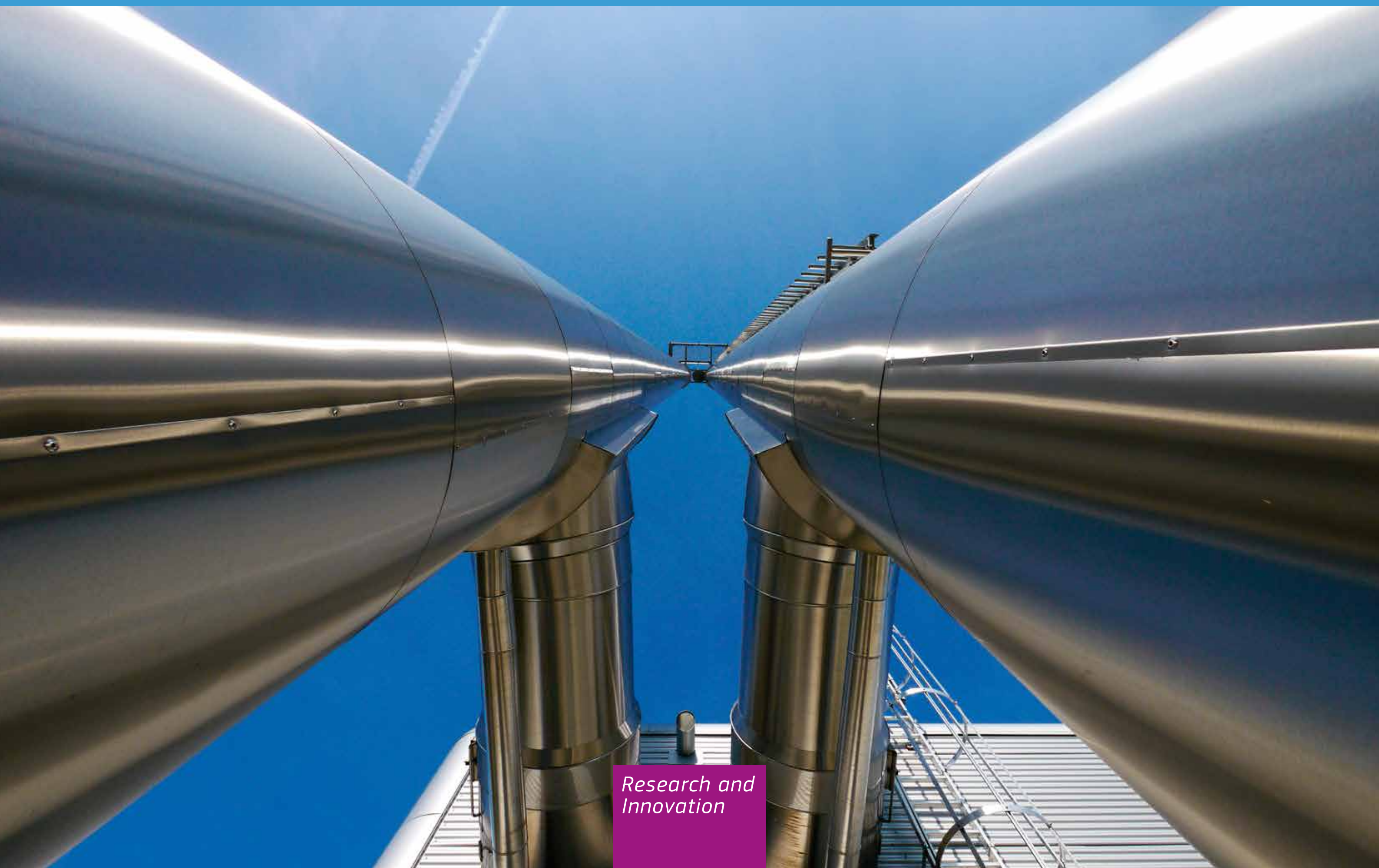
European Commission

Smart Steel

Research Fund for Coal and Steel:
Supporting steelmaking and use in the 21st Century



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edited by: Cordelia Sealy

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Directorate-General for Research and Innovation
Industrial Technologies

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Contents

THE AGE OF STEEL

Steel – a simple mixture of iron, carbon and trace elements – has, in one form or another, been with us for at least 3000 years. But thanks to innovators like Henry Bessemer and the development of low-cost, high-quality mass production in the 1850s, steel now forms the backbone of our modern age.

From skyscrapers and bridges to the finest precision machinery, steel is used by every major industry on the planet: from energy and transportation to construction, engineering, domestic goods and medical devices. Steel can be found in lightweight, fuel-efficient cars, high-tech computers, state-of-the-art satellites, cutting-edge medical equipment and earthquake-resistant buildings.

Not only does this unique material have a glorious past, it has an exciting future ahead too. Modern high-strength steels offer a superior mixture of low weight and exceptional strength that is vital to a wide range of applications. As a construction material, steel's unique combination of properties can help structures withstand earthquakes, storms, flooding and other natural disasters or extreme weather events that may become more common with climate change. Steel is poised to become increasingly important as the construction industry responds to demand for new buildings and infrastructure in rapidly growing urban centres, which will be home to two-thirds of the global population by 2050.

Moreover, steel is a vital part of the low-carbon energy revolution, providing the necessary materials for on-and offshore wind turbines, next-generation nuclear power stations, and the pipeline and cabling infrastructure to connect new energy sources to users.

Lightweight steel is similarly essential to the automotive and transportation sector to meet global targets for improved fuel efficiency and reduced emissions while improving structural integrity and safety.

Whatever its application, steel remains the ultimate recyclable material, promising the possibility of zero waste and total resource reuse in a sustainable future.

To move steel into the 21st century, every aspect of this inimitable metal's lifecycle is being scrutinised, from the efficient use of raw materials through the optimisation of production processes to end use and recycling. Thanks to broad-reaching research programmes like the Research Fund for Coal and Steel (RFCS), the steel industry in Europe is ensuring that society gets the most out of this matchless material. Bringing revolutionary concepts of smart manufacturing to this oldest of materials is opening up steel to new opportunities and ushering in a new age of steel.

The modern steel industry: unique challenges

With its roots in China and India, the foundations of modern steelmaking were forged in the Industrial Revolution of Great Britain. The 19th century saw industrialisation and mass production spread across Europe to North America and Japan. By the start of the 20th century, steelmaking was a major – and more often than not nationalised – industry in many countries.

The steel industry is now second only in magnitude to the oil and gas sector and has an estimated turnover of $900 billion globally, of which Europe contributes around a quarter[1]. The sector is a key industry for the European Union (EU), employing around 350,000 workers at more than 500 production sites across 23 Member States. Germany, Italy, France and Spain currently contribute the chief proportion of the 200 million tons of crude steel produced annually.

Steel maybe a mature industry with a long and illustrious history behind it, but it is now facing a unique period of challenge and opportunity. For most of the 20th and early 21st century, steel use per capita has increased steadily[2]. In recent years, however, the global economic crisis has created a more complex picture. Across the EU, steel production has stagnated or fallen, while manufacturing in China has continued to grow. European steelmakers now face significant overcapacity – both at home and worldwide.

[1] *The white book of steel.* (2012) World Steel Association. www.worldsteel.org
[2] From 150 kg in 2001 to 217 kg in 2014, according to figures from the World Steel Association.

