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Reducing Risk in New Green Steel Projects — The Wasmund Approach

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ABSTRACT

In 2011, Hatch's Dr. Bert Wasmund published an informative paper 'Implementing New Technologies in Metallurgical Processes: Building Plants that Work'. Wasmund reviewed projects that featured new metallurgical technologies with a focus on success factors that led to a rapid plant ramp-up and met stakeholder expectations. Today, adopting Wasmund's approach will be crucial to successfully implement emerging green steelmaking technologies and related facilities. This includes Hatch's Continuous Reduced Iron & Steel Process (CRISP+), where large electric smelting furnaces will process direct reduced iron into carbon containing hot metal, replacing blast furnace ironmaking. Hatch's CRISP+ development approach is reviewed to illustrate the application of the principles that Wasmund highlighted to provide successful outcomes when new technology is deployed.

Keywords: Steel Decarbonization, Electric Smelting Furnace, CRISP, Green Steel Technologies.

INTRODUCTION

Dr. Bert Wasmund and colleagues studied 23 metallurgical plant start-ups featuring new technology to better understand how to achieve a rapid ramp-up and meet business case and stakeholder expectations. This led to his 2011 publication where Wasmund reviewed the implementation path of new non-ferrous pyro and hydrometallurgical technologies with a focus on elements for success. [1] Fast forward to today and the iron and steel industry is undertaking a generational step change, implementing new process technologies to reduce greenhouse gas emissions (GHG) related to the blast furnace (BF) - basic oxygen furnace (BOF) steelmaking route. Processing direct reduced iron (DRI) in electric smelting furnaces has emerged as a pathway to significantly decrease steel emissions by replacing iron ore reduction by coal and coke with natural gas and/or hydrogen followed by electric smelting/melting. With extensive experience supplying electric smelting furnaces for over 70 years, Hatch now offers CRISP+, the Continuous Reduced Iron and Steel Process, as a solution to use electric smelting furnaces, combined with a direct reduction plant, to replace a blast furnace and its supporting facilities.

This paper is presented in three parts. In Part 1, electric ironmaking is reviewed and the CRISP+ process described. Part 2 discusses the challenges of implementing facilities with new technology features and explores Wasmund's observations on achieving successful outcomes. In Part 3, we review how Hatch has incorporated Wasmund's observations into our own development of the CRISP+ process as we prepare to implement some of the largest electric smelting furnaces (ESFs) built to date to replace blast furnaces and reduce GHG emissions.

PART 1 – ELECTRIC IRONMAKING AND THE CRISP+ PROCESS

The iron and steel industry is exploring technologies that can significantly decrease GHG emissions while utilizing the existing blast furnace iron ore supply chain. An emerging option is converting widely available blast furnace grade iron ore pellets into DRI using a direct reduction plant (DRP) and then smelting/melting the DRI into carbon-containing hot metal in an electric smelting/melting furnace (ESF). The resulting hot metal can be fed to a BOF or electric arc furnace (EAF) or be solidified for use at a second location (Figure 1). The DRP-ESF process route is an effective solution to replace a blast furnace and significantly decrease GHG emissions. Unlike typical DRP-EAF flowsheets, the same iron ore supply base can be used while maintaining the operation of the existing BOF and related steel refining and casting operations.

