Innovation and complex governance at times of scarcity of resources – a lesson from history

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Abstract

Historians understand the important role that access to critical raw materials has played in the development of civilizations, however access to materials has regularly led to distrust and conflict. Near future material scarcity scenarios appear to be severe and could include a mix of price volatility, supply disruptions and geopolitical tensions. Materials scarcity would affect the supply side of a range of materials upon which high-tech and renewable energy industries rely.

Historically, materials restrictions were placed by societies, onto themselves and were generally short term or limited in nature. The current materials scarcity challenge, whilst being self imposed, will be long term and global in nature.

One fundamental challenge will be to explore historical case studies that give us a reference point to explore potential responses. There are numerous case studies over the 20th century – mainly driven by conflicts and sanctions. This paper examines one case in particular – that of Britain during World War Two. This case has a number of facets that make it very useful for analysis. The first of these is the length of time – counted in years. Secondly - the materials involved and in particular the metals and the lack of easily available substitutes. Thirdly - the role of secondary sourcing (recycling and reuse). Fourth – it explores the role of government in facilitating change. The final and prime facet of the case is the role of innovation and design.

This paper will derive lessons that can be learnt from the case and show clearly how they may give indications of current responses to materials scarcity scenarios.

Keywords

Materials security, industrial design, materials substitution and sustainable innovation.

1.0 Introduction

There is a long history of countries finding themselves in conflict over resources.

An interesting example of this can be seen in the 17th century conflicts between England and Holland known as the Anglo-Dutch wars. There developed an intense rivalry between England and Holland as a result of their expansion in maritime trade and the growing demand on North Sea fishing, with the situation being exacerbated by the growing military strength of the Dutch since the end of the English civil war. Trade goods from the resources in the East Indies were being shipped into Amsterdam and that of the West Indies to Flushing (Vlissingen). Exports from England and Scotland passed to the Continent through Dort (Dordrecht) and Rotterdam. The Dutch East India Company extracted the wealth of the Far East and this can be seen in the heavily laden great Dutch fleets that rounded the Cape of Good Hope several times every year. On the West African coast, the Dutch developed colonies and trading stations and the growth of the resulting trade was very lucrative. In North America the Dutch had grown a settlement on the Hudson and were expanding into the colonies of New England.

For the English, this Dutch claim on resources that they felt were theirs, resulted in the English parliament voting the enormous sum of £2,500,000 to fund a military conflict to curb the Dutch and take over the bases of the valuable raw materials. This action was driven largely by the increasingly powerful merchants and backed by the English monarchy. War at sea began off the West African coast in 1664, and spread to the North Sea in the following year (Lee, 1998)

In the June of 1665 an English fleet of more than 150 ships, manned by over 25,000 men and mounting 5,000 guns, met a Dutch fleet of equal strength off the English coast near Lowestoft, see Figure 1, The battle of Lowestoft 1665. A long fierce battle was fought, in which many of the leaders on both sides were killed. In this battle the English artillery was markedly superior in weight and skill, and the Dutch withdrew damaged but determined to carry on the conflict.

Figure 1 The Battle of Lowestoft, 1665, showing HMS Royal Charles and the Eendracht, painted in 1665 by Hendrik van Minderhout

A year later an even greater battle was fought in June 1666 off the English coast near Kent and for four days the English and Dutch fleets battled and the sound of the guns was heard in London. This time the Dutch were the victors but within two months the English fleet was refitted, put to sea and triumphed. But the war was not at an end. The French joined in, and it became clear that the once-mighty English navy could not protect England. In the interests of maintaining growth and trade the combatants began peace negotiations. Peace came and with it a new city: one laid out by the Dutch who ceded to the English one of their New World territories. It was called New Amsterdam and King Charles II renamed it after his brother, the Duke of York (Lee, 1998)

The key reason for this conflict, like so many others in history, was reliable access and control to cheap and plentiful key resources to support economic growth. In the 20th century the two world wars surpassed anything seen in history both in scale of human suffering and the extreme social / economic cost. It is a case study before and during the second of the world wars that this paper focuses on. In that conflict the access to raw materials be they

food, fuel or minerals became a decisive factor in the struggle. A clear example of this is the case of Britain and the threat posed to the Allied war effort by the unrestricted U-boat campaign being waged by Nazi Germany (Weir, 2007). Much has been written on the so called Battle of the Atlantic – the struggle between Hitler's U-boat fleets and the Allied Navies and merchant fleets and this paper will not explore this complex military campaign. It is however worth reflecting that the British Prime Minister of the time, Winston Churchill reflected that the campaign was *"the only thing that ever frightened me during the war"* (Overy, 1996). It was simply an attempt by Nazi Germany to sever Britain's lifeline of raw materials and essential goods and therefore knock Britain out of the war. It was one of the longest and most bitterly fought campaigns. In the period between 1939 until 1942 the treat of Nazi success was very high indeed. Britain's imports - upon which it heavily relied - were halved during the war as a result of shipping losses. This was however foreseen (partly as a result of British experiences in WWI) and steps were taken to mitigate such restrictions in supply before fighting broke out (Williams, 2003).

It is the actions taken by British in the run up to and during the Second World War to manage with material scarcity that form the core of this paper. The main reason for this focus is the likelihood of the world facing difficulties in the easy, reliable and cheap access to critical raw materials (materials scarcity) in the 21st century. These near future material scarcity scenarios could be severe and could include a mix of price volatility, supply disruptions and resulting geopolitical tensions. Materials scarcity would affect the supply side of a range of materials upon which high-tech and renewable energy industries rely.
The reason for choosing the case study of Britain during the Second World War is that that was the last time Europe faced widespread severe shortages in critical raw materials (albeit for different reasons and in different circumstances than those of today) over a period of time – counted in years. A second reason is the materials involved and in particular the metals and the lack of easily available substitutes. Thirdly – the Second World War response had a high profile role for secondary sourcing (recycling and reuse). The final and prime facet of the British response was the role of innovation and design. It is here that a specific case study is looked at in this paper – the R.A. Riddles designed War Department (WD) "Austerity" 2-8-0 heavy freight steam locomotive, designed and first built in 1943.
The scope of this paper excludes an analysis of the conflict in the Far East and Pacific and has a focus on the European / Atlantic theatre of operations. The focus is also on non-energy materials and more thought being given specifically to metals. This approach does not seek to separate the link between energy and materials but is a result of the word count limits.