Exacerbating this challenge is the fact that steel is a mature, heavy industry dependent upon generic mass-production technologies with small profit margins. Steel faces increasing competition from other materials in its user market sectors such as aluminium, wood, concrete, composites, carbon fibre and polymers.

Steelmaking is also a designated 'energy intensive industry' (EII) subject to increasingly stringent efficiency and environmental legislation. European steelmakers, in particular, face environmental regulation and CO2 trading restrictions that make manufacture more expensive at a time when competition is fiercer than ever.

To combat these multifaceted threats, steelmakers in Europe are actively looking to develop new and more sophisticated advanced steels that meet ever more precise customer and societal needs. Steelmakers need, like never before, to extract the maximum output from process lines in the most energy efficient manner possible. The only way forward for the European steel community is a concerted and collaborative research and innovation effort.

Steelmaking in Europe: a unique community

Steel's strategic position at the heart of the industrialised world at the start of the 20th century meant that two world wars had significant consequences. In the aftermath, steel that was produced by mainly nationalised steelmakers for military purposes could be channelled into consumer goods instead. The rebuilding of Europe after World War II, in particular, saw the creation of a unique community – a common market for coal and steel.

The aim of the European Coal and Steel Community (ECSC) established in 1951 was to bring together formerly warring nations and reinvigorate decimated economies through trade and collaboration. Supported by levies on coal and steel producers across the region, the ECSC created a multibillion-euro fund over a 50-year period. When the ECSC treaty expired in 2001, the Research Fund for Coal and Steel (RFCS) was created to manage this endowment[3]. The RFCS provides annual funding of €30-45 million, on average for the steel sector, to innovative projects that aim to improve the safety, efficiency and competitiveness of EU-produced steel and coal in line with specific priorities that are set on an annual basis.

In the steel sector, the RFCS supports around 30-35 cost-share projects each year of one of three principle types:

- *Research projects* to acquire new knowledge to facilitate specific practical objectives such as new products, processes or services;
- *Pilot and demonstration projects* examining the potential of theoretical or research results in practice and leading to the construction or operation of industrial-scale installations; and
- *Accompanying measures* to support dissemination of knowledge.

Typically, 6-7 partners share an EU contribution of €1-1.5 million over a 36- to 42-month period.

Steel research in Europe: a unique approach

Historically, the RFCS Programme has set overarching objectives that set out areas of special interest in steelmaking and finishing techniques, the utilisation of steel, and the conservation of resources and improvement in working conditions. Annually, the RFCS considers more detailed strategic priories to focus efforts where progress or innovation would best support the steel industry in tackling current challenges [4].

Because the steel production process is so lengthy and complex, the demands on new solutions are high. But the rewards are commensurately large. Better decision making throughout the entire process chain leads to improved product quality, more flexible production organisation responsive to customer needs and more efficient management of production lines to reduce energy consumption and CO_2 emissions.

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[3] The European Commission manages the RFCS with assistance from the Coal and Steel Committee (COSCO) with representatives from Member States, Coal and Steel Advisory Groups (CAG and SAG) and 12 Technical Groups (three for coal and nine for steel).
[4] The current priorities for the RFCS are summarised in Table 1 in Appendix I.

In the current climate of heightened competition, tighter margins and stricter regulations, it is more vital than ever that steelmakers eke the most out of every aspect of their production lines. The drive for efficiency and productivity is being replicated across every aspect of the lifecycle of steel, introducing a revolutionary new paradigm for steelmakers.

The bottom-up approach of the RFCS programme is ideally suited to the challenge. The structure and organisation of the fund enables progress in processes, quality control, applications, and safety, which typically require large investments over long periods. The longevity of the RFCS programme gives much needed continuity and stability to a uniquely demanding industry and complements other EC funding instruments such as Horizon 2020[5].

Impact of the RFCS: unique benefits

The RFCS programme has added significant value to the European steel industry during its lifetime. For steel companies participating in research projects the benefits can be seen in cost reduction (resulting from savings in energy use and/or raw materials), increased productivity, improved sustainability and new market share through the development of innovative steel products or comprehensive assessments of existing grades for new applications.

At the heart of the RFCS programme is the quick and full exploitation of innovations and developments arising out of research projects. To extract the most benefit from the RFCS programme, exploitation needs to occur at both the level of the project participants and beyond across the wider sector to contribute to the competitiveness and sustainability of the European industry. Here the small scale of RFCS projects is a significant advantage over other research instruments. The small number of partner organisations participating in a project makes agreements over intellectual property (IP) sharing or project outcomes more straightforward. The partners in an RFCS project tend to be heavily involved in the research and are likely to gain immediate benefit from project findings, engendering a willingness to buy into the concept of IP sharing.

Recent analysis of a sample of 23 exemplar RFCS-funded projects indicated an annual financial return of €103 million for beneficiaries on a total project budget of €53 million[6]. For the whole RFCS programme across both the coal and steel sectors, the potential financial benefits amount €700 million per year. In addition, around half of the funded efforts have given rise to new processes, products and applications with valuable economic outcomes. RFCS-funded projects demonstrably add to the pool of knowledge within the European steel industry, providing long-term benefits to steelmakers and users.

In the following pages, some examples of recent successes from the current cohort of projects will be highlighted. But there are wider implications for Europe. Not only is steelmaking itself a vital part of the European economy, the steel it produces serves a number of other key sectors such as construction, transport, and energy. This report will also indicate how steel research is impacting on these key sectors as well.

[5] Horizon 2020: http://ec.europa.eu/programmes/horizon2020/en/

[6] Research Fund for Coal & Steel: Monitoring & Assessment Report. European Commission Directorate-General for Research and Innovation. http://bookshop.europa.eu

MAKING THE MOST OF STEEL

Steelmaking is a uniquely complex process. In simple terms, this alloy of iron and carbon is typically made through one of two quite different processes: (i) an integrated process involving blast furnaces and basic oxygen furnaces that turns a mixture of iron ore, limestone and coke into steel and slag; or (ii) via an electric arc furnace (EAF) where scrap is the primary starting material. Molten steel is then cast into slabs and rolled into finished and semi-finished products. Subsequent reheating, cooling, rolling, finishing and galvanising yield an almost infinite variety of different forms from ultra-strong sheets to thin foils.

Controlling the processing conditions, as well as the ingredients, enables steel's unique combination of formability and strength to be tailored to suit a wide range of specific uses and applications. But if processing conditions vary from the predetermined recipe, whole batches of steel maybe unusable and suitable only for scrap.

For steelmakers, avoiding unnecessary wastage and poor quality products is essential in maintaining economically viable production. Key to ensuring high quality production is accurate control of the processing line. But with the enormous complexity of steel production, the diversity of processes involved and the potential for small variations in conditions to lead to radically different quality steel, monitoring and control represents a significant challenge. Here the RFCS programme is taking a 'cluster' approach to the matter centring on the concept of a 'smart factory'.

Smart manufacturing: Industry 4.0

The smart factory of the future will be able to manage all aspects of a manufacturing or production process through a combination of automation, data sharing and management, and technologies that are collectively termed 'Industry 4.0' or the 'fourth industrial revolution'. Not only does Industry 4.0 envision ultimate cyber control over the properties and quality of the output, it also encompasses sustainability, energy efficiency, and process management in a single envelope of 'integrated intelligent manufacturing'.

