SUSTAINABLE MATERIALS SCIENCE – ENVIRONMENTAL METALLURGY

Volume 1 – Origins, basics, resource and energy needs

J.-P. Birat

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If further generations are to remember us more with gratitude than sorrow, we must achieve more than just the miracles of technology. We must also leave them a glimpse of the world as it was created, not just as it looked when we got through with it.

Lyndon Baines Johnson

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Table of contents

Foreword

In an e-mail about half a year ago, Jean-Pierre in between other things said and I quote: "I have spent the last year, during my free time, writing a book on materials sustainability, meant to be a textbook. It corresponds to what I have been teaching at USTB [University of Science and Technology, Beijing] every summer, lately." My first reaction was "Free time? - When does he sleep?" This reaction relates to knowing Jean-Pierre's work for several decades, and for the last twenty years, I have also had the pleasure of knowing him personally both as a colleague and as a friend. Like Jean-Pierre, I was borne in the first half of the last century. I have mainly worked as a researcher and teacher in Material Science, in particular Extractive or Process Metallurgy, and as the years have passed, my interests have developed towards the inclusion of environmental issues in these activities. Being a university professor naturally requires that I teach several courses each year, and my favourite is "TMT 4330 Resources, Energy and Environment" which incidentally is the name of my research group at Department of Material Science and Engineering, Norwegian University of Science and Technology.

Jean-Pierre Birat was born in France in 1947. He has an Engineering background with graduate studies in metallurgy and materials science at École des Mines in Paris and at the University of California at Berkeley. He has since worked mainly with the French Steel research, i.e. at IRSID, now ArcelorMittal Research, but also at Nippon Steel, Hiyoshi, Japan.

After retiring from ArcelorMittal, he was the secretary general of ESTEP, the European Steel Technology Platform in Brussels. He is an honorary professor at USTB, in Beijing. He now runs a consultancy, IF Steelman, where paper and book writing, teaching as well as participation in conferences and various committees are the main matters.

Jean-Pierre has worked in Solidification, Continuous Casting, Steelmaking, Electric Arc Furnace Steelmaking, environmental issues related to steel production and use, societal dimensions of metals and materials related in particular to the Circular Economy and to LCA/MFA/SAT methodologies. He was in charge of various research groups and departments and was finally a world expert for ArcelorMittal, while running several other things. He was the director of the two largest international research programs on low-carbon-intensity steel

production: "CO_2 breakthrough technologies", Worldsteel and "ULCOS - Ultra Low CO_2 Steel technology". He also founded the "SAM - Society & Materials" conferences and the SOVAMAT [SOcietal VAlue of MATerials] initiative and is chairing its scientific committee. In 2018, SAM12 takes place in Metz, Jean-Pierre's Hometown.

He has authored more than 500 papers, conference presentations and Keynote lectures, in a research context where grey literature is the norm. He has also received several awards, including the Bessemer Gold medal. Moreover, Jean-Pierre is on the editorial board of Metallurgical Research & Technology (MRT), formerly Revue de Métallurgie founded in 1904 by the famous metallurgist Henry Le Chatelier. MRT is a peer-reviewed journal dedicated to ferrous and non-ferrous metallurgy.

This book, "**Sustainable Materials Science – Environmental Metallurgy**" is entirely built on the enormous knowledge base that supports the accomplishments sketched above, and understandably; one volume was not enough, and we have:

I. Volume 1, Chapters 1 – 9, Materials: origins, basics, resource & energy needs;
II. Volume 2, Chapters 10 – 19, Materials: pollution & emissions, biodiversity, toxicology & ecotoxicology, economic and social roles, foresight.

Although this Foreword focuses on the first volume, I might stray into the realms of Volume 2 on occasions, partly because the introductory chapter covers both volumes, but not least, because "…everything is connected", and references are given to topics and details further deliberated in Volume 2.

In short, the book provides a multi-disciplinary approach that integrates the physical and earth sciences with aspects of the social sciences, energy, ecology and economics.

After several futile attempts to describe this book further, I stumbled across the following quote:

> *"For me, a landscape does not exist in its own right, since its appearance changes at every moment; but the surrounding atmosphere brings it to life - the light and the air which vary continually. For me, it is only the surrounding atmosphere, which gives subjects their true value.*

In my opinion, this quote is a quite precise description of this book by understanding "landscape" and "subjects" as Materials, and in particular Metals. The "surrounding atmosphere" is then Society and Environment. *Claude Monet*[1] is of course the famous French painter from the period called ***Impressionism*** emerging in France around 1860.