This paper will derive lessons that can be learnt from the wider British wartime case and show clearly how they may give indications for contemporary responses.

A brief review of selected, current, European materials scarcity literature is undertaken to give a current perspective. This allows for a comparison between the actions of Britain in the past and the European response recommendations on today.

This paper does not to simply propose that events and actions in a material scarce environment from 70 years ago will provide a blueprint for actions required in the 21st century. What is proposed is, that given a set of materials challenges, the British found a response that worked – and that re-visiting their response may help in the search for solutions today.

Finally there is also another aspect worth considering. Whilst the Second World War did not start simply due to tensions over access to raw materials (although this did play a part) once the conflict had started access to raw materials played a significant part (and this was foreseen by the British). As can be seen in the Anglo-Dutch wars in the 17th century nations can find themselves resorting to conflict over resources. This paper aims to propose that by looking for ideas for solutions to material scarcity that occurred in a time of tension and war, we may help to prevent new conflicts over resources (Overy, 1996).

2.0 The British and their wartime supply challenge

The history of the Second World War is a subject that is continually being explored – and with good reason. The scale and impact of the conflict surpasses anything before or since. Even as we approach the 70th anniversary of the end of the conflict the physical evidence in towns and cities across Europe is not hard to find and the legacy of the conflict can be clearly seen in the shapes of borders and the political make up of Europe. For Britain the conflict began in September 1939 with Britain declaring war following the refusal of Germany to withdraw their forces following the Nazi German invasion of Poland. The conflict however was not unexpected and Britain had been preparing for the worst whilst hoping and working for the best prior to September 1939.

2.1 Key dates – Germany

At this point it is useful to plot some key events and dates in the rise to power of Hitler and the Nazi party (Overy & Wheatcroft, 1999):

- 1930 – Nazi party second largest political party in Germany,
- January 1933 Hitler & Nazi succession to power, October 1933 – Germany leaves League of Nations,
- 1935 introduction of compulsory military service and start of major rearmament,
- March 1936 – occupation of Rhineland,
- 1938 'Anschluss' (Union) with Austria, August 1938 – German military mobilisation, September – October 1938 the 'Czech' crisis - Munich conference of September 1938, culminating in the German occupation of the Sudetenland area of Czechoslovakia,
- March 1939 –complete German occupation of Czechoslovakia, September 1 1939 – Germans invade Poland, September 3 1939 – Britain declares war.

Munich 1938 was pivotal in helping Britain decide that Hitler could really not be trusted and it was in that year that Britain started to plan for a wartime economy in peacetime. Prior to that industrial preparation for war was conducted separately from military re-equipment.

As the European situation worsened in the late 1930's, the plans acquired substance and definition, and by mid 1939 they had become sufficiently detailed to offer a framework for the holistic organisation of wartime production and this was deployed in the first 12 months of the war.

This wartime framework was predominated by governmental organisation and plans (Postan, 1952).

2.2 Timeline – British events and activity in securing material supply

The following section outlines the time line of events and activity from a British perspective and this has been divided up into 3 periods that reflect the British activity. These periods are
I = 1917-1936 - lessons from the First World War,
II = 1936 – 1939 - A new focus, planning for war and
III = 1939-1944 - War and making the plan work.

2.2.1 Period 1 1917-1936 – lessons from the First World War:

This period of thinking reflected the British experience in World War I. This first period did little more than allocate, in a very general fashion, the industrial resources of the country for foreseeable wartime uses. During this first period plans for the acquisition of raw materials assumed that raw materials which might become critical on the outbreak of hostilities, would be bought as soon as the warning of an emergency was received.

May 1924 – 1927 Committee of Imperial Defence (C.I.D.) set up. Under this committee the sub-body which took charge of the economic and industrial plans was the Principal Supply Officers' Committee (P.S.O.C.). This committee was to prepare plans for the supply of commodities essential to a war effort; to ascertain and watch over stocks of raw materials; and to maintain a list of contractors capable of being drawn into war production.

1927: P.S.O.C. was split into:

- the Board of Trade Supply Organisation which looked after raw materials,
- and the Supply Board which had the duty of planning for the production of war-stores.

These bodies decided what materials would have to be controlled at the outset of a war and the productive capacity in the country.

Late 1920's – early 1930's: A special section of the War Office was set up. Appointment of an official - also chairman of Supply Committee No. 1. Task; direct planning of war potential

December 1933: Appointment of an advisory group of industrialists. The group gave a broad assessment of the potential resources that industry needed for the manufacture of armaments and set out the main principles for the development of a 'shadow' armament industry. Its views were also sought by the Cabinet and the Supply Board (not until 1939) on other aspects of industrial mobilisation. In general it made available to the Government

expert opinion on industrial matters at a time when government plans could not be disclosed to the whole of industry (Postan, 1952).

2.2.2 Period II. 1936 – 39 – A new focus, planning for war:

From here on thinking changed to reflect the new requirements of modern war. In addition the pace of events began to focus thinking. In this second period the final plans made for raw materials were more definite and concrete. Preparations in the field of raw materials included the final blueprints for future controls and measures to secure strategic stocks.