Industry 4.0 links together physical systems (including manufacturing equipment, assembly lines, products and workers) and enables them to communicate and share data (or 'interoperability'). The concept also enables the management of large sets of data from on line sensors – from production equipment, assembly line, monitoring equipment, quality control, etc. – to create a 'virtual' factory, which can be compared with models to ensure that processes are running as planned or to introduce new processes (or 'virtualisation'). Furthermore, the virtual factories are able to make decisions by themselves and run remotely in real time (or 'decentralisation'). The concepts of interoperability, virtualisation and decentralisation have the potential to make the manufacturing process an infinitely variable and controllable one, which can react instantaneously and take the trial and error out of new processes and products.

Smart manufacturing concepts for the steel industry are being explored in a number of flagship RFCS projects. The inherent complexity of steelmaking makes the sector an ideal candidate for Industry 4.0 approaches, but is also a testing one.

Integrated Intelligent Manufacturing

The basis of integrated intelligent manufacturing (or I^2M) is to create a description or virtual version of a production line or factory using semantic technologies, which in software terms means tagging content or data to enable it to be linked together. The ability to make connections been data points within different documents or datasets enables computer systems to perform human-like understanding and reasoning.

For a steelmaker, I^2M enables communication and information exchange across the entire supply chain from process control, product tracking and quality control through to order tracking and logistics. The concept encompasses three levels of integration: vertical – across all IT and automation systems in a plant; horizontal – along the complete production line; and transversal – incorporating technical, economical and environmental issues. Individual processes are modelled as 'cyber physical production systems' (CPPSs) and then linked together to create a network for communication and information exchange. Simultaneously, 'Big Data' techniques are added to handle the large amounts of disparate information – from physical data to customer details – along the complete production chain. For a steelmaker, this enables a new way of thinking. Instead of optimising a single process stage at a time, the entire production line can now be explored in one go and evaluated as a whole.

A number of RFCS-funded projects are or have looked at the application of I^{2}M concepts to various aspects of steelmaking. A few examples are discussed here.

Finding new products in waste: I2MSTEEL

I^{2}MSTEEL, a three-year project that commenced in 2012, set out to develop and demonstrate a new paradigm for factory- and company-wide automation and information technology applying I^{2}M concepts to steelmaking[7].

The project created software modules or programs known as 'agents' that are de-centrally deployed, run autonomously, and communicate with each other. In the demonstration system run at ArcelorMittal, individual agents for the furnace, hot rolling, annealing, transport and coiling processes, etc. and the product were created. As well as communicating with each other, the agents work together (in what is termed a 'holon') to solve problems.

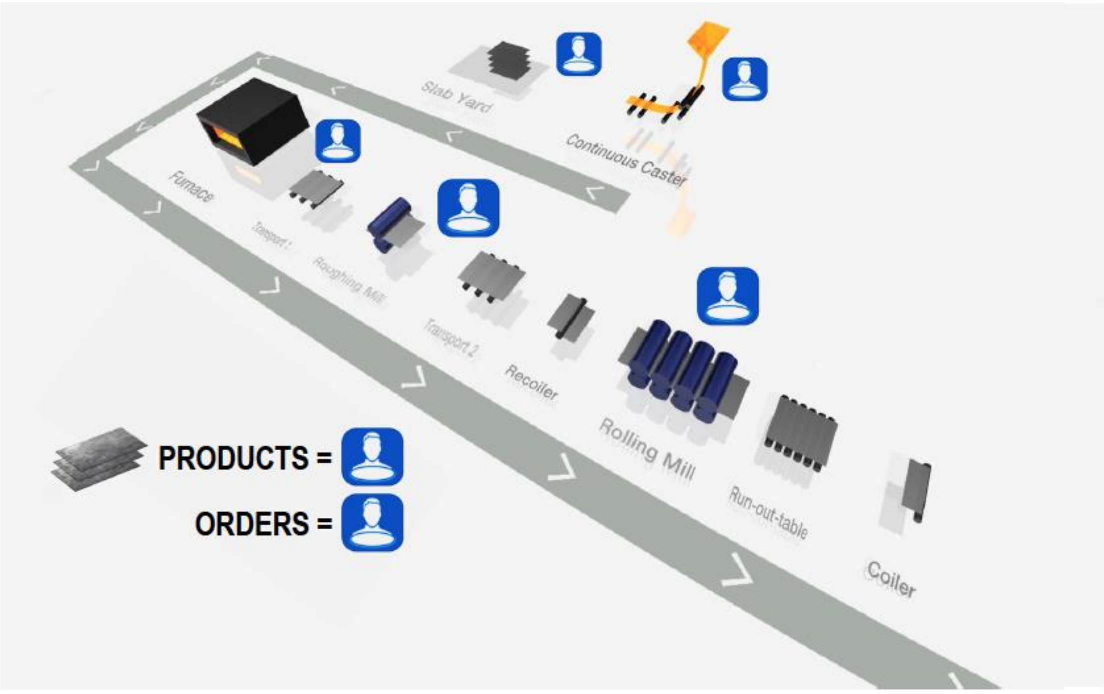

Figure 1. Schematic of the steel production line. (Courtesy of Marcus Neuer, BFI.)

The architecture of the system is service oriented (or SOA), so agents can request data from database services as and when required. For example, one agent monitors the thickness of coils as they come off the production line. The nature of the process means that the thickness varies, but usually off-spec coils are discarded. But using the I^{2}M approach, the collected physical data can be compared to forecasts of the required thickness. Where the output deviates from requirements, the product can be matched to other customers' orders or requirements within the producer's database. The system can even incorporate pricing information and a virtual marketplace so that off-spec output can be matched and potentially sold to interested customers. Moreover, by connecting up with a producer's existing customer database, potential customers can be drawn from across the entire order book.

[7] I^{2}MSTEEL: Development of a new automation and information paradigm for integrated intelligent manufacturing in steel industry based on holonic agent technology. PROJECT partners: ArcelorMittal, Centre d'Excellence en Technologies de l'Information et de la Communication (CETIC), Centro Sviluppo Materiali (CSM), Primetals Technologies, Siemens and VDEh-Betriebsforschungsinstitut (BFI).

The results from the prototype at ArcelorMittal appear promising – less output is being wasted and profits are being garnered from secondary or what would have been scrap products.