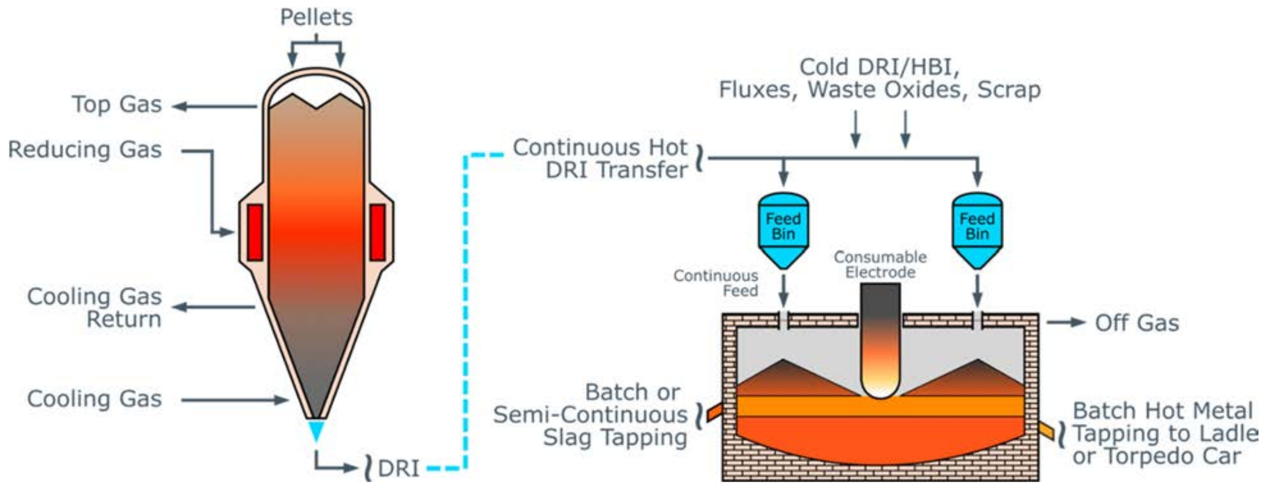


Figure 1: The Direct Reduced Ironmaking (DRI) – Electric Smelting Furnace (ESF) Ironmaking Process

History of Electric Ironmaking

Carbon-containing hot metal was first produced in ESFs in the early 1900s. [2,3] Commercial-scale operations started in the mid-1920s in Norway, Sweden and Italy. The Tysland-Hole furnace, commissioned in Norway in 1925, formed the basis of the electric smelting technology used to this day (Figure 2).

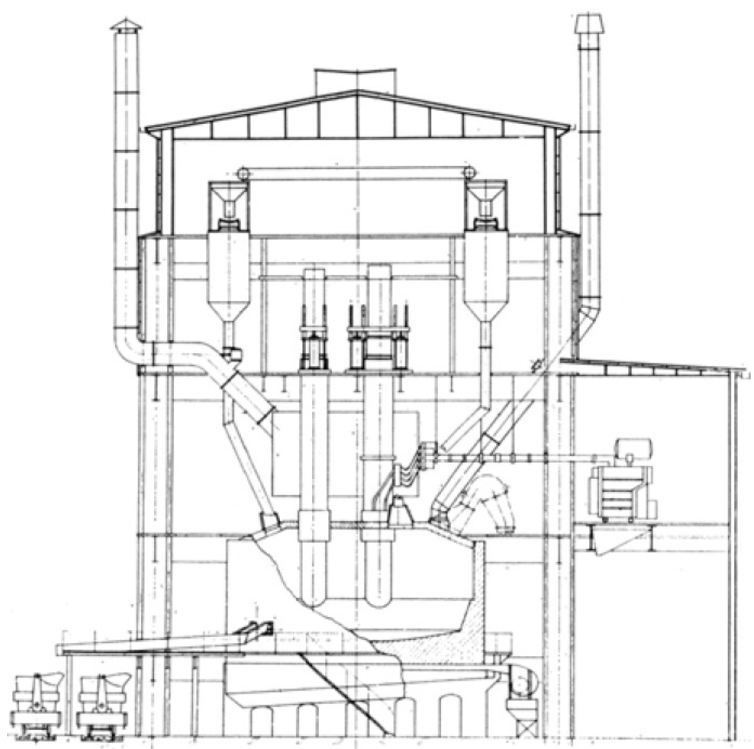


Figure 2. The Tysland Hole electric smelting furnace concept developed in 1925 [2]

By 1963, Astier reported that there were about 100 electric ironmaking furnaces collectively producing 3–4 million tonnes per year. [2] The largest plant located in Venezuela, produced 1,000–1,200 tonnes per day of hot metal from multiple ESFs based on smelting sinter produced from local iron ore. These early furnaces smelted a range of iron ore and sinters, some pre-reduced or pre-heated, before being charged to the ESF. Iron ore consumption was comparable to today's blast furnaces at ~1,700 kg/t HM considering the ore grade was relatively low at ~60% Fe. The operating cost was comparable to blast furnaces when pre-reduced ore or sinter was used, and electrical power costs were low. [3] While these ESF operations provide rich knowledge on methods to process iron ore into hot metal, they were much too small to challenge the fast-maturing blast furnace operations with each furnace producing 4,000–5,000 tonnes of hot metal per day in the 1960s.