February 1936: Minister for Co-ordination of Defence appointed. In charge of all aspects of rearmament including those of war potential, and involved in all the major problems of rearmament, both financial and administrative.

1936: Radical change in the Government's attitude towards the accumulation of strategic reserves. The requirements of the Services had grown and firms were expected to turn over to war production more quickly than expected. Demands for raw materials in the early months of a war were expected to be very high. In addition allowance had to be made for considerable dislocation in European supplies; allowance also had to be made for the possibility that their neutrality policy might cut off supply of raw materials from the United States. The only way of meeting the new situation was for the Government to accumulate reserve stocks in time of peace.

June 1936: Policy and Requirements Sub-Committee of the Committee of Imperial Defence accepts the new situation and begin to plan for building-up of reserves of a number of raw materials.

1936: Minister for Coordination of Defence created. This minister was appointed to ensure a coordinated effort in rearmament.

1936–37: Planning officers appointed to conduct detailed planning of production, firm by firm – this work included gaining a detailed understanding of their material requirements.

1937: The Air Minister warned that so long as the Government did not allow rearmament to interfere with the normal processes of industry the re-armament programme could not be completed by the end of 1939.

1938: Secretary of the Committee of Imperial Defence wrote to the Minister for Coordination of Defence stating normal industry could not be allowed to continue. February 1938 the military Chiefs of Staff support this view. In assessing the situation they argued strongly against the policy of non-interference with normal trade.

1938: Discussions between ministries and service chiefs on setting up a ministry of supply. This ministry would take over total control of all production and the corresponding material supply. This was resisted by the cabinet due to the fear of interfering with industry in peacetime but chiefly because in its view the existing arrangements were sufficient. A Ministry of munitions set up.

March 1938: The Cabinet decided that the policy of ‘the course of normal trade should not be impeded’ should be ended.

March 1938: The Prime Minister in the House of Commons stated that existing plans must be accelerated and there must also be increases in some parts of the programme. From this it followed that 'men and material will be required, and rearmament work must have first priority in the nation's effort. The full and rapid equipment of the nation for self-defence must be its primary aim'

Oct – Nov 1938: Though 'business as usual' was now pronounced to be over, 'life as usual' still went on. With respect to supply and production of defence equipment over civilian production the cabinet did not establish anything more than a rough and superficial system of priorities. This encouraged manufacturers to accept armament orders at the expense of their ordinary business. They did not do so for reasons of profit – as there was no advantage to be had – but out of a sense of patriotism and duty. There was at this time no question of denying raw materials to non-essential businesses. Civilian demands continued to compete with military needs for production resources on more or less equal terms, and until the initial months of the summer of 1940, little was done to check competition by political and administrative measures.

April 1939: Secretary of State for War expressed a desire for a Ministry of Supply. The cabinet was politically and psychologically less afraid of disturbing the normal process of industry. It became clear in 1939 that the Ministry of Supply would not be formed in the style of previous ministries and committees

June 1939: The Cabinet decided that the Ministry of Supply would be so overarching that it could take over the responsibility for raw materials, and thus make it unnecessary to establish a separate Ministry of Material Resources.

July 1939: The blueprint of the concept of a new Ministry of Supply finalised. At the end of July the Government authorised the Board of Trade to purchase for war reserves.

August 1939: Ministry of Supply started operations in August. The Ministry of Supply – took over the Production, Contracts and Inspectorate branches of the War Office. This aspect means that Research and Design comes under the ministry of supply. Among the plans worked out in the concluding phase of peace were also various schemes for rearranging the sources of supply to suit the expected changes in international trade and communications; to develop home supplies of commodities like timber, iron ore, flax; to secure greater economy in the use of scarce materials and their substitution by other materials. Production would be based on a system of priorities (Postan, 1952).

2.2.3 Period III 1939 – 1944 – War and making the plan work

1939: On the 3rd of September 1939 war breaks out. Several important commodities, such as bauxite, zinc concentrates, wool, flax, rubber, were on the 3rd September available in quantities sufficient for nearly six months of the estimated annual requirements at war. The main feature of the pre-war plans was their avoidance of too clear-cut a principle. But this very avoidance set the tone for the future history of raw materials. In the first place no attempt was made to establish an overarching single organisation. The planners assumed that the separate problems of individual materials would in each case determine the character of the controlling organisation, and that in the course of war the changing supply position would lead to change in the organisation of the controls. Most, but by no means all, of the control were to be given statutory powers to control prices and to lay down conditions of purchase, sale and use. Compulsory government controls were to be imposed on some materials, but where a material, though essential for the national effort, was not expected to be critical, e.g. rubber, asbestos, silk, the control was to be organised on a voluntary basis: as a rule by the corresponding trade association under the supervision of the Raw Materials Department of the Ministry of Supply. The instrument of policy would be licensing system and not allocations.

1940: As the first phase of the war (the ‘phony war’) was drawing to an end it was becoming obvious that a large proportion of scarce materials were used in producing non-essential

products, and within war industry itself materials were not distributed in the quantities and in the order which the national need demanded. A group of 'essential' commodities—iron and steel, some non-ferrous metals, wool, leather, timber, hemp, flax, jute, paper and aluminium—which were scarce or were in danger of becoming scarce were placed under full-fledged controls. Another group of commodities, including rubber and mica, was subjected to the voluntary control of its trade associations, and still another group, including plastics and some non-ferrous metals, were left uncontrolled (Taylor, 1966).

May 1940: The system of priorities could not be continued. It proved too crude a method of discriminating between objects of greater and lesser importance. It implied that no requirement of lower priority could be met as long as any requirement of higher priority remained unsatisfied. From the administrative point of view the system was highly inefficient in that it led to the accumulation and conflict of requirements to which high priority had been given. As a result, the final sorting out of relevant urgencies was often left to accident or to the decision of the firms themselves.