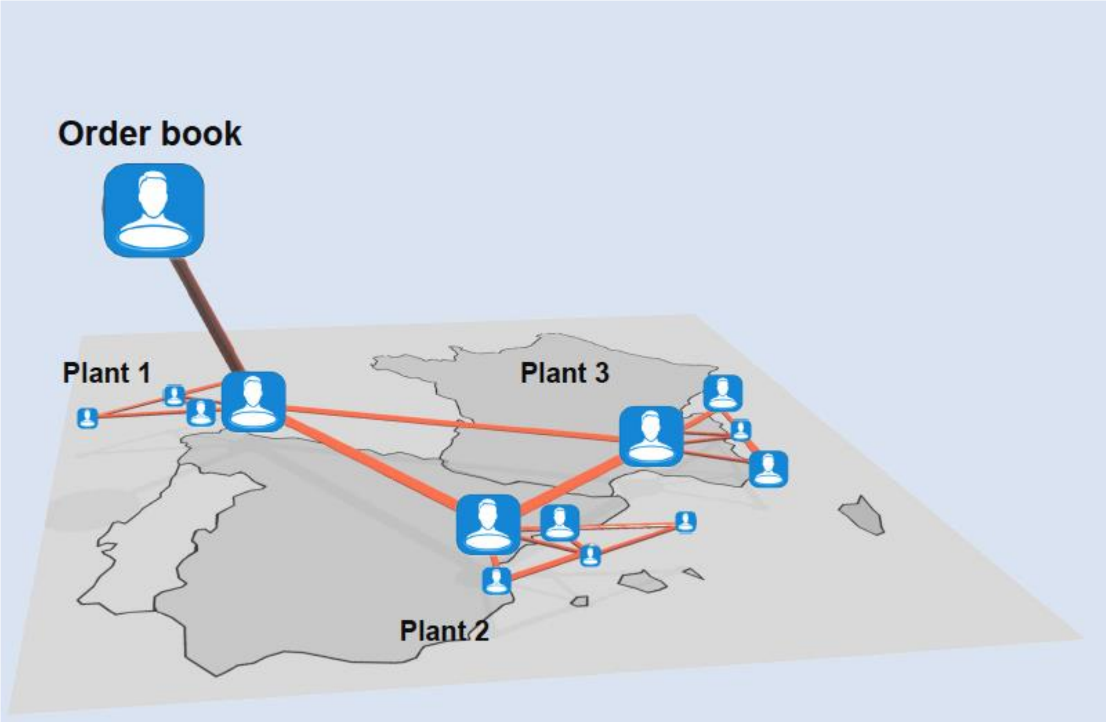

Figure 2. Schematic of communication network between a producer's sites and order book enabled by I²M. (Courtesy of Marcus Neuer, BFI.)

Smart energy use: DYNERGYSteel

The wider implications of the I^2M approach are being demonstrated in DYNERGYSteel, a four-year project started in 2014 and running until the end of 2017[8]. Here the I^2M approach is used to manage energy use during steel production dynamically in real time.

Steelmaking is a highly energy consuming business, requiring an estimated ~0.67 MWh of electrical energy per ton produced. Energy costs for Europe's entire steel output amount to over €13.5 billion per year. But an increasing proportion of renewable energy in the supply has significant implications for steelmakers. Both the supply of energy and its price, thanks to new market structures, are now subject to increasing fluctuations. This presents both a challenge and an opportunity for energy-intensive steelmakers.

[8] DYNERGYSteel: Integrated dynamic energy management for steel production. Project partners: CSM, Acciai Speciali Terni, Hoesch Hohenlimburg, ORI Martin, Ricerca sul Sistema Energetico (RSE), Scuolo Superiore Sant'Anna di Pisa, BFI, and Lech-Stahlwerke (LSW).

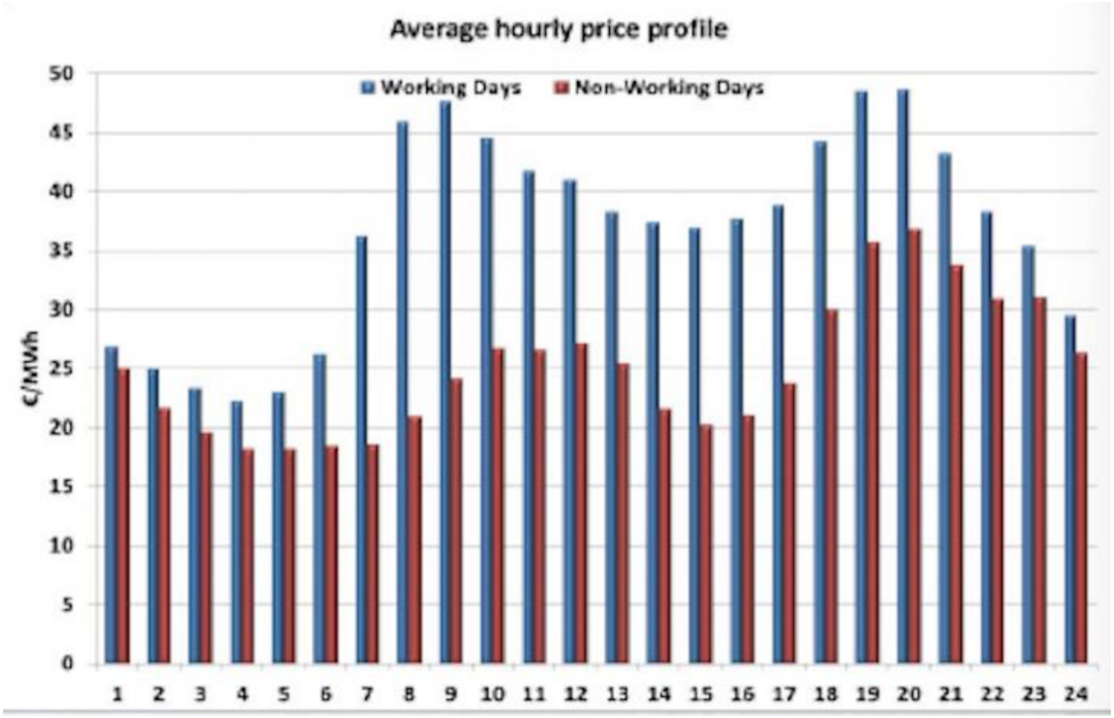

Figure 3. Average hourly energy price (in euro/MWh) during the course of a typical month. (Courtesy of Fabio Sanfilippo, CSM.)

Energy markets are now operating on a day-ahead or same-day (intra-day) basis. To take economical advantage of the opportunities offered by fluctuating energy prices and avoid being penalised by paying more for energy than necessary, users require minute-by-minute or even second-by-second information and control of production lines.

The I^{2}M concept is ideal for managing these complexities. By taking an energy-oriented approach to production planning, steelmakers can exploit falling energy prices and play an important role in helping to manage the electricity grid. The DYNERGYSteel project is exploring these possibilities by combining day-ahead forecasting to exploit lower energy costs, production rescheduling based on process knowledge, and the ability to react to electricity grid events quickly. The project is creating an ICT system capable of identifing or developing equipment and/or processes that can be turned on or off (or sped up or slowed down) or switched to a different energy source in real-time and in response to market or price information.

Like the I^{2}MSTEEL project, DYNERGYSteel requires high levels of interconnection and cooperation between all aspects of the production line, as well as workers and external energy pricing information. But bringing together data management, real-time simulation, smart planning and scheduling with process control creates a new paradigm of automation that breaks the traditional hierarchy of production but could lead to significant energy efficiencies and cost benefits.

The outcomes of DYNERGYSteel, like those from I^{2}MSTEEL, could be a means of turning a challenge for the steel industry into a new opportunity. A dynamic energy management system could reduce or minimise energy costs for a steelmaker and open up new financial benefits from dynamic energy markets, as well as positioning the sector as a key part of the new flexible energy grid.

Putting data to use: PRESED

The modern steelmaking process is highly monitored and will become more so in the on-going drive to maximise output and efficiency. With increased monitoring of all aspects of the production line comes the inevitable generation of large volumes of data (or 'big data') that need to be handled in new ways. Techniques such as data mining are emerging as effective means of exploring big data by looking for patterns and interrelationships between variables. The PRESED project, running from 2014 until 2017, aims to use data mining tools to improve product quality and reduce manufacturing costs[9].

