivalent of the bourgeoisie is the unwoke and the climate catastrophe deniers who are to be suppressed and silenced by being ‘cancelled’ and ‘no platformed’. Dissenting opinions are not allowed. Just as Marx claimed a pseudo-scientific support in the inevitable forces of historical change in the form of dialectical materialism, so those holding to the imminent crisis of climate are supported by ‘proven science’ in the form of climate models held to be sacrosanct. Often claimed to be so by stated percentages of scientists agreeing. More parallels apply as they require the overthrow of the bases of our civilization, as was required by Marxist Sovietism; in the current ideological climate it is that basis, the very engine of our success in economic growth, which is under attack and seen as the engine of our climate disaster.

Our civilization has been based on the growth of freedom of choice and the minimization of coercion in favor of persuasion. In Sovietism whilst lip service was paid to these values in fact the policies enacted were the opposite. It was not sufficient for Lenin and Stalin to persuade and await organic change; change had to be imposed through police action, occasional deliberate starvation and often execution. Here in our kinder and more caring world, climate enthusiasms are enforced through legislation, targets and fines for failure to meet them, and increased taxes directly and through levies: all without a democratic mandate.

Targets, often with fines for punishing failure to meet them, and outright bans are frequent instruments; the Automobile producers are to meet targets for BEV sales or face penalties. Home heating through certain sorts of boilers is to be restricted and then eventually forbidden. Heat pumps are to be mandated whether appropriate or not as they are 'clean'. Enough surely has been said to make the point. Central planning and the wisdom of experts and small numbers of the equivalent of Plato's Guardians or Philosopher Kings are back and with them Plato's dismissal of democracy. Behavioral change through 'forced limitation' is required.

In addition we now have rampant subsidies for selected technologies on the basis of apparent but shallowly researched technologies such as BEVs. Subsidies are proven time after time in planned and free economies to be dysfunctional and counterproductive as they are the deliberate explicit and planned misallocation of capital and wealth destruction. This is deemed to be required to meet scientifically justified targets for CO2 reduction to avoid inevitable catastrophe for the planet and by implication humanity itself. If the subsidized investment was wealth creating then capitalist enterprise and the great Adam Smith mechanism of the invisible hand of beneficent selfishness would invest voluntarily and quickly; no subsidy would be required.

This then is the paradox; our political systems have chosen a failed model to achieve change over a proven successful one. One which they have witnessed first-hand and only a generation ago. Behind this choice is a denial of democracy; no democratic mandate exists for this policy choice. We are in the world of Plato's Guardians, and must trust to their purity of motivation and clarity of thought. There is a democratic deficit, as there is with all our global and intergovernmental institutions which will lead to the demise of any and all of them over time unless rectified. I shall return to this topic of the democratic deficit of acceptance in later sections, especially when I address the fundability and executability of NZ and its related changes. I will now review a major and inescapable aspect of any reflections on I&S and its future and on any economic aspect of the world; the shape of future demand and especially China's role.

The future shape of global steel demand

In 1993 I was asked by the American Iron and Steel Institute (AISI) to present to the annual gathering of their Chairmen and CEOs on the topic of global steel demand for the next 25 years. I focused particularly on China whose production and demand then was less than 100mtpa. My considered opinion was that by 2020 Chinese production and consumption would be 500mtpa. This led to an animated debate and was regarded by almost all those present as an extraordinary overestimate that the Chinese would find impossible to achieve; it was exceeded and production by 2020 was 1bn tonnes.

By the early years of this century it had become commonly accepted that the Chinese economy would exceed that of the USA by well before mid-century. In **'Steel 2050'**, I was predicting that the Chinese economy would probably never match that of the USA, and on the contrary it was likely that the Indian economy would exceed that of China's by 2050; this was greeted with extreme skepticism. Not many readers accepted my belief as it seemed ridiculous given the countries' respective growth rates at the time and the highly organized and directed economy of China compared to the apparent almost chaotic nature of India's. I remember being told in private discussion by an eminent Indian that; ' India has law but no order, China has order but no law.' Which sums it up very well. My belief is now appearing much less ridiculous. China is expanding at a slowing rate and India is progressing at an increasing rate. Steel production in the latter is 130mtpa and forecast to reach 300mtpa by 2030; China's has most probably peaked and will likely decline in the short term, certainly in the long term given the country's demographics and inevitably declining work force combined with the impossibility of it continuing to export so much of the world's manufactured goods, now faced as it is with new vibrant competitors looking similar to themselves as of two decades ago.

India's annual contribution to global GDP growth, not to GDP in total, which has never matched China's is forecast to exceed it in 2024. This signals the point of inflection in the forces driving my 2014 belief. Further witness to the emerging speed of growth, size and strength of the Indian economy are the numbers above for steel production. We should also take note of the Automotive sector as a key element in the Indian, as with any industrializing, economy. Major global car companies are now prioritizing the country for investment encouraged by low labor costs and its material availability and quality equivalent to world standards. The numbers support their priorities and hopes with exports of cars at 662k last year, component production growth up 33% and the market being now the third largest in the world.

There is a growing consensus that China has hit the limit of its economic model of autocratic central planning and construction intensive growth; although the current policy of the CCP is to double down on the formula, increasing central control and refusing to reduce the % of GDP generated from construction which remains above 40%. Without radical change, equivalent to the change of direction driven by Deng in 1979, it is in severe danger of languishing or, even worse, of going into a period of extended deflation, contraction and economic decline. This could easily bring social and political chaos as the CCP would lose credibility and authority.