One of Monet's most popular paintings, ***Lady with a Parasol***[2] highlights both the model and her son. Her parasol, which also creates a contrast of light

[1] http://www.theartstory.org/artist-monet-claude-artworks.htm
[2] http://www.theartstory.org/images20/works/monet_claude_4.jpg

and shadows on her face and clothing, is very central in the picture, indicating which direction the actual light is coming from. Quite uniquely, Monet paints into the light letting the model's features fade into the shadow.

This is in my mind parallel to the way Jean-Pierre describes the origin and development of the materials' history using precise "brush strokes". Although the narrative is very clearly put forward, it is to also very much influenced by the effect of the society in which this history is evolving. Moreover, when dealing with the not so distant past, the inclusion of effects from and on the environment become more pronounced.

A contemporary artist, at least chronologically, nevertheless, often included in the "Post-impressionism" period referring to a number of styles that emerged in reaction to Impressionism in the 1880s, was *Paul Cézanne*[3]. In his works, the light was no longer an "outsider" in relation to depicted objects; rather light emanated from within, as seen clearly in ***Mont Sainte-Victoire***[4] where mere brushes of paint suggest rocks and trees as opposed to being extensively depicted. The primary means of constructing the new perspective included the collocation of cool and warm colours as well as the bold overlapping of forms. Instead of the illusion, he searched for the essence.

As I translate this into "Sustainable Metallurgy" we have an immensly complicated synthesis of many diverse topics, some of which are of metallurgical origin, while others strictly speaking belong to other diciplines. It is, however, the full amount of this blend that is the important issue here.

In this book Jean-Pierre Birat is painting the big, holistic, picture of how materials have been produced and used in interaction with society as well as the physical surroundings. The reader will see that in earlier periods before industrialisation, the materials used needed to be made by the users themselves; material production was then an integral part of society. The material production aimed at optimising functionality and usefulnes, and not at trade value and profit in those days.

Industrialisation reversed this situation and slowly trade value and profit dominated as the driving force for decisions made pertaining to which material qualities should be produced and how this should be done in practice. After some time, the industrialists and economists dominated the industry, not only the material producing industry, but industry in general. Present and future development may in a way revert back to the assimilation between material production and societal and environmental matters.

Before you start reading this book, you should be aware of a few matters:

i. The book is structured as a textbook, but it is not a textbook in "Steel Making", "Material Science", Environmental Engineering" or "Industrial Ecology" etc.; it is a textbook that finds its place in curricula of all of these fields of science. Development of the narratives are, however,

[3] http://www.theartstory.org/artist-cezanne-paul.htm
[4] http://www.theartstory.org/images20/works/cezanne_paul_8.jpg?2

along two main axes: Material Science and Industrial Ecology, but with emphasis on the links between the Anthroposphere, the Geosphere and the Biosphere.

ii. Although the book tells a story, or rather several stories, it does not aim at continuous reading, from cover to cover. Read the book chapter by chapter, in the order of your interests and, maybe, read each chapter in several portions: abstract and introduction first, then the overarching conclusion putting things into a broader context before diving into the details, or switching to a different chapter.

iii. The structure of each chapter is according to the same pattern and it becomes easy to navigate between the topics of your interest when you get used to this systematics. You will find much help on structuring your reading pattern in Chapter 1, and especially in in Table 2 to Table 5 at its end.

iv. ***Beware: Reading this book and delving into its main implications might irreversibly change your frame of mind on the societal value of materials.***

I hope "everybody" concerned with production and use of metals and materials will read this book and really invest enough effort into application of the philosophy presented here to contribute to the sustainable development of our material-dependent society in a wide sense. For my own part, I will certainly use this book as compulsory course material in TMT 4330 simply because it provides the best possible background for getting involved with Material Science and in particular Metallurgy.

Trondheim, Norway, May 2018
Professor Leiv Kolbeinsen
Resources, Energy and Environment Group
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Preface

"Time and space are not independent of one another,
and not even atoms or subatomic particles
can be considered in isolation."

Pope Francis [1]

"By the way, do you know what an astronomer means by "metals"?
It's not what you think…"

Matt Streissler [2]

Knowledge is organized in categories, the result of a long historical maturation that can be traced back to the earlier Greek philosophers like Aristotle [3], Epicurus [4] or Roman Lucretius [5] and then refined by Kant [6], Husserl [7] and others. These categories reflect how knowledge is taught in schools and universities and how it evolves through research.

This structure is shared all over the world, although it is deeply related to Western culture, which has been adopted as a modern *lingua franca* in most higher education institutions. Thus, *Sciences* on the one hand and *Social Sciences and Humanities* (SSH) on the other are the most common distinctions: science is often termed *hard science*, while SSH is sometimes termed *soft science* or *subtle science*. Inside each category, there are many subcategories, like mathematics, physical sciences or life sciences.