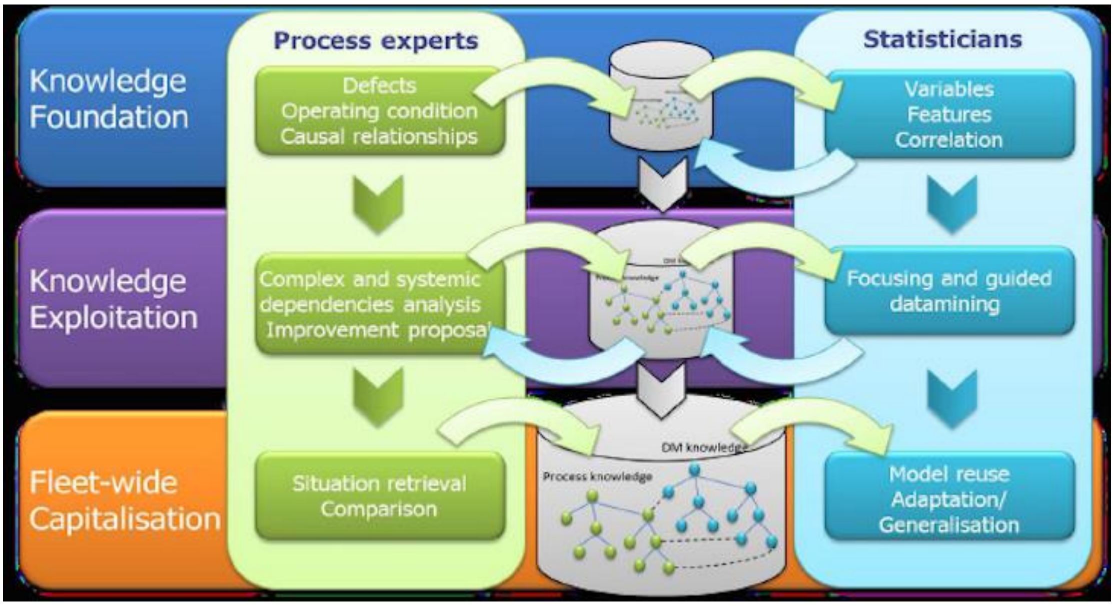

Figure 4. Schematic of knowledge model forming the basis of the PRESED project. (Courtesy of Gabriel Fricout, ArcelorMittal.)

PRESED is focusing on the use of data mining techniques to tackle the problems of silver defects in continuous casting, the surface quality of hot-rolled products and mechanical properties of dual phase (DP) steel grades. By extracting and comparing large amounts of physical data from products with and without defects, the new tools will identify the causes of poor quality and optimise manufacturing steps accordingly, as well as predict product quality as soon as possible to minimise costly production mistakes. The new approach to data mining, which brings together data collection, preparation and visualisation techniques, could lead to a predicted 20% improvement in defect prediction rate over state-of-the-art statistical methods.

The creation of a 'knowledge model' that is easy to visualise, share and refine by experts from the process, quality control, and statistical side will lead to a real step forward in data analysis performance.

New tools for the steelmaker

Superior product quality and zero-defect manufacturing is one area in which European steel producers can compete effectively in the global marketplace. As the PRESED project is demonstrating, the drive for better quality products relies on improved monitoring, evaluation and, crucially, data handling.

Other projects such as EvalHD, SoProd and EiRes are examining similar aspects of factory-wide control. EvalHD[10], for example, is exploiting big data handling techniques to use production process data – in this case for flat steel production – to monitor and improve product quality. In this three-and-a-half year project, which was completed at the end of 2015, high-resolution measurement data was used as the starting point to develop an advanced web-based system for supervising product quality.

Like DYNERGYSteel, SoProd[11] is using real-time, decentralised control systems to manage resource efficiency and productivity with the aim of decreasing energy consumption. The

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[9] PRESED: Predictive Sensor Data mining for Product Quality Improvement. Project partners: ArcelorMittal, BFI, PREDICT, Riva Acciaio, RapidMiner, Université Pierre et Marie Curie.
[10] EvalHD: Refinement of flat steel quality assessment by evaluation of high-resolution process and product data. Project partners: BFI, Ilva, Swerea MEFOS, ThyssenKrupp Rasselstein, Scuola Superiore Sant'Anna di Pisa.
[11] SOProd: Economic and flexible decentral self-optimising production. Project partners: BFI, Hoesch Hohenlimburg, Ilva, Scuola Superiore Sant'Anna di Pisa.

project, which runs from 2014 to 1017, is developing and implementing a combination of real-time decentralised process-optimised scheduling, process self-optimisation and inter-communication at one of its partner sites.

The industry 4.0 approach can also be applied to some of wider issues facing steelmakers such as environmental impact evaluation. The EiRes[12] project, for example, is linking simulation models of steel plants with life-cycle analysis (LCA) tools to predict the environmental consequences of process modifications and identify potential improvements.

These research efforts – and other RFCS-funded projects – are complimented by an I^2M working group established by the European Steel Technology Platform (ESTEP)[13] in 2007 to develop an I^2M roadmap for the steel sector and coordinate priorities for the RFCS programme and related European research instruments. Steel producers, plant manufacturers, IT companies, research institutes and universities are now working on a revised roadmap, taking into consideration the latest developments in enabling technologies like IT, data handling and metrology. The roadmap will outline directions for future research, particularly in key areas such as handling and evaluating big data to improve decision-making along the steel production line, self-organising structures for material scheduling and other tasks, and complete tracking of all intermediate and final products.

The RFCS is an ideal starting block for such innovative and far-reaching projects because it enables a concentrated number of specialist partners from different areas of expertise to come together and focus on specifics of the steelmaking process. The approach provides an ideal means of bringing new specialist knowledge into the steel industry.

[12] EIRES: Environmental impact evaluation and effective management of resources in EAF steelmaking. Project partners: Scuola Superiore Sant'Anna di Pisa, CSM, Dalmine - Tenaris, Deutsche Edelstahlwerke (DEW-STAHL), Gerdau, ORI Martin, Riva Acciaio, Tecnalia, BFI.

[13] European Steel Technology Platform brings together steel manufacturers, universities and research institutes active in steel research, steel users such as carmakers, and public bodies such as the European Commission and national governments to foster international competitiveness of the European steel sector, http://cordis.europa.eu/estep/home_en.html

STEEL IN ACTION

Making the grade: all steel is not the same

For as long as the human race has made and used steel, it has been known that variation in the process leads to an infinite variety of properties. Ancient Damascus steel swords renowned for their sharpness, for example, still defy modern replication. For millennia, our ability to make exquisite steel has exceeded our understanding of the underlying science. Now that situation is being reversed, and increased metallurgical knowledge of the relationships between microstructure, strength, forming properties, fatigue and corrosion resistance, and process conditions is informing the production of steel grades with 'designer' properties.

There are now over 3500 different grades of steel, containing controlled amounts of carbon, manganese and trace elements such as silicon, phosphorus, sulphur, and oxygen. Each grade has a specific set of mechanical, chemical, and environmental credentials that can be tailored to individual applications.