A vibrant economy should and must be able to absorb young employees to instill hope in them for their future; however, youth unemployment figures – those aged between 16 and 25 - have ceased to be published with the official rate at 20%. Some estimates make it 50% and GDP per capita is still only 20% of that in the USA. Hence, I believe China will not exceed the USA's economy whilst under the control of the CCP, or without radical policy changes by the CCP, a change attempted by the USSR bringing about its own demise, again as was discussed in my book. The USA's economic performance continues to exceed expectations as the latest quarterly growth suggests, at an annualized rate of above 3%, and employment expanding faster than expected with 350,000 new jobs created in January 2024, all despite interest rates having risen.

This change in China's prospects has impacted on metals markets expectations and sent anxiety through them as the Chinese economy consumes approximately half of Iron ore, Copper and Zinc and is the largest producer and consumer of Aluminum. These numbers are causing a degree of panic in their respective markets and with investor appetites. Yet, as often, short term reaction is over reaction. In **Steel 2050** I made much of what I called 'the next 20'; that is the 20 next largest developing economies and their importance. Amongst these was India. They are now much more important and in the absence of future growth from China are well capable of supporting current demand and more for metals driven by their local construction needs and increasing participation in manufacturing. China is already experiencing a decline in exports of around 25% in H1 2023 and imports of about half that, mainly in materials for its exports. Only a near term collapse in demand from China would be a major problem for metal producers and their supply chains.

There are fears of recession in the developed economies but if this happens it will be temporary on our NZ time scale. Global consumer demand is becoming fragmented geographically but is growing strongly commensurate to the rise of middle classes. Production of developed countries requirements will re-shore significantly from China as its costs rise, innovation declines and supply chain vulnerabilities are exposed as recently with multiple international stresses. Increased investment in the relevant areas is already strong in the USA. It will also move to other countries in the 20; India is a witness for this. The metal required will, after supply chain disruption, move to other countries. This will be facilitated by the emergence of the Mega-Hubs mentioned earlier. These will be able to manufacture semi-finished steel at economic scale in large volumes and enable countries with smaller demand for finished steel to meet their needs by off-taking semis and rolling and finishing locally.

Economists at the IMF and other public and private institutions are expecting a decline in the growth rate of global GDP. In the 1990s it was 4%pa; in more recent times it has trended to 3.5%; current expectations are for 3%. The reasons given are expectations of decline in the pace of globalization and its benefits resulting from re-shoring and increased geo-political stresses; maybe this is no more than the numerical impact of China's decline in its growth rate. I say more about China in the next section in addressing the funding for NZ and D in general. In this scenario steel will find its markets fragmenting geographically but still growing in parallel with other materials although the electrification of the world drives expectations for faster growth of metals required for green technologies and some base metals. In this environment any short-term price pressures will probably be moderate and prove short term. Aluminum is often a leading indicator and this price has fallen about 40% over the past 2 years but has stabilized in the last months with current expectations of recovery. Aluminum can transfer, through the structure of commercial contracts, the reduction in price to Alumina and further back to Bauxite so the impact on the producers is mitigated. Copper is known as 'Dr Copper' for its utility in taking the temperature of the global economy and its historical tendency to match global growth rates and cycles; it is currently holding to high price level of $8,500 per tonne with only modest daily and monthly variations.

In short I hold to my view of China, India and the ‘next 20’ in total. If my 2014 predictions come to fruition then Steel production is going to be in excess of 3 billion tonnes per annum, the emergence of Mega-Hubs will ease the difficulties of achieving this, and energy consuming manufactured products will rise in parallel. The challenge of D will get bigger and the ambition of NZ more difficult to fulfil. I will turn to that now.

Funding and executing decarbonization ambitions

'That most delicious of all privileges – spending other people's money.'

John Randolph, American Politician, 1773 – 1833.

We have seen that the transition in the ore processing and liquid steel stages of I&S can be funded via a combination of SWFs in support of those steel companies with strong balance sheets plus iron ore miners needing to defend and possibly enhance their market positions, and of course as always with Steel businesses, by appeals to sovereign governments. The assets funded would be both in Mega-Hubs and sometimes as replacement of BFs in current process flows by DRI modules. The sums involved could run into the low trillions of $s, over the years to 2050, and the SWFs would have incentives to provide funds and suitable Project Financing structures could be designed; this funding by Project Finance will provide an excellent opportunity for Investment Bankers, especially where there can be multiple off takers as with Mega-Hubs. The resulting operating cost structures for brownfield retro fitted DRI processes should be less than currently as the stages of Coke, BF and BOF would be reduced to DRI and BOF or EAF. Maximizing the use of EAFs would maximize scrap use and that would reduce mining and transport and logistics costs, even in countries with a deficit in scrap arisings and thus dependent on imports. If and when GH is available it will require electricity for the H production. It is estimated that a 2mtpa DRI module using H rather than NG will require 6 Terawatt hours of electricity; if this was provided in an attractive location such as are available in the Middle East it will likely be half the cost in the EU with a saving of around 300m Euros pa. Again Nuclear with its reliability will have advantages elsewhere.

As we have seen there is the need for the rolling and processing stages of steel to be green and this requires power in the form of electricity. The biggest funding challenge comes from the provision of GE; electric power free of CO2 emissions, as this would be whole society wide for all activity and industry, hence much more capital consuming and without the neat revenue attachment which could come with project finance.