An upscaling of electric smelting furnaces was experienced in the FeNi industry in the late 1990s. Larger rotary kiln-electric furnace (RK-EF) plants were built during a period of strong nickel prices. This led to substantial increases in the capacity of ESFs with more powerful furnaces being deployed. Material handling capacity increased to over 1.5 Mtpa, furnace hearth area increased from 100 to over 400 m2, and operating power doubled reaching 80–100 MW (Figure 3). Many features from the FeNi experience in process upscaling are applicable and can be used in large-scale ESFs for the ironmaking applications envisioned today.

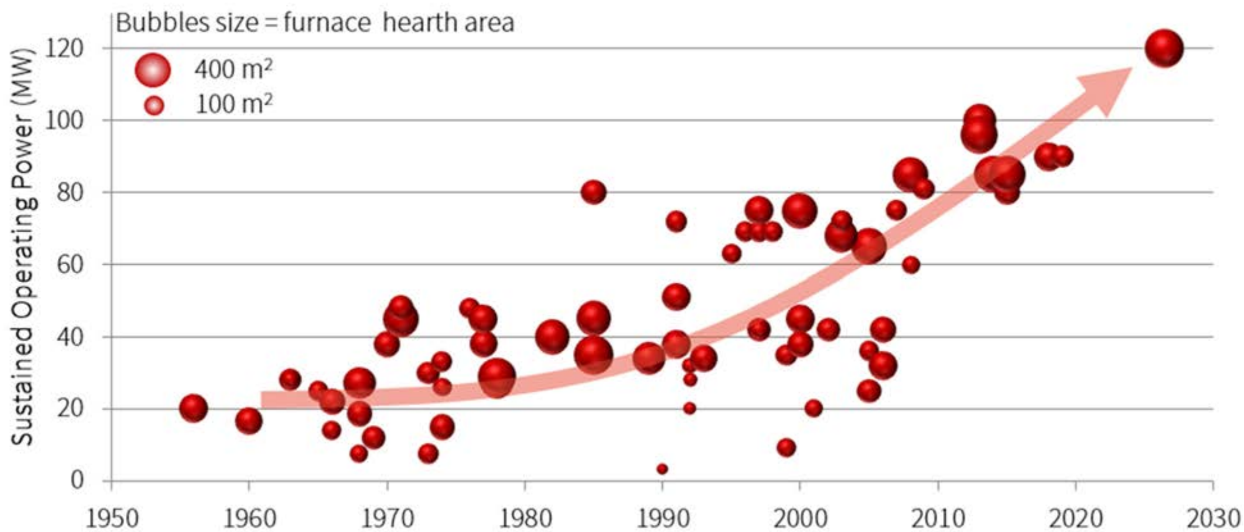


Figure 3. Progressive development in electric smelting furnace power and size. [4]

Hatch's Continuous Reduced Iron and Steel Process
Hatch had been actively developing concepts to smelt DRI in an ESF since the early 2000s, patenting the Continuous Reduced Iron and Steel Process (CRISP) to produce low-carbon steel directly from DRI. Extensive large-scale pilot tests were completed to prove the concept. [5-7]

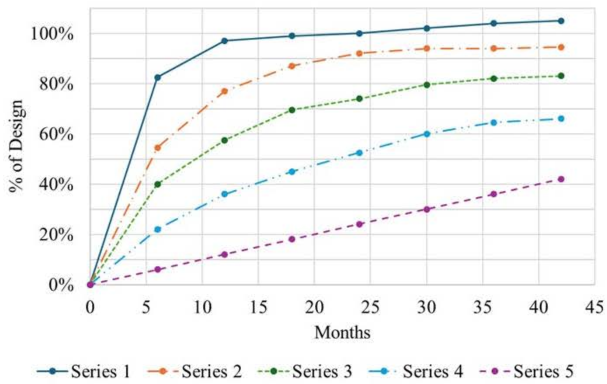
In the early 2020s, steel industry interest in ESF ironmaking emerged to replace the blast furnace and reduce GHG emissions. Hatch adapted our ESF design for hot metal production and named the ironmaking version CRISP+ to differentiate the steel and ironmaking modes of operation. CRISP+ is a commercially-ready solution built on Hatch's 70 years of experience supplying electric smelting furnaces to the non-ferrous and ferrous industries. Two large rectangular ESFs, featuring six Söderberg electrodes and with a capacity of 1.4–1.6 Mtpa of hot metal are well matched to the largest 2.0–2.5 Mtpa direct reduction plants available today.

As the CRISP+ furnaces will be among the largest and most powerful smelting furnaces built to date, Hatch has taken many steps to reduce risks for this application. In Part 2, we will discuss the challenges of implementing new technology and Wasmund's observations regarding keys to success.