In combination with better control of production, it is now becoming possible to fabricate steel to meet end-user needs like never before. The almost infinite possibilities of steel herald a new era of increased usage as this versatile metal alloy makes the grade for new applications.

Construction represents the largest single market for steel, accounting for over 52% of global output annually, according to the World Steel Association. In Europe, steel accounts for 40% of residential/non-residential and civil engineering construction. Moreover, this sector is expected to grow in coming years, as expanding urban populations turn to fast construction methods to meet demand for new housing, office and industrial space, infrastructure like hospitals and schools, and civil engineering projects.

But with the increasing pressure on existing space, development is and will continue to take place in earthquake and flood-prone regions. Moreover, densely populated urbanisations will be more susceptible to devastation in the event of extreme weather events and natural disasters. Steel is the ideal construction material to meet these exacting demands – strong, flexible, easy to produce and quick to use. Steel products are now penetrating further into the construction market, particularly in challenging environments, at the expense of competing materials like wood and concrete.

The ability of steel to withstand extreme conditions is vital to other construction and engineering sectors like bridge building, energy generation and infrastructure, and renewables.

The transport sector, meanwhile, makes up just under a quarter of steel use in Europe. Here there is a major focus on lightweight steels to reduce fuel consumption and help carmakers meet increasingly stringent CO_2 emission targets. Over the next decade, carmakers will have to meet targets for fuel efficiency and emissions of 54.5 MPG in the USA[14] and 95 g of CO2/km[15] in the EU, respectively, for average light-duty vehicles. Since the typical light-duty vehicle comprises around 58% steel, there is plenty of scope for new, even lighter weight steels to contribute to realising these targets.

Building the future: steel construction

Steel construction is quick and easy, giving architects and designers the ability to create innovative shapes and structures. Steel enabled the construction of skyscrapers in the early part of the 20th century, and now allows the construction of earthquake-resistant structures. Steel made the construction of long-span suspension bridges possible, but where the Golden Gate Bridge required 83,000 tonnes of this magical metal, a modern structure would only require half the amount.

[14] Corporate Average Fuel Efficiency (CAFE) standards set by the US Environmental Protection Agency (EPA) stipulate 163 g of CO2 per mile or 54.5 MPG by 2025. http://www3.epa.gov/otaq/climate/regs-light-duty.htm

[15] EU legislation sets mandatory emission reduction targets of 95 g of CO_2/km for new cars. http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

As a construction material, steel has the advantage that it is up to 100% recyclable and sustainable. It can be designed and manufactured in a precision-controlled manufacturing environment with guaranteed quality. Its strength and tailorable properties mean that it can produce large, unsupported adaptable spaces without need for internal columns or reinforcement. Steel perfectly fits the bill in the construction sector's drive for more efficient and scalable modern construction methods.

Construction is a key sector in Europe – representing 8.8% of GDP for EU28 and nearly 30% of industrial employment (or 6.5% of all employment across the region). The sector has a significant influence across the whole economy, with an additional 42 million workers depending upon construction for employment. But unlike the steel sector, which has a handful of key producers, the construction sector is made up of over 3 million individual enterprises, mainly SMEs with less than 20 employees.

The nature of the construction sector has, traditionally, made it a difficult one for steelmakers to reach. Most SMEs serve local markets and are low on innovation. Steel has traditionally been viewed as a high-cost material susceptible to corrosion and fire damage. Persuading millions of small organisations to turn steel has proved a difficult task. Compared with the USA and Japan, steel is much less well used as a framing material for dwellings and office buildings in Europe, where concrete tends to be the dominant construction material.

Nevertheless, the construction industry is poised on the brink of a major revolution. Developers are now increasingly turning to 'big data' as well to model the operation and management of large, complex buildings, developments and even whole cities. Building information modelling (or BIM), which integrates build logistics, capital costs and facilities management, is now being used increasingly by large developers. Combining this type of advanced digital design with networks of temperature, humidity, air quality, etc. sensors brings the possibility of operating internal environments for optimal comfort, energy efficiency and building integrity. Such concepts are also being expanded to incorporate measures that can support increasingly aged populations. There is and will be a significant opportunity for the steel industry to design and make products suitable for such construction projects.

Across the board, therefore, there are numerous opportunities for steel to increase its market share in the European construction industry and develop new products that exploit steel's unique advantages to meet emerging needs.

Building in green: BASSE, STEELPV

Like other sectors, the construction industry is looking to adopt more environmentally friendly and energy efficient technologies to meet new national and European standards while reducing costs. Steel is the ultimate recyclable material and is ideally placed to meet new demands of off-site fabrication and zero on-site waste. The sector is increasingly interested in using prefabricated parts that can be readily constructed on-site and dismantled, reused or recycled at the end of their active life.

The BASSE project[16] is taking this concept a step further by integrating renewable energy technologies into well-established steel construction products. The concept underpinning this three-year project led by Tata Steel is the incorporation of a heat exchanger system into a steel sandwich panel, which is widely used for the exterior of buildings, to harvest solar energy. An integrated heat pumping system redistributes the captured energy into the building for heating and hot water. The project could lead to a simple and straightforward product that enables the incorporation of renewable energy technologies into the envelop of a new or retrofitted building.

[16] BASSE: Building Active Steel Skin. Project partners: TATA Steel, Dow Italia, Empresa Municipal de la Vivienda y Suelo de Madrid (EMVS), European Thermodynamics, NIBE, Tecnalia. http://www.basse-eu.com/web/home.aspx

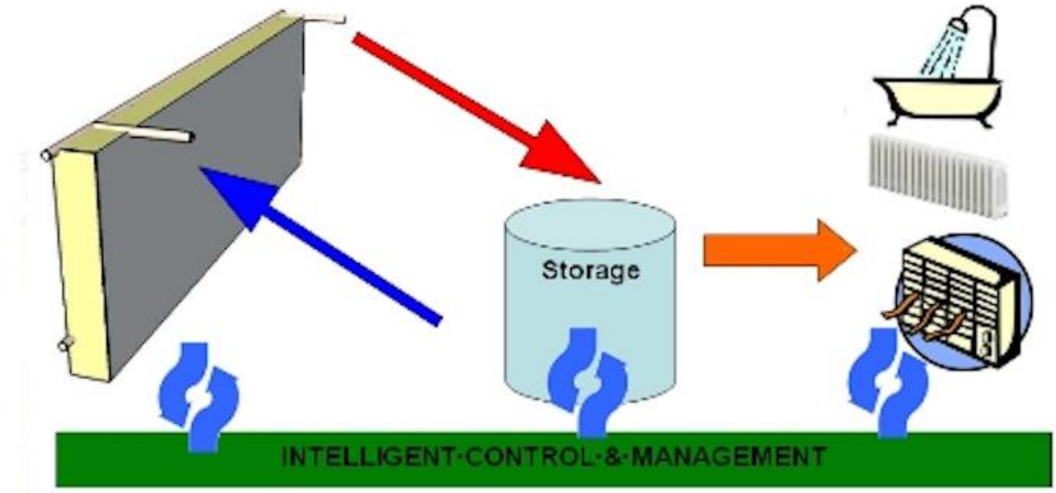

Figure 5. Schematic of the intelligent control & management system being developed by the BASSE project. (Courtesy of Samir Boudjabeur, TATA Steel.)