The UK represents an example, not unique, of the scope of the funding challenge problems. The boss of Siemens, one of the world's largest power engineering groups and Britain's largest wind turbine maker, stated at Davos 2024 that the cost of wind power in the search for NZ is not being fully acknowledged and accounted for and consumers will inevitably pay more for power in the future. As the cost of wind power is overwhelmingly a capital cost with its related depreciation and maintenance, he was in fact saying that the investment funding requirement was not being adequately acknowledged. HMG shows little signs of acknowledging the problem as it set a strike price which resulted in no bids at all for the last licensing opportunities for wind farms in the North sea as they would not have made a profit.

The current, although inadequately acknowledged, funding requirements for NZ in the UK alone, largely for electricity generation, transmission and distribution are estimated at £50 billion each year from now until 2050, which is of the order of £800 per person in the UK. Currently the average salary is £32,768 pre-tax, £27,573 post-tax, so the £800 is a 3% reduction in disposable income, but a much greater percentage of discretionary income; perhaps 10 – 15%, for capital cost alone. Over the period the funds required amounts to a total of £1.35 trillion. This is in 2019 prices which have already been overtaken by significant inflation of 14% cumulative. The UK has a truly abysmal even catastrophic track record of delivering large capital projects to time and budget, the finest example currently being HS2. It has also just been announced that the Hinckley Point Nuclear project is running over budget by many billions and the chances of it being still an underestimate must be better than 50/50.

Yet the acknowledged funding requirement is little short of laughable. There is a gaping hole or non-sequitur in the basis for the estimate of £50bn a year. The need for non-fossil energy sources of whatever , except nuclear, is dependent on weather patterns, the level and intensity of wind, hours of sunlight and so on. These can be supplemented by storage which can be carried forward from year to year. Nevertheless annual variability patterns are critically important in assessing the requirements for energy from renewable sources and their particular forms and for making judgements as to the level of risk of power outages acceptable as variability in these factors must be subject to standard deviations. Sound logic would require a long time series over many years as a necessary base for such a key assessment as the requirements for national power supply and its means after transition. The Committee on Climate Change in the UK, given legal authority to control the pace of D, to set regular Soviet style five-year progressive targets, claimed to have commissioned the required analysis which became the basis for the NZ commitments of the Theresa May government, supported subsequently by succeeding administrations and lay behind the calculations of the capital cost of achieving NZ mentioned earlier.

A recent study for the Royal Society undertaken by Sir Chris Llewellyn Smith, emeritus professor and former director of research at Oxford University, revealed that the forecasting was based on one year only. This had previously been made known to the committee, was ignored, and under questioning has been acknowledged to be true. The basis for all NZ calculations in the UK is fallacious, spurious and inadequate.

It can be assumed that the capital costs involved will be much more than the £50bn a year as the year used by the CCC was a high wind year. Inflation, underestimation, inadequate management of implementation could all be expected to lead to a doubling or more of the funding required. A recent unpublished study by France, important to them as the government owns EDF responsible for Hinckley Point, has estimated that the UK’s 50bn could amount to as little as 20% of the eventual requirement. The question then to be asked is whether that is feasible; the funds have to come from tax payers or bond markets or HMG expenditure savings. All means are subject to political and practical limitations driven by risk appetite, alternative uses for funds and tolerance – in the case of tax payers – for the pain of loss of life style from diminished disposable income. The bond market limitation is a function of its perception of the country’s ability to repay the borrowing and the interest along the way or alternatively to refinance. Needless to say the bond market does not have infinite patience nor infinite capacity. Currently the UK’s explicit sovereign debt burden is almost exactly 100% of GDP. This is avoiding any contingent liabilities in the form, for example, of unfunded state pensions. The GDP is just short of £2.5 trillion. Net borrowing for the year ending in March 2024 is forecast to total £130 billion. The pressures on HMG expenditures are increasing with a need to increase defense expenditures and perpetual increases in welfare and health budgets which no government seems able to restrain. The conclusion must be that meeting NZ capital investment from savings in expenditures is extremely unlikely.

Maybe the bond market will provide the funds? Historical comparisons will help for some perspective on bond market ability and willingness to fund. In 1700 the burden of bond borrowing was near zero. It rose gradually as a percentage of GDP to a peak of 200% after and because of the Napoleonic Wars. It then fell with dips and peaks throughout the rest of the 19th

Century of comparative peace and economic growth to about 20% before WW1. It then reversed again with a period of recovery in the 1930s until an all-time peak of 240% at the end of WW2. The access of the UK to debt markets is fundamentally different now than before and during the two world wars. The UK was until the 1920s the world's reserve currency, as is the US $ now, and retained some of that status until into the 1950s when it was still the empire's currency: Australia only renounced the £ on February 14th 1966. As with the US $ now, borrowing in £'s was easier and markets saw the £ as a currency of safety and security; as a safe haven. This is no longer the case. The long period of growth until about 1990 saw the debt/GDP ratio fall to 30% since when it has climbed again until now. The simple message from all this is that economic growth is the only way the ratio is reduced, the bond markets will not come to the rescue to the level required to meet NZ and it will not work to seek to impact anything by increased taxation, which itself is at a 70 year high of 38% of GDP.