June 1940: Allocations introduced. Under a system of allocations each requirement could assessed in the order of its importance and be given a corresponding share in the supply of materials. Those materials which were under the jurisdiction of the Materials Priority Sub-Committee were now allotted to each department in more or less firm quotas, and the germ of an orderly system of allocations was created. The period for which the allocations were made was reduced from a year to six or even three months, and the departments had to ensure that the allocations they sponsored did not exceed the total amounts allocated to them by the Materials Priority Sub-Committee. In the later stages of the war, with the general tightening of the system, individual materials were gradually transferred from the second group to the first, and materials not previously controlled were brought under control.

June 1940: Introduction of the first of the Limitation of Supplies (Miscellaneous) Orders designed to reduce the consumption of raw materials in a number of civilian industries.

Late 1940: The growing scarcity of raw materials was not, however, wholly due to the cutting off of customary sources of supply and would in any case have developed with the increased requirements of war industry. The Ministry of Supply was thus called upon to remedy at short notice a series of shortage, some of which were immediate, others merely probable. One of the measures it now took was to extend the earlier schemes for developing domestic sources of supply and to improvise a number of new ones.

Development of home sources inevitably created difficulties and problems for the users. The iron ore mined at home was, as a rule, of inferior grade, and especially of lower iron content than the import ore. Home-grown hardwood was not always a good substitute for imported softwoods. Nevertheless, by the end of 1941 industry had adapted itself to the changes, and in this way the country became more self-sufficient in its supplies of raw materials than it had been in peacetime.

July 1941: Research and development of weapons were taken out of the competence of the production divisions and brought together under a centralised department, and placed under a Controller General of Research and Development.

Late 1941: The entire system of committees was rearranged. Originally under the Ministerial Priority Committee there had been two separate sub-committees for production and for materials; the two were now renamed the Joint Materials and Production Priority Committee. With shipping getting scarcer—both in fact and in prospect—the Government had to meet the raw materials problems not only by larger orders in regions yet untouched by war, but also by various measures of economy at home. Hence the overwhelming need for greater economy in the use of raw materials and for more efficient distribution of available supplies.

End 1941: Indeed there was some ground for satisfaction. Assisted by better estimates both of requirements and supply the officials had in the course of 1941 succeeded in fully organising the distribution of materials and capacity. Towards the end of the year allocations of materials generally took one of two forms. They could be made, as in the case of steel, cotton and timber, on a departmental basis, i.e. the Materials Committee would allocate to each department a certain tonnage and leave it to the department to determine whether or not the Control should issue the material to individual contractors; or else the material, such as rubber, paper and jute, would be allotted not to the department but the 'end use', i.e. the product to be manufactured.

1942: The conflict in the Far East, the diversion of US shipping and the US switch to her own military build up causes a new strain on supplies. More importantly was the new shipping situation. In 1942 the U-boat activities in the Atlantic raised the rate of sinkings to new and alarming peaks. It is, therefore, no wonder that the expectations of raw materials imports had to be drastically reduced.

Dec 1942: Indeed, so dangerous appeared the position and prospects of stocks that the Prime Minister was obliged in December 1942 to intervene with a direction that stocks

should not be allowed to drop to a level which would leave this country without 'elbow room' for possible contingencies. It was however sustained. At no time during the period was munitions production in the country interrupted or even slowed down by a failure in the supply of raw materials. This was due in part to a decline in munitions requirements, but also to the steps which the Ministry of Production took in April 1943 to restrict consumption.

June 1943: total stocks of raw materials began to rise again by midsummer 1943

1943 – 44: The higher rate of imports in 1943 and 1944 was not only, and perhaps not even the main, cause for the satisfactory rate of supplies. Domestic sources also proved very buoyant. The main relief, however, came neither from the better rate of imports nor from the higher output from domestic sources, but from a much reduced rate of consumption (Postan, 1952).

2.3 Main points from the British approach to critical material supplies 1936 - 1944

A useful starting point would be to ask if the approach taken by the British with respect to securing critical raw materials was successful. The approach was successful with regard to maintaining production of essential war winning products – which was the primary aim of the planning activity.

2.3.1 The period of war preparation in a time of peace 1936 – 1939

This period from the perspective of this paper is the most interesting as the planning and preparations had to be carried out in a period of peace when the British economy, business and trade had to continue to function whilst planning and changes took place. The time span is under 4 years and the changes that took place were profound. In terms of preparation for materials scarcity Britain was as ready as could be expected by 1939 for the total disruption of material supplies. The starting point was the acceptance by both government and industry that there was a need for planning – and this with in the backdrop of society wanting to avoid war and not use tax revenues preparing for such an eventuality. The next step was the acceptance of a plan to build up reserve stocks of critical raw materials – which was enacted shortly before the conflict started. Next the government appointed officers to work with industry to understand fully their material requirements. Following this review there was an acceptance that ‘business as usual’ could not continue. This is interesting because it must have gone against the grain of the private companies involved but they accepted this

approach. Once the end of ‘business as usual’ was accepted then the setting up of the Ministry of Supply with complete control over production was created. This peacetime period laid down all the plans and structure required to tackle the on-coming crisis.

2.3.2 The period of plan adaptation as material scarcity bites 1939 – 1944

This period saw all the plans laid down in the previous 4 years being tested. This meant that were there were weaknesses then the system was adapted and changed to suit. It could be argued that this occurrence was envisioned and planned for in itself. The major change was the move from the priority system to one of allocation which given the benefit of hindsight seems a much better approach. The priority system was one developed in peacetime and designed to work with ‘free’ companies. As the Ministry of Supply developed and research and design as well as materials, production and even delivery came under their control the freedom of companies was restricted and allowed the introduction of allocation. Essentially it was a difficult transition from free enterprise to one of state controlled enterprises.