A similar idea is being developed by the STEELPV project[17] to incorporate the capacity to generate electricity from sunlight into the façades and roofs of buildings and other physical infrastructure. This 39-month research project is developing structural steels, including galvanised/aluminised cold-rolled low-carbon steel and bare cold-rolled low-carbon steel, as substrates for thin-film photovoltaic cells. The approach could lead to photovoltaic steel panels, flexible sheets and coils that could be used to cover the envelop of buildings or as part of the load-bearing structure.

Building resilience: standing up to extreme conditions

As a construction material, steel's combination of strength and flexibility has the potential to bring greater resilience to extreme conditions such as fire or earthquake. But steel has had a poor reputation for fire resistance and traditional safety regulations have not favoured its use.

A number of RFCS-funded research projects over the last decade[18] have explored the behaviour of steel construction materials when exposed to fire. Through a better practical and theoretical understanding, steelmakers like ArcelorMittal and its partners have developed more realistic 'natural fire' safety concepts that more accurately reflect steel's performance under actual fire conditions. Based on model scenarios for different types of buildings and simulation of the behaviour of whole structures when subjected to fire, these new guidelines have been disseminated across the region (through projects such as DIFISEK+ [19] for example) and are being introduced into Eurocodes and national regulations.

There are some very tangible results of these RFCS-funded efforts evident in the construction of large steel-frame buildings such as the Maison de la paix and International Basketball Federation (FIBA) headquarters in Geneva, Switzerland, the car park of Toulouse Blagnac Airport in France, and the Heron Tower in London, UK.

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[17] STEELPV: Sustainable steels for direct deposition of photovoltaic solar cells. Project partners: Fundación ITMA, Abengoa Solar New Technologies, Bangor University, CSM, MK Metallfolien, University of Wales Swansea.

[18] Fire safety related projects between 2003 and 2014 include: FIRESTRUC, SSIF, FICEB, UCoSiF, ROBUSTFIRE, FIDESC4, LOCAFI, and FRISCC.

[19] DIKISEK+: Dissemination of structural fire safety engineering knowledge throughout Europe. www.difisek.eu

Figure 6. The Heron Tower in London under construction.

In addition to fire safety, there is a substantial current focus on using steel structural elements to deliver earthquake resistance. The recent HSS-SERF project[20], for example, evaluated the performance of dual-steel structural systems where mild carbon steel dissipates the energy of the earthquake and high-strength steel maintains the integrity of the structure. An alternative approach to energy absorption during an earthquake can be afforded by using steel bars to reinforce concrete. The current NEWREBAR project[21] is developing a new class of dual-phase (DP) steels as reinforcing agents with better mechanical properties and improved corrosion resistance that could represent a breakthrough for the European construction sector. Other aspects of seismic resistance are being investigated by a number of projects (such as FREEDAM, Meakado, PROINDUSTRY and MATCH), and INDUSE-2-SAFETY, which is examining particularly at risk structures such as petrochemical plants.

An understanding of how steel can withstand fire and seismic events can also have important implications its use in applications where extreme conditions are the norm. The SCIENCE project[22], for example, is examining the potential of steel-concrete-steel composite structures for nuclear power stations, offshore wind turbine foundations and other marine structures.

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[20] HSS-SERF: High strength steel in seismic resistant building frames. Project partners: Universitatea Politehnica din Timisoara, Gabinete de Informática e Projecto Assistido por Computador, Rautaruukki Oyj, University of Liege, University of Naples Federico II, University of Ljubljana, University of Stuttgart, RIVA Acciaio, VTT Technical Research Centre of Finland.

[21] NEWREBAR: New dual-phase steel reinforcing bars for enhancing capacity and durability of antiseismic moment resisting frames. Project partners: University of Pisa, Celsa, Ferriere Nord, ISB, Instituto de Soldadura e Qualidade (ISQ), Riva, Scuola Superiore Sant'Anna di Pisa, University of Ljubljana, University of Patras.

[22] SCIENCE: Steel-concrete-steel composites for industrial, energy and nuclear construction efficiency. Project partners: Steel Construction Institute, CTICM, EDF, Egis Industries, Karlsruhe Institute of Technology, University of Surrey, VTT Technical Research Centre of Finland.

Steel parts for on- and offshore wind turbines have to be able to withstand extreme weather conditions on a day-to-day basis. The SteelWind project[23], for example, is currently investigating ways of increasing the reliability of wind turbines by improving the tribological, fatigue and corrosion properties of the steel bearings in gearboxes. Other efforts targeting the wind turbine sector include BESTSEAT and SHOWTIME.

Building bridges: SBRI

The safety of steel structural elements is a major concern when it comes to infrastructure like bridges. This competitive construction market is dominated by concrete but steel can offer alternative aesthetic, sustainability and build-time advantages.

As many bridges in Europe face demands for refurbishment and strengthening to handle increased, heavier traffic and more stringent safety codes, recent projects such as SBRI[24] have taken a holistic approach. Bridge design requires consideration of interrelated functional, environmental and economic factors, and there are strong national biases in material use. This three-year project combined lifecycle assessment, costs and performance into a single design approach from initial construction to demolition, weighing up the effects of degradation processes such as fatigue and corrosion against the costs of inspection, maintenance and repair. Current projects such as PROLIFE[25] are continuing the same theme assessing new ideas for saving costs, reducing environmental impact and minimising traffic disruption during bridge improvements. OPTIBRI[26], meanwhile, is assessing the potential lifecycle benefits of HSS in bridge design.

Figure 7. Dultenaugraben Bridge in Baden-Württemberg, Germany during construction. (CC 2008 Wladyslaw.)

[23] SteelWind: Design and development of a new high nitrogen bearing STEEL for offshore WIND turbines with improved surface fatigue, wear and corrosion properties for in service life increment. Project partners: CSM, Technical University Denmark, ECOR Research, Energietechnik Essen, Gerdau Investigacion y Desarrollo Europa, ISQ, Schaeffler Technologies.

[24] SBRI: Sustainable steel-composite bridges in the built environment. Project partners: University of Stuttgart, Dillinger Hütte, ArcelorMittal, BASt, BRISA Engenharia e Gestão, IFSTTAR, Rambøll, SÉTRA, University of Coimbra.

[25] PROFILE: Prolonging lifetime of old steel and steel-concrete bridges. Project partners: Luleå University of Technology, Alessio Pipinato & Partners Architectural Engineering, ArcelorMittal, Movares, Ramböll Sverige, Schimetta Consult Ziviltechniker, University of Coimbra.

[26] OPTIBRI: Optimal use of High Strength Steel grades within bridges. Project partners: University of Liege, Belgian Welding Institute, GRID International Consulting Engineers, Industeel Belgium, University of Coimbra, University of Stuttgart.

RFCS-funded research such as SBRI project, and previous efforts like COMBRI and COMBRI+, have made significant strides in demonstrating the advantages of modern steel structures and composites when it comes to bridge design with a wealth of case studies, handbooks and design tools[27]. But encouraging the use of non-traditional steel and steel composite materials, and making inroads on conventional materials like concrete, will require steelmakers to continue to work closely together with bridge authorities.