Only crises such as war or economic collapse (the policy choice with Covid) enable markets to be manipulated into providing debt funds beyond the norm. In times of war capital controls and other measures such as nationalizing banks, as was done in 1914, 'force' savings to be invested in government bonds and in WW2 the USA provided much debt support; paid for after the war. In times of crisis, motivation to tolerate deprivation in the population is high. Money printing by other names such as quantitative easing (QE) during the financial crisis of 2007/8 and again during the Covid panic was a piece of magic which created a false market in bond issuance and redemption by the Bank of England (BoE) and other central banks. Currently, as we commence on the NZ funding journey we are not experiencing the crisis of war or disease or uncontrolled and unresolved economic collapse; the crisis – AGW - is self-identified whether justified or not and, even if genuine, will the motivation to suffer the required deprivation last for 26 years until 2050?

We are starting from a high base line ratio of borrowing and are not alone amongst sovereign nations in this and we have a low to zero economic growth rate a condition shared across Europe but not in North America. We cannot look to enhanced tax revenues from growth or from fiscal drag without inflation. And we face escalating demands on the state to fund larger and larger welfare budgets and especially health services due to aging populations. We could create substantial inflation which would automatically deflate the debt but bring with it its own problems as has been witnessed many times and could only be a temporary expedient. Without substantial economic growth we would quickly reach a point where only continuous increases in the tax burden would provide for debt servicing and that would result in continuous substantial reductions in the population's standard of living. Positive economic growth from new green technology jobs is exactly what the proponents of NZ argue is going to happen; experience already disproves it. Gordon Brown in 2009 forecast 400,000 such jobs by 2017; as of today the Office for National Statistics (ONS) has calculated 34,000 have been created in green related production type activities in addition there are 67,000 jobs in green related PR, Legal services, Lobbying groups, Civil servants, etc. The ONS gives no estimates of the numbers of jobs eliminated by D and NZ such as at TSE..

The inescapable conclusion I offer is that NZ cannot be funded in the UK and this probably true in the other developed countries of what we refer to as the West. The possible exception is the USA with its currency having the status of the £ before WW2. The escape route of high inflation would surely lead to social stress from many directions, possibly social disintegration and civil disobedience and perhaps worse, and reduced living standards. Increased taxation would impact standards of living likewise which, if not accompanied by an explicit democratic mandate is likely to lead to the same outcome as inflation. The political systems in the West have deliberately avoided seeking a democratic mandate for NZ, instead substituting what I have referred to on several occasions as 'catastrophism' driven by fomented fear, combined with legislated enforcement. One result is visible in the rise of so called 'populist' or 'far right' political parties responding to popular disenchantment and distress and as I write mass protests by farmers across the EU. Political name calling is not helpful; listening, understanding and responding to popular feeling and argument could be helpful.

Whilst the UK is a convenient example, as I am English and data is readily available and over long time periods China could be different. It has been such an exception since its emergence from Maoism in 1979. It has grown rapidly and has become the world's 2nd largest economy. When I wrote in 2014, most economic forecasters were expecting China to be the world's dominant economy by 2050; those expectations are now not so strong. However, it should not be suffering from the debt and sclerotic growth problems that a super mature economy such as the

UK is experiencing. Examining the same and similar fundamentals as we did with the UK reveals equal if not worse problems.

Emerging from the so called Global Financial Crisis which seemed to hardly affect China, the ratio of debt to GDP was 150%, it is now 300%, significantly worse than the UK's. with the historical GDP growth rate of between 6 and 10% this could quickly be eroded by the capacity of the CCP to adjust and manipulate tax revenues without undue push back from the population, but the demographics are turning viciously against this; the workforce contracted by 6.6m in 2023 and will do so by 7.9m in each year through to 2030. It will shrink similarly for many succeeding years in a declining total population; demographics are truly forecastable. The growth potential is reducing rapidly and the capability to increase productivity through investment is already limited. China has invested a greater proportion of its GDP than the rest of the world for every year since 1970. The proportion has grown on a trend line from 30% to 43%, the world average is steady over many decades, at around 23%. The country is also experiencing a declining increase in the productivity of new investment, whereas the ratio was 2 to 1 in the 1990s it is now 9 to 1; that is 9 units of investment are required for 1 unit of increased product or service. The conclusion must be that even China cannot find the capital to fund the shift to a green economy: there is no need to be concerned about their commitment to this ambition as it is, as with ourselves and Europe, undeliverable.

The escape route of mass creation of new green jobs cannot come about. Without the positive revelation of new, previously unknown laws of economics and physics, it is unrealistic to expect a green economy will be more prosperous through increased productivity of resources, that is factors of production, than the one we have at present. We are explicitly substituting less productive energy technologies for more productive ones and hastening the process by not waiting for the old one's obsolescence but proactively and prematurely destroying viable assets. Civilization has progressed by energy transformations in the opposite direction; from human power to animal to water to wood to coal to oil and gas to nuclear. Each transition improved the ratio between energy input to output. Now we are intent on reversing this and the result must be a less productive economic process. Economic growth per head of population will be impossible; decline looks inevitable. Without an economy which is growing more productive we will not be able to service debts and provide the capital to achieve the greening we appear to desire except through economic and social impoverishment which must lead to social conflict, probably catastrophic conflict. This is the emerging and threatening catastrophe.

Crises, Catastrophes and Choice

'Human history becomes more and more a race between education and catastrophe.'

H G Wells, from The Outline of History, 1920.