There is also another level of differentiation between *basic knowledge* and *applied knowledge*, for example basic sciences vs. engineering sciences or technology. In the SSH field, economics and business science reflect a similar dichotomy.

This organization is deeply embedded in the governing structure of universities [8], in the organization of national research institutions [9], or of national academies [10, 11, 12, 13, 14], in the structure of encyclopedias, in the disciplinary domains covered by scientific journals, etc. This is why categories are robust and sustainable, even though knowledge keeps changing and evolving.

However, the gap between categories and the content of knowledge becomes at some point obvious and unsatisfactory. This is particularly the case, when progress cannot fit inside existing categories any more but stems from elsewhere, from new categories or from combinations of older categories, or when it simply does not match this conceptual framework at all.

A popular way out of this conundrum has been to foster *interdisciplinary or pluridisciplinary studies*. Lively seminars and conferences abound, which bring together different disciplines and explore the no man's land between them. However, the distance between the disciplines engaging in these conversations is usually small, so that the famous *silo effect* is only addressed at the margin [15]: seminars where hard and soft sciences meet and dare to exchange with technologies are still rare [16]. Moreover, after the meetings and the publication of proceedings, everyone goes back to his own world, confined by the categories which prevail in his own universe and control the financing of his research and his professional progression: the lucky ones belong to structures which have already acknowledged change, usually nimble organizations in countries that are leading in terms of productivity gain and growth, while most are back in the old and rigid categories and have to spend energy pushing back the walls in their own intellectual space.

A popular example is economics, which has institutionalized the borders beyond which the discipline is no longer valid and where one should only tiptoe with the utmost care. The relevant concept is that of externalities, i.e. factors which are undoubtedly important, but do not have any effect on economic variables in mainstream neo-classical theory [17]. *Environmental issues* constitute one form of these externalities, along with such things as public goods or ecosystem services. They are not ignored by mainstream economics, but treated as outside parameters with methods analogous to perturbation theory, thus at the margin or as a final chapter in a book [18] or even as an afterthought [19, 20].

Some economists, however, have decided to tackle the matter more directly and have developed alternative approaches, *environmental economics* [21, 22] and *ecological economics* [23]. They deal more directly with the environment, either still as a sub-field of economics or, on the contrary as the major character in the play, where economics is described as a subsystem of the environment.

Ecological economics emphasizes the concept of *natural capital,* which is to be preserved, and sometimes explores alternative political agendas, like *green economics* and *zero* or *negative growth.*

Studies like the Stern Review on climate change [24] and the TEEB on biodiversity [25] are claimed by both schools of thought, environmental and ecological economics.

Economics and social sciences have entertained a close relationship for a long time, probably because the awareness of social issues has challenged intellectuals for longer than environmental issues. Historians were at the forefront of this approach, thus not economists or social scientists as such: classic studies were initiated by H. Sée [26] and F. Braudel & E. Labrousse [27]. The field has since been recaptured by economists, in *History of Economics* courses.

Another example is *Industrial Ecology*, which is recognized as an academic discipline in the US, Japan and Norway but not in France, where it is hidden in the CNU[1] categories as a sub-chapter of Mechanics, and there again as a sub-chapter of Ecodesign. Not unsurprisingly, some of the leading schools of Industrial Ecology are therefore located in the US, Japan and Norway!

Other disciplines are also faced with environmental and social issues and have also been treating them at the margin, as economics did initially.

Metallurgy and Materials Science have adopted this approach, thus acknowledging the deep connection between their field and broader environmental and social issues, but keeping the discussions separate, as if engineering sciences, to which they belong, could stay aloof from *societal* challenges – to use the vocabulary of the European Union [28]. The difficulty lies with the mixture of disciplines and approaches, which extend across the fields of physical sciences, life science, earth sciences, natural and industrial ecology as well as the broad range of social sciences, reaching towards "technologies" or applied disciplines like political science, policy making, management and business strategy. Experts with such an overarching culture are difficult to find.

The case for developing an integrated Environmental Metallurgy approach and thus attempting to give it disciplinary status has become strong today. It is no longer satisfactory to deal with the issues in a separate chapter of a metallurgy course or to mention metals and materials as an extra chapter of an industrial ecology book. The gap has been bridged by applied researchers and by industry players for a long time and policy makers have also been following this line of thought to encourage research and innovation through funding.

The exact scope of this new discipline is still open to discussion. *Environmental Metallurgy* constitutes the lowest common denominator and covers most of the work already carried out in the area. However, provision for the future should be made at this point: the extension to Materials Science can be taken for granted; but environmental issues seem somewhat too narrow and a broader approach would be interesting to follow, like what we did when we launched the *SOVAMAT initiative* and the *Society and Materials cycles of conferences* [29]. Thus, *Sustainable Materials Science* would appear to be a better title.