Whilst allocation was reviewed, the reduction in consumption seems to have become a key factor. If less could be used (starting with good design), more re-used and alternatives found then this would have a significant impact. The nation as a whole was engaged in this activity (the nationwide absence of many fine railings bear testimony to this). Equally important was the drastic reduction in the production and consumption of non-war essential products. Civilian rationing and the simple absence of goods and products in stores ensured this happened.

2.4 Case study: The WD (War Department) 2-8-0 “Austerity” Locomotive

This case study covers the design of a heavy freight steam locomotive that was introduced in 1943 for war service. A total of 935 were built in Britain. It was designed by R.A. Riddles who had been appointed Director of Transport Equipment at the Ministry of Supply in 1939. The locomotive was designed (see figure 2) to equip the British armed forces to provide military supply in continental Europe following the planned for invasion. The essential information of this case can be viewed on a British Ministry of Supply newsreel - "Locomotives for Second Front" – with a precursor title “The other man’s job” – meaning that not only fighting troops were winning the war – product design, singular uniform design, lower materials consumption, fit for purpose performance, adaptability and design for repair and re-use were also winning the war. The other point made – and can be seen in the clip, is the role of women in the production process – (see figure 3). This is indicative of the society-wide materials scarcity engagement process where everyone did their bit (Locomotives for second front, 1943).

Figure 2. A team of designers with the design drawings of the “Austerity” Locomotive in 1943

The designers worked to a ministry of supply order and for example reduced steel casting consumption from 21 tons to 4 and eliminated the need for asbestos lagging. The performance was however not high. It could haul a 700 ton (usually freight) train but worked best below 35 mph (56 km/h). This is against the backdrop of locomotives like the LNER class A4 Mallard which is still the holder of the official world speed record for a steam locomotive at 125.88 mph

(202.58 km/h) in July 1938. It broke the German (DRG Class 05) 002's 1936 record of 124 mph (200.4 km/h). The noise of the “Austerities” earned then the nickname of “Bed Irons” so it appears they hardly represented sleek beauty in product design – but they got the job done. They were designed in and for material scarce environment.

Of note at the end of the war over 180 ‘Austerity’ locomotives were handed over to the Nederlandse Spoorwegen (Dutch National Railways) to help them to re-build their rail system.

Figure 3. The first “Austerity” locomotive and a team of mainly women at work in 1943

3.0 Critical Raw Materials (Materials Scarcity) in the 21st century

As this paper clearly points out communities and nations have regularly experienced scarcity of materials for millennia. This has normally been localized, short term in nature and technology developments eventually overcame the situation be that new mining technology or the technology of war. The challenge of the first half of the 21st century will not present us with anything new but it will be on a widespread, multi-dimensional, global scale with no quick - easy fixes available. The literature on the more recent research on this phenomenon is not widespread but it is growing. This section undertakes a limited review of some key publications from the past few years and uses them to gain an understanding of the situation from an activity perspective. This review is not intended to explore the extent of the phenomena (which materials and when impacted) but to point out the strategies proposed with a view to effective preparation.

3.1 Diederen, TNO, The Netherlands

Diederen proposes that if global economic growth is exponentially sustained, the world will soon 'run out' of cheap and plentiful metal minerals of most types. He suggests that extraction rates will no longer be able to follow demand. He also links energy (in particular the concept of 'peak oil') with the materials scarcity problem because of the embedded energy in materials. He proposes that there will not be timely and adequate technological breakthroughs to solve the material scarcity challenge.

Diederen argues that conventional mitigation strategies including recycling and substitution are necessary but insufficient .He goes on to suggest that as soon as possible there should be the creation of a co-ordinated policy of managed austerity to address metal minerals shortages.

He proposes the application of a framework of what he terms 'managed austerity' which enables a transition towards the application (wherever possible) of the 'elements of hope'- these being the most abundant metal (and non-metal) elements. This approach would allow for the conservation of critical metal elements for essential applications where complete substitution is not viable. He concludes by proposing that reducing consumption significantly is the solution. In Figure 4, *Roadmap towards sustainability?,* Diederen proposes a future where product lifetime is tripled, re-cycling is at +90% and energy consumption is like that in the 1950's/60's by 2030 (Diederen, 2009)

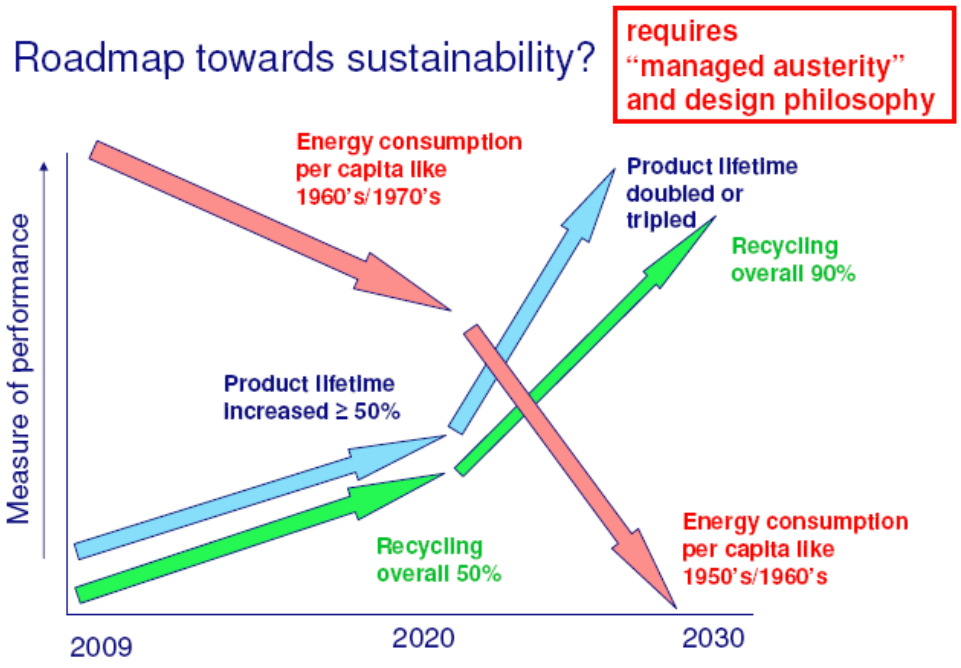

Figure 4 Roadmap towards sustainability?