The world is undergoing enormous stress in many different areas; global warming is not alone in being seen as a crisis, it is just the most conspicuous and generating the most violent anxieties and appeals to politicians and 'activists' as worthy of their attention. There are no shortages of crises current and emerging to choose from; it may be that with reasoned consideration one or more will be assessed as more serious than the potential crisis of climate. These are in addition to the ongoing and continuous geo-political and oft time military out breaks of inter nation state and terrorist conflict. As I write there is war in the Ukraine, Gaza, and the Yemen. There is persecution of the Uyghurs claimed as a possible real genocide in Western China, Venezuela is threatening Guyana with illegal seizure of an oil rich border province, and so on. Even amongst natural or nonpolitical stresses that of climate or AGW is only one amongst several. Some of these crises demand large scale funds to have any hope of being rectified or ameliorated; this is especially true of the natural crises. Given the complexity of many natural crises and their uncertainty it is a matter of choice as to which we make a priority.

In **Steel 2050** I made a strong point about the poorest in developing countries who can now, with modern telecommunications, TV and especially ever cheaper and ubiquitous mobile and internet connectivity, see and absorb the attractions of life styles available in the West. I suggested that we in this West had a choice; we could facilitate the rapid growth of poorer economies to make it attractive for people to live there or expect them to move in large numbers to share or expropriate our wealth. The latter is now happening with mass displacement of people voluntarily or involuntarily either seeking asylum or simply effectively finding entry either legally or illegally. The UK had over 700,000 net immigrants in 2023 alone. In one month the US border force estimates 250,000 made it from Mexico to the US.

Anyone who does not recognize that this is a crisis is suffering head-in-the-sand syndrome. Here in the UK there is intense pressure on housing with less than 200,000 new homes being built per annum and thus rapidly escalating costs for such accommodation, so large numbers of immigrants can only increase accommodation pressure for all the population. The National

Health Service is struggling to the point of failure with waiting lists expanding continuously from already historically high levels. All across Europe, in every EU country, right of center parties are gaining popularity and polling indicates they could hold power, as in Holland where they are the largest party in the national assembly, in traditionally center left dominated countries within the next 2 years. Their voter appeal includes a negative attitude to immigration for economic, social and cultural reasons. The potential for conflict is obvious and migration is becoming a crisis.

This immigration surge which is expanding the demands on many services and facilities and bringing cultural stresses is matched by the slower emerging crisis in the opposite direction; one of depopulation. I have presented the Chinese crisis but Europe is experiencing the same; as it is slow burning it is little felt and perceived. However it is about to reach an inflection point and being demographic it will be very difficult and slow to change its direction – if at all. In 2026 the EU population will peak at 463 million and thereafter decline to 415 million at current rates of births per woman unless compensated for by immigration. The evidence indicates that subsidies in favor of child bearing have little to no effect; South Korea has spent $200 billion on this policy with no positive result. This decline has many and varied consequences as it works through the age cohorts; there will be a rapid decline in workers per inactive citizen, so a rising burden will be placed on tax payers to fund government expenditures, forcing a range of difficult and reluctantly taken decisions such as pensions versus welfare versus health care versus defense.

However, the biggest potential crisis is over water; one which has many parallels to the potential AGW crisis as it is a function of man interacting with nature. Whilst 75% of the planet is water, that available for human use is much less. Of the 75%, 69% is frozen in glaciers (maybe AGW could release this !?), 30% is underground and 1% in lakes, rivers and swamps. Only 1% of the planet's water is suitable for human consumption without purification. Demand is rising fast and unlike the climate crisis there is no doubting this; it has risen by 40% over 40 years and is expected to rise by another 25% by 2050. Consumption is greatly underestimated in the average person's mind. Few would guess that to make a cotton T Shirt requires 2500 liters and to wash a tonne of coal requires 24 full bath tubs. Demand is about to escalate, and drive up the expected growth to 2050, with new requirements putting even more pressure on supply than we expected as little as 10 years ago. The newest factor is electronics and in particular semi-conductor production and then their consequential data centers and the requirement for their cooling. A semi-conductor factory has a pure water requirement equivalent to 100,000 homes and purity is absolutely essential for production. Sea water is unacceptable and even desalinated water if it contains any contaminants will be destructive of required product quality and integrity. In addition data centers produce heat and cooling is required usually by evaporative water; that is water which evaporates into the atmosphere, not as with most water use which is withdrawal water, which after use gets purified and reused. Google required 250 billion gallons for cooling in 2020 rising to 500 billion by 2030. Bank of America has estimated that the world would run out of pure water by 2040 at the current rate of increased usage. The impact of the crisis would be little short of catastrophic, will be difficult to avoid and is more forecastable than AGW. We all know water is essential to human life. Rationing or restricted use are likely to lead to social turmoil. There would be intermittent economic shocks as tight supply intersected with erratic weather patterns in new and extended periods of water stress. World GDP could fall by 6% in a decade and every decade thereafter, health impacts could be considerable and migration could increase dramatically.

The one thing we can do is reduce wastage. Water supply is very inefficient especially in old systems in old cities and industrialized countries. This has been a perennial problem in the UK. It takes trained engineers but most importantly money for investment. Bank of America estimate $1trillion per annum worldwide from now and into the distant future is required simply for maintenance, not for expansion; pipes and other infrastructure continue to erode and deteriorate every year. All these potential consequences are similar to those predicted by the claimed AGW crisis and its expected catastrophe. The difference being that water conditions are much more knowable and predictable and modellable than climate.

It should now be clear why this section is entitled, ‘Crisis, Catastrophe and Choice’. AGW is seen as somehow unique and uniquely threatening and proven by its models – we can set that aside for now and come to it towards the very end of the paper. AGW is not unique and the crises identified above have some differences from AGW. Firstly the water and depopulation crises are knowable and predictable in ways that AGW is not. They are driven by long term trends which are irreversible in other than generational time scales, as with the depopulation crisis. In the case of water the relationships between variables are definite and simple. The immigration crisis is not determinable and is subject to unpredictability. All these crises, to the extent they are avoidable, will be requiring funds maybe on a lesser scale than AGW but competing with it and adding to the already unsustainable burden, and they are not the only other demands on global funds.