The ambition is not simply to reflect the larger complexity of contemporary technology and engineering sciences, but to show that such an approach should eventually lead to a more detailed and accurate description of reality, even if this reality becomes protean in the process. This is a classic objective for science and knowledge creation. Moreover, being in a position to have a larger perspective on things, beyond the traditional barriers of one discipline, should lead to a clearer view of that complexity.

After exploring the issue from different angles [30, 31, 32, 33, 34, 35], along with many other researchers, the author reached the conclusion that the best way forward would be to write a dedicated book presenting the case.

[1] CNU: Conseil National des Universités.

The concept was field-tested in a class given at the University of Science and Technology of Beijing, since July 2016 [36].

The book has been written with *students* in mind, undergraduates but also graduates and post-docs. Thus, it is meant to be a *textbook*, to be used in connection with classes taught in universities across the world. Effort has been devoted to explaining the basics of the very many disciplines it tackles for someone from a different intellectual background to be able to acquire the necessary culture, albeit superficially. Along with students, their *professors* may find it useful as well.

The book is also targeted at researchers, engineers and practitioners in the "hard" sciences and in the "soft" sciences, as well as in applied disciplines such as engineering, Life Cycle Analysis or management. As such, it would be a *reference book,* at an elementary but transverse level. A *treatise* would be too ambitious a name for the book, as a treatise necessarily evokes disciplinary depths which are impossible to fathom in an interdisciplinary effort.

Finally, the book might be of interest also to people outside of the knowledge community, thus to various stakeholders in Society, in which we travel together. There are *curious people* in all walks of life, who are willing to spend time to go a bit deeper into important contemporary issues than what a good, even a very good newspaper can provide. There is a habit, in France, of writing books called "*dictionnaires amoureux*", the aim of which is to introduce all kinds of topics with ambition in terms of content and complexity of treatment: these are less honkish than the present book and written with literary ambition, which we did not have. But there is also some similarity.

Note that most of the chapters were created, initially, from journal's articles I published in the past and which I have only partially rewritten. Therefore, the style is not completely uniform: sometimes a neutral narrator is in charge of telling the story, while at other times it is either myself or myself and the coauthors of these papers, speaking as "we". Moreover, the papers were written over a period of several years and this shows in references, data and approach. Finally, there is some overlap between some chapters: this could have been easily corrected, but it was felt that keeping the texts as they are made it easier to read each chapter as a self-supporting document. Cross-references are given, anyway, to point out the connections.

Since we have been playing with the concept of this book, a new journal called "*Journal of Sustainable Metallurgy*" has surfaced, with D. Apelian, B. Blanpain and S.-Y. Kitamura as chief editors [37]. Moreover, the Journal of Chemistry now has a regular section on Environmental Chemistry [38].

Related topics have been coming up regularly, as special issues or single articles in more classic materials journals [39, 40, 41, 42, 43].

Jean-Pierre BIRAT,
Semécourt,
January 2018

SUSTAINABLE MATERIALS SCIENCE
ENVIRONMENTAL METALLURGY

Volume 1 – Origins, basics, resource and energy needs

J.-P. Birat

Materials are at the core of our societies and of our economies. They are part of pressing environmental challenges but they also provide powerful answers. It is therefore no longer possible to think of materials from the restricted standpoint of Materials and Engineering Sciences and this book proposes a more holistic vision of their connection with the Environment and with Society.

The book is meant for students, researchers, engineers, and concerned citizens interested in how materials, nature and people interact: at the level of raw materials and energy resources, of innovation and emergence of new materials functions, of historical continuity with materials of the past, and of emissions to air, water and soil and thus in connection also with health and toxicology issues, climate change and collapse of biodiversity. The book examines how materials relate to society with complex metrics, but also, more deeply, how they generate eco-social services, and, finally, have agency along with the people who use them and invent them (Actor Network Theory).

This book is unique in its approach across so many fields. There are many excellent treatises on materials science and more on industrial ecology. However, the connection with the social dimension of sustainability is still rarely discussed and the pluridisciplinary cocktail of approaches used here is truly new.

Jean-Pierre Birat *is a metallurgist, who discovered environmental issues as a researcher with a major steel producer. He is a graduate of the Paris School of Mines and UC Berkeley. He has worked in France (IRSID, ArcelorMittal Research)), Japan and Belgium (ESTEP), headed the ULCOS program and has been organizing the "Materials and Society" conferences for 14 years. He teaches the content of this book at the University of Science and Technology of Beijing.*

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