3.2 Wouters & Bol, M2i (Materials innovation Institute), The Netherlands

Woters and Bol propose that materials scarcity is about the shortages in metal and mineral resources which are expected in the following decades as a result of levels of consumption predicated by a growing world population.

Their work explores the challenge of poorer quality ore grades and the pursuit of technology to overcome this.

They also explore the more near term challenge of geo-politics playing a part in creating the phenomena of scarcity by restricting or controlling supply.

The report aims to highlight awareness of the phenomena of materials scarcity with a focus on industry in the Netherlands.

They maintain that the problem is global in scale, complex and multi-dimensional.

In terms of solutions their tendency is towards properly directed material innovation. In more detail the first element is to reduce the use of materials, by more efficient production processes and longer lifetime of products. The second element is to greatly enhance the recycling of materials. The goal should be no less than ensure that materials are fully recycled to serve as new materials for new products, which is the Cradle to Cradle philosophy. The third element in the solution for material scarcity is to find alternatives for scarce elements and reserve these scarce elements to be used in specific applications for

which no alternatives are yet available. These three elements or building blocks to work on material scarcity are combined in this report into a 'Trias Materialis'.
They propose that the search for solutions for material scarcity will require the concerted effort of universities and research institutes (to find substitutes for scarce materials and work on material innovation which enables the recycling of the materials), industries (to develop new products and production processes requiring less material and energy, and including recycling), and government (sponsoring long term research in material scarcity solutions and providing a level playing field for industry to implement material scarcity solutions).
They feel that the transition to sustainable use of materials will be as difficult and time consuming as fighting climate change or replacing fossil energy by other, sustainable energy sources (Wouters & Bol, 2009).

3.3 Kooroshy et al, Scarcity of Materials –a strategic security issue

This report from the Hague Centre for Strategic Studies looks at the threat to national security as a result of tensions over scarce resources. More specifically at whether minerals may be scarce in the near future and the geopolitical and security implications this may have. They point out that it is not a question of running out but there are limitations to what can be effectively extracted.
They make the important point that mineral reserves are not a physical but an economic variable. Scarcity of minerals is not about depleting existing stocks but about the amount of extraction that becomes profitable under existing market conditions.
The control of the supply of scarce minerals is in the hands of a few countries and companies. Faced with the prospect of increasing demand and tightening supply of minerals used in critical applications, access to scarce minerals and stockpiles are increasingly framed as issues of vital interest or national security. Mineral scarcity is no longer a trade-issue but an issue of strategic interest.
They propose that Europe's policy response to this emerging challenge has been rather slow and hesitant. They seek an approach of a hard and united European position on these issues should be actively promoted in multilateral forums like the WTO, World Bank, or the G-20. They observe that simultaneously, Europeans should demand that allies in the G-8, NATO, World Economic Forum, OECD and similar institutions join the EU in actively protecting and promoting the free market principle in mineral markets.
The authors propose that coping with the challenge of mineral scarcity will depend mainly on four key factors:

1. The development of energy scarcity, as energy is key to mineral extraction and processing.
2. Substituting scarce elements, particularly in emergent technologies.
3. The extent to which mineral consumption per capita can be reduced in affluent societies, and scarce mineral resources will be re-used and recycled globally.
4. The balance between increasing geological and geographical sources, and R&D in mining technology (Kooroshy, et al, 2010).

3.4 Catinat - Critical Raw Materials for the EU

This large (including a significant appendix) report looks at raw materials as essential for the EU economy, and the Group proposes that availability is increasingly under pressure. This report identifies a list of critical raw materials at EU level.
With regards to geological availability, the Group observes that, geological scarcity should not be considered as an issue for determining criticality of raw materials within ten years. The report considers changes in the geopolitical-economic framework that impact on the supply and demand of raw materials. This report analyses a selection of 41 minerals and metals. In line with other studies, the report puts forward a relative concept of criticality. Two types of risks are considered: a) the "supply risk" and b) the "environmental country risk". Building on existing approaches, this report sets out an innovative and pragmatic approach to determining criticality.
The Group considers that 14 raw materials are critical. One of the most powerful forces influencing the economic importance of raw materials in the future is technological change. The Group recommends that the list of EU critical raw materials should be updated every 5 years and that the scope of the criticality assessment should be increased.
The Group recommends that steps be taken to:

- . Define critical raw materials
- improve the availability of reliable, consistent statistical information in relation to raw materials and disseminate this information effectively;
- encourage more research into life-cycle assessments for raw materials and their products on a “cradle-to-grave” basis;
- further analyse the impact of emerging technologies on demand of raw materials.
- promoting research on mineral processing, extraction from old mine dumps, mineral extraction from deep deposits, and mineral exploration in general – including in homes

- Geo-politics - maintain current EU policy choices in the negotiation of bilateral and regional trade agreements
- Make recycling of raw materials more efficient
- Substitution should be encouraged
- . Minimising the raw material used to obtain a specific product function; including smart production and substitution

The report notes that many of the measures above are interdependent and in most cases an interdisciplinary approach is needed, as shown for metals in figure 5 (Catinat, 2010).