If we look back rather than forward there has been one period when similar fears to AGW have surfaced and been taken very seriously. In the 1970s an anxiety developed about dependency on oil with the impetus of the oil price spikes. Analysis showed the world would exhaust its oil resources in 30 years. ‘The Club of Rome’, a collection of the great and good from business and politics, had been established in the late 1960s on the back of concerns for the degradation of the global environment. They produced a famous volume called ‘Limits to Growth.’ This became a bible for those concerned about the loss of oil and exhaustion of other raw materials and it argued for the abandonment of growth and for zero growth economics; it was a modern Malthusian thesis whereby demand would grow exponentially for resources and their availability would grow only incrementally at best. I was granted two year’s funds to study, ‘the conditions of zero economic growth’ and how businesses in that environment could be managed. I will not say more than that it was a fruitless and dead-end exercise. Zero-growth was a null hypothesis at a business level, where there was only growth or decline. Furthermore, it was shown that we had always had only 30 years availability of oil and that many resources had been forecast to reach exhaustion before ‘something happened’. This something being technological development to increase efficiency of use, or replacement in use, or processing developments to make ‘new’ reserves appear as lower grades could now be utilized, new discoveries, etc. 30 years seems to be the norm for resource exhaustion and is so because it is not economically sound to explore and develop them beyond 30 years. The time value of money determines this – a human dimension. At the time substantial resources of capital, scientific research and brain power with government financial support was devoted to finding alternatives to oil and technologies for the future. Exxon in particular devoted a whole division – Exxon Enterprises – to new businesses to replace its Oil and Gas business; similar to initiatives to replace hydrocarbons now. The Club of Rome still exists and is closely related to the World Economic Forum. The Club’s concerns and ideas live on in AGW and Climate Catastrophe thinking; one wonders if the lack of reality is the same, only time will tell. Perhaps the old saw of ‘what goes around comes around’ is being seen again.

Crises are not in short supply; some are more pressing and better founded in their existence than AGW. Similarly catastrophes are a common currency of politics and political agitation. We have choices to make in both categories but the choices are real and not predetermined.

Some overarching considerations

'There are systems of concepts and values through which we see all the others. Which I call appreciative systems.'

Sir Geoffrey Vickers, Interview, 1978.

The thinking and millions of words behind AGW and its crisis and coming catastrophe justifying all the D and NZ activity and investment is led by modelling showing the implied outcomes from unchanged human behaviors: how we will destroy the planet's ecosystem and our way of life or perhaps even our lives. Behind the modelling are theories of the interconnectedness between fossil fuel burning, CO2 generation, global atmospheric temperatures and the climate in its many manifestations; hurricanes, rainfall, forest fires, etc.

This is as far as the theories and implications go. Behind the theory level and thus behind the modeling there always has to be the 'appreciative system', in Sir Geoffrey's words at the top of this section. Sir Geoffrey is one of the most distinguished British men of the 20th Century. I had the privilege of spending a private day with him in the mid-1970s, whilst researching the implications and feasibility of implementing the Club of Rome's Zero Growth hypotheses which had a strong parallelism to AGW and the implications drawn therefrom. I found it one of the most illuminating, interesting and intellectually challenging days of my life. He had lived a long and richly active and thoughtful life; served in both World Wars; won a VC in the first; served his professional career largely in the public and semi-public sectors in the UK; is regarded as one of the founding fathers of Systems Theory in its broadest and deepest sense, amongst many other things. One of his clear perceptions, which I share, was the limitations of systems thinking and theory in general and the need for a higher or 'meta theory', much as physical science needs metaphysics, as understood by Einstein for whom analysis followed synthesis of disparate facts made into a coherent whole by a new appreciation of their interrelations, this being an appreciative system. I think this understanding is what he simplified into; 'Science without religion is lame, religion without science is blind.'

The appreciative system is something we bring or create through intuition and metaphor, to complex social and human situations. It precedes theory and is what our theories are derived from, it is the frame through which we see - appreciate – the world or a major part of the world.

An appreciative system cannot be tested as it determines the test and how it is interpreted. We can reject the system only through losing faith in it; deciding that, by finding it does not work or meet our needs. It is not open to direct empirical review; although an accumulation of empirical exceptions, readings and data which do not fit within its explanatory framework, and are in fact anomalous to the appreciative system, is the usual way in which an appreciative system gets overthrown and replaced. The replacement is not directly a result of reasoned thought but of faith and its loss followed by insight through metaphor or analogy.

In this way the appreciative system is analogous to Thomas Kuhn's paradigms and their shift. Appreciative systems are found all through the history of politics, social thinking, religion and historical understanding. Marxism and its derivatives in various branches of Socialism are appreciative, Islamism likewise, Democratic Capitalism likewise and so is AGW; those who are owners of this system of appreciation will struggle against this observation as they think it 'scientifically proven'. I would suggest they revert to history and consider how Copernican and then Newtonian theories were 'proven' until the anomalies accumulated and someone showed that 'the emperor had no clothes'. In the political economic sphere Marxism is such an appreciative system and even now with the accumulation of numerous instances of its failure and the massive consequential human misery, it has adherents and as we have seen earlier its tenets are behind and inside the policies being used widely to attempt to enforce human behavior change with regard to AGW. Why this should be is not for this paper to examine, enough that it be the case; the paradox is too complex for such a short paper as here.