Lightening the load: steel on the road

Increasingly stringent international safety and fuel economy standards are driving automakers to adopt new materials that are stronger and lighter. Newer steel grades like HSS and advanced HSS (AHSS), which is extremely strong and highly formable, can readily meet requirements for superior manufacturability, durability, quality, efficiency, emissions and recyclability at low cost. For the user, meanwhile, advanced steel body parts bring greater crash resistance and improvements to passenger safety.

Consequently, over the last thirty years, the use of steel in vehicles compared with other materials has increased steadily from around 53-55% in the 1980s to 58-60%[28]. New grades of AHSS, such as dual phase (DP), transformation induced plasticity (TRIP), twinning induced plasticity (TWIP), and high-manganese steels are now among the fastest growing materials used in automotive manufacture. Modern lightweight AHSS grades are making steel a very credible alternative to other lightweight materials and metals, such as aluminium.

Historically, the RFCS has had a long-standing focus on lightweight steels for automotives. Thanks to two RFCS-funded projects a decade ago, PROMS and EAF-PROMS, for example, the world's first production line for high-manganese ultra strong steel alloys was established by Salzgitter[29]. Likewise, the STRAINHARD project[30] demonstrated the value of switching to lightweight steels for realising economic, raw material and energy savings.

More recently, efforts such as the GPHS project[31] explored the use of hot stamping processes to produce press-hardened components for structural elements in vehicles. Using stamping to produce complex parts from high-resistance formable AHSS grades has the potential to simplify and streamline manufacturing.

A number of current projects, including MicroControl-PLUS[32], JoiningTWIP[33], HOTFORM[34], iCUT[35], and effiPRESS[36], are also working on improved production processes for AHSS for automotive applications.

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27 http://sections.arcelormittal.com/en/library/steel-research-reports/bridges.html
28 Steel Market Development Institute. http://www.autosteel.org/
29 PROMS: http://cordis.europa.eu/projects/rcn/80326_en.html; EAF-PROMS: http://cordis.europa.eu/projects/rcn/80408_en.html; Salzgitter: http://www.salzgitter-ag.com/
30 STRAINHARD: Investigation of the strain hardening behaviour of modern lightweight steels considering the forming temperature & forming rate. Project partners: RWTH Aachen University, ArcelorMittal, CSIS, ThyssenKrupp Steel Europe. http://bookshop.europa.eu/uri?target=EUB:NOTICE:KINA23599:EN
31 GPHS: Green press hardening steel grades. Project partners: Tecnalia, ArcelorMittal, University of Padova, Volkswagen.
32 MicroControl-PLUS: Combined Online Microstructure Sensor and Model for a Better Control of Hot Rolling Conditions and Final Products Properties. Project partners: ArcelorMittal, Imagine Optic, Swerea KIMAB, Swerea MEFOS.
33 JoiningTWIP: TWIP-Steels for multi material design in automotive industry using low-heat joining technologies. Project partners: Salzgitter Mannesmann Forschung, COMTES FHT, Centro Ricerche Fiat, EJOT, ThyssenKrupp Steel Europe, University of Hannover, University of Paderborn.
34 HOTFORM: New multiphase AHSS steel grades for hot forming, with improved formability and reduced springback. Project partners: Tecnalia, Centro Ricerche Fiat, Tata Steel Netherlands, Volkswagen.
35 iCUT: Integrative cutting solutions to produce high performance automotive components with high-Mn steel sheet. Project partners: CTM, Centro Ricerche Fiat, IUC Olofström, Rovalma, RWTH Aachen University, Salzgitter Mannesmann Forschung.
36 effiPRESS: Development of energy-efficient press hardening processes based on innovative sheet and tool steel alloys and thermomechanical process routes. Project partners: TU Chemnitz, Grupo Antolin, CTM, Fraunhofer Gesellschart zur Foerderung der Angewandten Forschung, Rovalma, Salzgitter Hydroforming, SSAB EMEA, University of West Bohemia.

BACKBONE OF THE 21ST CENTURE

The foundations of the modern world have been built over the past century with steel and this adaptable metal will continue to dominate in the future. A growing global population will need steel more than ever before to meet its needs in construction, transport and energy.

Despite the potential for increased steel usage, which the World Steel Association predicts will reach 1.5 times current levels over the coming decades, the steel industry in Europe is at risk. The twin challenges of overproduction and increased fiscal burden from climate change legislation are exerting pressure on the European steel sector as never before.

Better knowledge = better future prospects

In the face of such pressing challenges, European steelmakers must take action to maintain competitiveness. Innovation in highly technological steel products and processes is key. EU Commissioner Vestager emphasised this necessity in a recent statement:

“The European steel industry needs to be competitive globally and it needs to take the steps to ensure that it is.”

How can Europe’s steel industry compete in an over-capacity market? It has two major – and unique – advantages that set it apart from its global rivals: close cooperation across the entire industry value chain and an active, well-developed research network. It is here that the RFCS, and other European research instruments like Horizon 2020, have an essential role to play. Together, the European steel sector can continue to develop innovative, technologically advanced steels produced in the most energy efficient and environmentally sustainable manner possible. The RFCS is central to other European Commission initiatives designed to enhance industrial competitiveness, such as the €315 billion Investment Plan for Europe, the Single Market Strategy, and a new High Level Group on Energy-Intensive Industries.

Where will steel take us next? Steel will is essential to meet the needs of a growing world population and ensure that vital infrastructure can withstand the predicted effects of climate change and other natural disasters. Steel is central to enabling a new age of clean energy generation and transportation. Steel, one of the oldest metals, is central to a new age of advanced technology. The knowledge gathered as the complexities of steel production are unravelled and mastered will be an asset to other industries in turn. And more than ever, the steel industry needs to show the market that this metal is the ultimate of materials, capable of meeting every need from precision engineering to safe transport to smart homes. Despite its challenges, steel is and remains unique and irreplaceable.

Appendix I

Table 1 of 2015 priorities for RFCS steel projects.

Priority	Description
2.1	Improved energy efficiency in high temperature processes by recovery of waste heat without drawback on environmental impact compared to present best available technologies
2.2	Integration of process monitoring (online/offline) AND control AND technical management of steel production using mathematical methods for a multi-criteria optimisation of steel production with respect to at least two of the following aspects: productivity, resource efficiency, product quality
2.3	New OR improved resource efficient processes to transform low quality primary raw materials OR secondary raw materials (e.g. slag, dust, scale, sludge, low quality scrap) into valuable products
2.4	Solutions directly aiming at minimizing the ecological footprint of the Steel Works with respect to one of the following issues: air, water, soil, biodiversity, CO_2 emissions
2.5	Measurement AND on-line control of mechanical properties, through either new measurement techniques OR improved physical models
2.6	Development of new steel grades with improved technological property combinations (e.g. strength, formability, toughness, etc.) enabling more efficient steel applications (e.g. weight reduction, energy absorption, thermal shock resistance, wear, etc.)
2.7	Development of steel solutions for transport OR sustainable construction (focusing on energy efficiency AND carbon neutralisation) OR energy applications (including renewables) with improved life cycle assessment (LCA) results
2.8	Safety of steel infrastructures (e.g. tubes, pipes, pipelines, vessels, fittings, structural elements) for cost-efficient fluid storage AND transportation in the energy sector
2.9	Improvement of working conditions in steel production through innovative solutions by use of both modelling AND monitoring activities linked to health OR safety aspects risk management

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