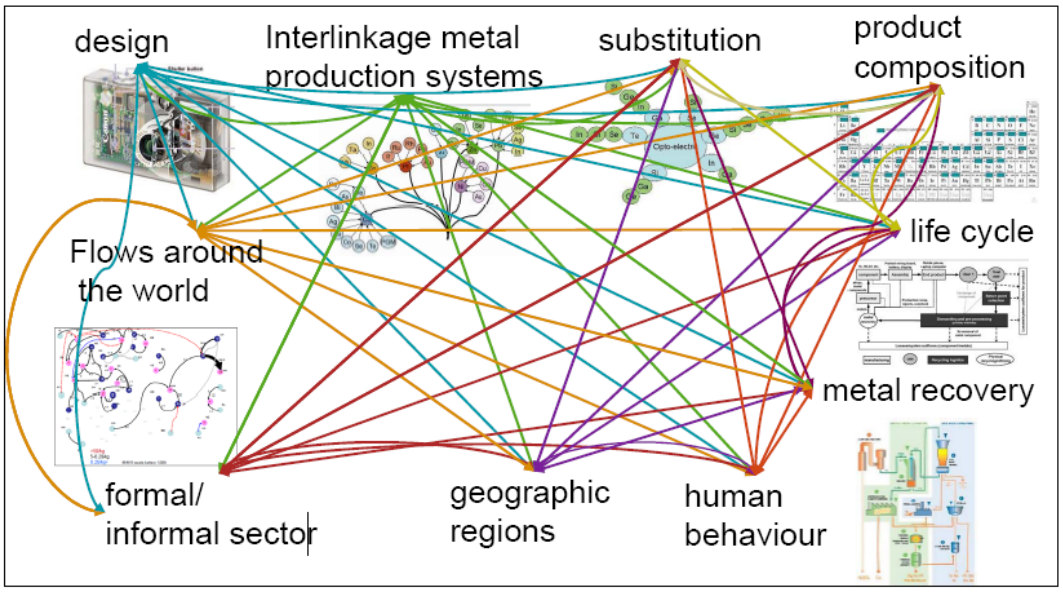

Figure 5 Interdependence of measures – The case of metals

3.5 C- Tech innovation / KTN Material Security - Ensuring resource availability for the UK economy

This UK (British) report pre-dates the others included by a couple of years. This work proposes that material security concerns the access to raw materials to ensure military and economic sufficiency. They see the situation as a limited short term availability of some raw materials, widespread large increases in raw material prices, oligopolistic industry structures and dependence on a limited number of sometimes politically unstable countries as sources of key materials. They make a number of proposals:

Recommendations for policy makers include;

- Incorporation of the social costs of environmental impact into the costs of mining and metal production companies

- Assistance with environmental and social regulation of industries in developing countries
- Adopt policies that encourage aggregation rather than dispersal to the environment
- Maximising recycling and recovery rates of metals

Recommendations for business include:

- Promotion of products mined and produced using green strategies
- Voluntary codes and agreements to incorporate environmental externalities
- Products should be designed to discourage dispersal to the environment and easier recovery
- Adopt Life-Cycle Management policies

Recommendations for innovation funders include:

- Encourage projects that develop substitutes for the least secure metals
- Take account of displacement effects when funding "green" technologies that use insecure materials including technologies such as nanotechnology that are potentially substitutes
- Technologies to enable "mining" of waste streams for insecure metals
- Stimulate sustainable design approaches that consider the overall life-cycle issues rather than one specific component (energy consumption during use), (C-tech innovation, 2008)

3.6 Overview of the Critical Raw Materials (Materials Scarcity) in the 21st century literature review – key points

There are a number of key themes that are common in the literature reviewed. The diagram shown in figure 3 captures the main points that can be related to actions. The first of these is the design of products. The recommendations by all the reviewed works proposed that product design and innovation were key in reducing the risk of the impact of materials scarcity. The areas of focus that designers should look for are material substitution (using a less critical material), using less material quantity and designing for product re-use and/or recycling (life cycle approaches). This design aspect extends to investigating the possibilities offered by nano-technologies. The second key recommendation is related to mining. The proposal is to ensure that mineral reserves within the EU are exploited as fully as possible. The third recommendation is securing supplies via the development of relations with supplier countries – including a focus on developing countries. The fourth recommendation is mining materials from 'society'. The fifth recommendation is to conduct an audit of materials use in the EU – an appraisal of where and how much of a material is used across all sectors.

4.0 Discussion

The first question to be addressed is does the WWII case have anything to say today? The answer is, unsurprisingly, a complex one.

The first of the points that may prove useful is simply that severe critical material scarcity on a prolonged large scale can be coped with. The literature demonstrates that the reduction in supply of critical raw material imports did not result in a corresponding decline in industrial production. There has been a tendency for some in society to indicate that given the scale and complexity of the threat facing nations today there is little that can be done, but this case suggests there is a lot that can be done quite quickly. There is however a cost attached to the planning and preparation phase. Overy and Wheatcroft point out that the financial cost of arms buildup (including spend on material stockpiling) to the British economy was totally unsustainable and that if war did not start by late 1939 then the spending would have to be dramatically curtailed (Overy & Wheatcroft, 1998). This economic cost went on through the war and by February 1946 the state of Britain's finances was in a very poor way (Lee, 1999).

The timescales involved are also useful to note. A more serious approach to planning did not start until 1936, were ready just before the war started in August 1939 and most modifications to the planning were completed by 1944. This means the preparation phase took less than 4 years to complete. This indicates that a significant amount of preparation can be completed very quickly. There is, however, a note of caution with this pace of preparation – again the financial cost both the government and business. If the planning and subsequent change can be introduced over a longer period of time then the cost and the impact of the cost can be reduced. It is also useful to note that with timing came a plan that adapted to circumstances and allowed for increased government intervention as the events unfolded.