As appreciative systems are not scientific, they are what lies behind any possibility of science, the question is how do we evaluate them and is it possible to do so or is it just purely a matter of faith as we might think of religious belief. In the Anglo-Saxon intellectual tradition we must rely on common sense and reasonableness, and a sense of the human place in the universe and the limits and scope of human agency and its causality. And all this in the context of the complexity of the system we are trying to 'appreciate'. Note that what is needed is not blind or all-seeing faith, and not science or modelling – it transcends and precedes such. So, the question arises; does AGW and its related catastrophic theorizing seem reasonable regarding man's agency and potential scale of impact on the climate, who's structure and functioning has evolved over billions of years and is the result of innumerable causes. Is the AGW hypothesis reasonable and reasoned adequately?

There has been a very recent change in tone amongst the scientific community or perhaps it is only that it has been given space to articulate in public, and its commentariat concerning the nature and certain aspects of the climate change narrative; in the way it is appreciated in Vickers' sense. It is obvious that this narrative has been dominated by increasing catastrophism and hysteria for the decade since my book was released. I have been hoping for more common sense and a more realistic perspective to break out: it is emerging into the public domain. The new head – Jim Skea, a Nobel prize recipient - of the UN sponsored Intergovernmental Panel on Climate Change has in his first extensive public statement in that role called for exactly those two things – common sense and realism – in other words asking for an escape from the ideology, or appreciative system of crisis and imminent catastrophe as these are perhaps becoming seen as giving too much agency to mankind and too much urgency to current changes given the extremely long time over which the climate has evolved. Simultaneously a group of 1600 scientists have signed a joint statement asking for the same things. They are not saying change is not happening but are questioning responses including NZ and calling for 'adaptation' to change not just 'mitigation to eliminate' change. The latter having been the dominant approach to perceived changes. Such a change which might seem only one of emphasis would have significant implications for human behavior change, investment, new technology and all other aspects of response: to everything I have been considering here.

We may therefore be at 'peak catastrophism' and more balanced opinions and policies will be beneficial; for hysteria and extremism of any kind is not compatible with the search for rationally justifiable and sound, reasonable and well-reasoned responses to challenges. Reality has a habit of reasserting itself and in the process revealing the misallocation of resources. I am reassured by these developments; they do not invalidate what is written here but it does help in a rational understanding of the implications.

A change of this nature would also put 'climate science' in a proper perspective. We are all very familiar with an oft stated assertion that '97% of scientists believe global warming is happening. This is often elided into the assertion that AGW must be happening, however science is neither a popularity contest nor a matter of consensus. Then there are claims of extreme weather events becoming more extreme and more common. We are told to just look at hurricanes, temperatures, rains and flash floods, forest fires, and every 'weather' phenomenon but weather is not climate and however many scientists 'believe' does not impact on truth or falsehood. How many negative experiments does it take to disprove a theory – one. It needs to be controlled and verified and capable of repetition and so validated, but one is enough. I am reminded of Einstein's response to a letter signed by several hundred German scientists claiming to have proven his theory of relativity wrong; his response was to ask why they needed so many to sign, that it only required one to be right for him to be proven wrong. As we have not yet found a way of conducting experiments on the climate in all its complexity and world-wide scale the claims to scientific knowledge in this field are nebulous and their certainty spurious. In the commonly accepted Popperian logic of scientific proof there can be no climate science so the question is irrelevant. Science requires hypotheses to be disprovable. Experiments cannot be carried out on our climate. How would they be conducted? Where is the controlled case? At least we have not yet found a way to conduct them.

What does seem possible is modelling, but with this we encounter a different problem. To put this simply; we must recognize two different types of systems, and again to simplify they are closed and open systems. As an example an internal combustion engine is a closed system. All the elements determining its performance are known, can be designed and a new engine design can be extensively run to determine a model of its performance. Similarly in Steel we can model an Electric Arc Furnace or a Blast Furnace. These are complex systems but limited and knowable. They can be effectively modelled and outcomes predicted under different conditions of use; those conditions being the only ones of interest, the closed nature is acceptable. Other systems are too complex for this to be done. Human behavior being one; Covid-19 proved to be another. Modelling the latter proved to be very misleading, at least that which was paid attention to, and extremely costly when used to inform policy. When the virus arose and even now we have insufficient knowledge to make it a closed system. Lockdowns and the consequential direct costs through furlough payments and the costs of masks and vaccines, etcetera, may have amounted to £400bn in the UK and damaged the economy for many years to come, as well as the debt to GDP ratio. Furthermore the redirection of the NHS to Covid treatment will have cost the lives of unknowable numbers through delayed operations and treatments for regular conditions such as cancer and other illness. It may well prove to cost more lives than it saved. Covid as an example of inappropriate application and interpretation of modelling: Covid was treated as a closed system with well understood causal relationships between variables when it was not; it was an open system with poorly understood structures. Policy should have been decided on that basis and the use of appreciative judgement, of metaphor and analogy, and taking of the related responsibility by decision makers should have been the mode, not a false reliance on so called 'science'.

The earth's climate is much more complex than Covid and it is naïve to think it is well understood. It is the product of billions of years of history of our planet, its solar system, its galaxy and the whole universe. Any models are only partial and limited representations of the climate, as they are of any open and complex system. In the absence of a closed system we have to rely on our judgements and not on the science as it does not exist. We have to accept an appreciative system of the climate first and speculate theories from it and not over interpret them for practical purposes.

There are many weaknesses in our ability to judge and many over or under appreciations of reality, and appreciation is partially an act of creation or perhaps it is more accurate to say it is the application of metaphor. It often leads to spurious specificity in the attempt to relieve anxiety or create a false impression of reassurance. This is obviously the case in expectations of the 1.5C degree of raised warming. It is both over specific and over general. History clearly shows us that global temperatures vary greatly across periods of time of differing durations; ice ages arrive and disappear; global warming and cooling is variable and irregular in time and location.

It is a strange and powerful form of arrogance to claim that natural phenomena as complex as climate described above can be impacted so much, overwhelmed even by man-made actions and conditions and by one or many gases where human production is a small fraction of their total generation. Mankind is not so important nor does he have so much agency.

This is hubris; a regular human condition perhaps best exemplified in the 20th century by Hitler. Hubris was prevalent in the West's reaction to the fall of communism. We see it all around us in so many ways especially but not only in the political sphere. What could be more hubristic than believing that we as humans could, by releasing CO_2 into our environment, have catastrophic consequences in such a short time on something which has taken billions of years to create and develop entailing a myriad of elements and events inside and outside our solar system. It would be wise to have a strong degree of skepticism and to seek an appreciation of any changes a little more common sensical and sophisticated and take our time about it. It is comforting that this appears to be emerging. There is something deeply appealing to the human psyche about catastrophism and millenarianism. Our positive drives seem to be needing balance with negative ones on a regular basis: it is time to mount a deep challenge to the AGW version.

Epilogue

'*Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?'*

Thomas Sterns Eliot, poet, dramatist and cultural commentator, from 'The Rock', 1934.

The conclusions I draw from my work presented here are several. First, is that the Ferrous sector and Steel in particular has a way to D and with reduced costs. The way to the reduction of D in hot metal currently produced through the BF & BOF is by DRI using NG followed by using H when available. It is not necessary for all BOF to be replaced; I expect further BOF capacity to be built in developing countries; not all are as firmly committed to NZ as they are to higher living standards for their people. Mega-Hubs will emerge and can fulfil a great deal of requirements; maybe equivalent to all the growth in consumption. And as the world economy progresses over the short and medium term the CO2 generation from Information Industries will out-grow Steel and require more urgent action under current policies.

Green electricity needed for everything to achieve NZ will require Nuclear generation; it will predominate in future investment and be the long-term solution. Renewables will play minor roles suited to particular and limited geographical circumstances. If economic rationality dominates decision making we will see a resurgence of NG generation as the transition power until Nuclear has been built. The use of local gas resources will be least CO2 generative and fracking needs to be allowed urgently where the resource is available.

The BEV is an enthusiasm with a short life. Apart from what I have already written there will emerge an understanding of the social consequences of such as the BEV. The mining and sourcing of minerals such as Cobalt leads to exploitation of labor, including children, in places such as the Democratic Republic of the Congo. It involves damaging and even eliminating lives today for the hypothetical saving of lives tomorrow.

The most important observation I can make is that the policies to achieve NZ in the West are not deliverable. They are not fundable without a degree of permanent impoverishment never previously experienced; certainly since the Black Death in the 14^{th} Century. As NZ and D in general are policies made by elites without wide spread democratic authority they will eventually generate irresistible popular opposition: the longer the policies are pursued without elimination of this democratic deficit the more violent will be their end. I doubt the willingness of any large body of humans to have significant impoverishment forced upon them. Wise leadership will lead the necessary process of rethinking required, starting immediately. It is to be hoped that this change of direction can occur before too much viable industry has been destroyed in too many countries. An issue beyond this short study is the need for the revitalization and redesign of democracy: it has atrophied into a form of oligarchy dominated by elites overly influenced by minority interests and enthusiasms, many of whom claim to be the experts Robert Cecil warned us about. There are ways to revitalize democracy but the subject is beyond the scope of this paper.

With more wisdom and a better appreciation of the real world and its complexity, if we wish for decarbonization it can be achieved but not in the way we are attempting it now.

To end I offer another little piece of Mr. Elliot from his poem 'Little Gidding', written in 1942, which expresses something of my understanding of what this paper is all about, for I did not know when I started its journey and I do not believe it by any means ended yet.

' We shall not cease from exploration

And the end of all our exploring

Will be to arrive where we started

And know the place for the first time.'

Thank you.

Glossary

AGW, Anthropogenic Global Warming

Al, Alumina

BEV, Battery Electric Vehicle

BF, Blast Furnace

BOF, Basic Oxygen Furnace

BoE, Bank of England

CCC, Committee on Climate Change

CCP, Chinese Communist Party

CCS, Carbon Capture and Storage

CO2, Carbon Dioxide

COP, Conference Of the Parties

D, Decarbonization

DRI, Direct Reduced Iron

EAF, Electric Arc Furnace

GE, Green Energy

GH, Green Hydrogen

GS, Green Steel

HBI, Hot Briquetted Iron

I & S, Iron and Steel

ICE, Internal Combustion Engine

IEA, International Energy Agency

LNG, Liquid Natural Gas

NG, Natural Gas

NZ, Net Zero

O&G, Oil and Gas

ONS, Office of National Statistics

QE, Quantitative Easing

Si, Silica

SMR, Small Modular Reactors

SWF, Sovereign Wealth Fund

TSE, Tata Steel Europe

WEF, World Economic Forum

VC, Victoria Cross