The materials plan also held course no matter what happened politically or militarily. An example of this is the fall of France and the Low Countries and the change of war leader from Chamberlain to Churchill in May 1940 (Lee, 1999)

It is interesting to note the involvement of business from an early stage – 1934 onwards. This involvement continued through the war with senior positions in government being given to industry leaders – Beaverbrook being a good example of this. It is also interesting to note that business was in an advisory capacity and not an executive one. It is also worthy of note that industry declined their domestic production more rapidly than the government instructed them to do and this was not primarily for reasons of profit or business gain but through a

sense of patriotism. What was key was the sense of 'buy-in' from business leaders, even when this went against their own interests and instincts.

The case offers a series of lessons that may be of even greater interest. The first of these is the build-up of strategic stocks of critical raw materials. This is currently not prominent in the recommendations for most of the authors but was a response in the late 1930's. It allowed a buffer period for new sources to be exploited, tougher restrictions to take place and for new more efficient and effective designs to be developed. Buffer stocks allowed a breathing space for industry to adapt. Today the promotion of building up of significant strategic reserves would prove difficult for governments to enact. It could disrupt commodity markets, de-stabilise prices and involve government at the heart of product production. That is before the question of cost to the taxpayer arose. In the late 1930's the threat was real and apparent and on the doorstep – today the threat cannot even be agreed upon.

Connected with strategic reserves, the phase 3 of the case (1939 – 1944), introduced critical raw material allocation to industry. This is the most direct challenge to the model of free market economics of today. It is essentially rationing based on a governments view of priority products. The philosophy of consumer demand does not predominate. This also has a knock-on effect on the economic model of consumption based growth – and nearly all economies in the world do not have a proven, successful, alternative model to hand. The effect of the British strategy in the 1930's and 1940's were economically disastrous (Lee, 1999). Allocation, armaments orders and industry product planning strategies curtailed domestic consumption but also consumption across the board was dramatically reduced. It is this reduction in demand through making do with less that had a very significant part to play in the success of the strategy. It is interesting to note that with decades of Total Quality Management, Kaizen, Lean Production and Just in Time that the current raw material consumption models are – in a wider sense, so profligate.

This approach of valuing every scrap of raw material extended society wide and was not just an industry phenomenon. In the domestic arena people were encouraged to find scrap metals and un-wanted metal products for use in the war effort. The strategy of make do and mend (driven by the very limited availability and rationing of domestic products) in the home meant that there was a society wide value given to every product and item of material. This thinking was born out of a society that had, in widespread living memory, experienced the First World War and the economic depression of the 1930's. It was a society more

accustomed to haves and mostly have not's. In Western Europe today such a make do and mend approach would be very difficult to.

The final key point of note is that of product design. It is clear that this aspect was instrumental in not only reducing material consumption, but also in developing war winning equipment. The reduction of material consumption, production in quantity, on time delivery and optimal performance of course go hand in hand and are predicated by the product design activity. There was a consistent trade off to be balanced between developing new products which match or outperform the enemy, producing products in sufficient quantity to equip ever growing forces (and war losses) and designing products that consume less material per product. In many cases the allies opted for equipping their forces based on quantity and efficiency. The goal of high performance against the competition was not always achieved. Mass production of a design usually resulted in the opportunity to optimize that design with regard to reducing material use and to re-cycling / re-use of products. This approach is more difficult when constant new designs are produced that keep pace with the competition (or enemy). This point is made in the case of the "Austerity" locomotive in section 2.4. In a wider sense this point is made in a range of "Austerity" designs that were seen in the post war period.

5.0 Conclusion

This paper asks if there is anything to be learnt from the last time Europe experience severe critical materials scarcity and shortage. The historical case study of Britain is explored. A brief review of selected, current, European materials scarcity literature is undertaken to give a current perspective. The discussion then asks if given the current challenges is there anything to be learnt from the British case.

This paper has outlined the sequence of key events in Britain that formed the planning for critical material scarcity leading up to World War 2 and the adaptation made to that plan when war broke out. The time period is sub-divided into 3 with the focus being on the second of these periods – 1936 – 39. It was in this period that peace-time planning for critical material scarcity in war was made. A number of key policy and industry actions were taken that built up as the threat and likelihood of war became clearer. They deployed a precautionary principle. They based their planning on severe restriction with regards to continental European supply, restricted Empire supply and severely restricted USA supply. In the event the continental supply was non-existent (after spring 1940), the Empire supply was as restricted as expected and the USA helped more than expected (up to Dec 1941). In general supply was as bad as feared and their critical raw material supply plans more or less worked.

The current European perspective on the potential materials scarcity challenge offers a range of recommendations. As a rule most of these recommendations appear to align with most of the early actions of Britain in 1936 – 1938. These are:

- If sufficient planning is made and timely action taken the situation can be coped with.
- The planning and action needs to have consistency over a long term timeframe.
- There needs to be a full appraisal of the consumption of material.
- Consumption of materials would need to be limited.
- Re-cycling and re-use have an important role to play.
- Planning for ‘managed austerity’ may be required.
- Government lead (national and EU) with involvement from industry is required.
- Society wide engagement will be important and for that awareness will be needed.
- Product design is at the core of coping with critical scarce material futures.

6.0 Recommendations for further work

The first logical step would be to arrive at a shared (as far as possible) understanding of the phenomena of materials scarcity. This should be arrived at in a multi-disciplinary manner. This approach could result in a full mapping of the use of scarce materials

Once that has been established and risks quantified then a widespread awareness and buy in from business and wider society would be required. Materials scarcity can be managed as a strategic change problem affecting the product innovation process and further work needs to done to fully understand this

This task could be started by conducting an assessment of the technical and economic feasibility of different solution strategies for dealing with critical materials. This would be complimented by research into material substitution and/or enhanced recycling options (depending on the product under consideration).

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