PART 2 – NEW METALLURGICAL PLANT IMPLEMENTATION CHALLENGES

New Technology Projects in Metallurgical Industries
In Wasmund's review of metallurgical plants featuring new process technologies, he found a surprising degree of alignment regarding the reasons for success and challenges that need to be managed. Wasmund cited papers by McNulty and Merrow to illustrate the challenges related to implementing innovative technologies. [8, 9]

McNulty studied 41 projects in the mining and metals industry with a focus on mineral extraction and grouped their performance into five series described in Figure 4.

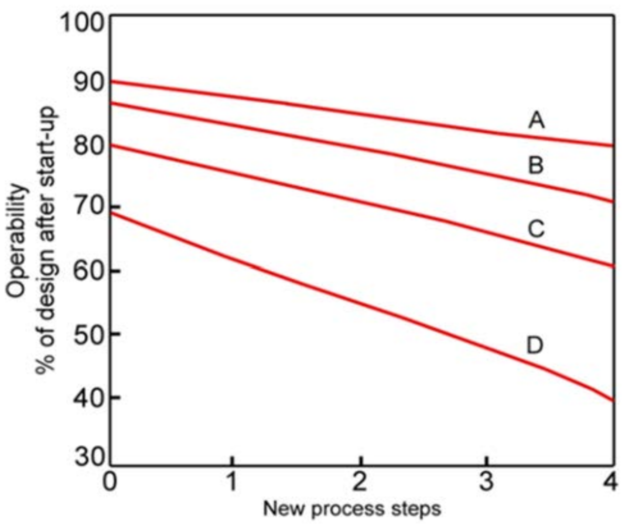


Series	Description
1	Resource well-understood, thorough development of process design criteria, extensive pilot plant work, experienced, and engaged owner and project manager.
2	At least one flaw (e.g., prototype equipment not fully tested, non-representative samples, simple unit operations overlooked).
3	Series 2 characteristics plus at least one more (e.g., feed characteristics not fully understood, serious design flaws, project fast-tracked with engineering ahead of process development, inexperienced owner and management).
4	Shares some Series 2 and 3 flaws plus unduly promotional executives, inadequate financing, ignorance of market, poor product.
5	A catastrophe only partially curable with money and time.

Figure 4. McNulty's assessment of new metallurgical plant performance. [8]

McNulty found that the plant's ability to reach its design capacity was severely impacted for Series 2 through 5 when the project development team encountered the challenges described in Figure 4. As flaws accumulated, ramp-up periods were extended and the potential to reach less than 80% of the target design increased, even after years of effort by the project team to correct the identified flaws.

Merrow further delved into the reasons for poor performance. He studied 508 new technological developments and focused on the number of new process steps that each new flowsheet considered; his results are found in Figure 5. [9]



A	All liquid and gas
B	Solid intermediate product
C	Refined solid feed
D	Raw solid feed

Figure 5. Impact of multiple process steps on the plant operability 12 months after start-up per Merrow. [9]

Merrow showed that as new/novel process steps were added and flowsheet complexity increased, the ability to reach name plate capacity within one year of start-up dropped significantly. Performance further decreased when solid feed materials were used with a dramatic drop when processing raw feedstocks.

New iron and steelmaking plants extracting iron from ores with decreased CO2 emissions will process raw solid feed and, therefore, fall into Merrow's D category. When considering just two new process steps, a new commercial-scale green steel plant could expect to reach 50–60% of design capacity 12 months after start-up, representing a major business risk to the owners. Wasmund further studied new technology projects to identify causes of failure and pathways to success.

Wasmund's Review of New Metallurgical Technology Projects

Wasmund studied 23 major metallurgical projects to compare the ramp-up performance to the trends identified by McNulty and Merrow. Of the 23 projects:

- Seven of 23 (30%) plants met design capacity 3 years after mechanical completion.
- Nine of 23 (40%) plants had difficult start-ups, reaching design capacity after more than 3 years of operation.
- Seven of 23 (30%) plants were failures with the plants being abandoned without reaching design capacity.

Of interest to the next-generation DRP-ESF process route is the development of ferro-nickel plants based on the rotary kiln-electric smelting furnace (RK-ESF) or shaft furnace-electric smelting furnace (SF-ESF) technologies due to similar ore reduction and smelting requirements. Wasmund noted that the first generation RK-ESF plants had a poor ramp-up with these plants falling below McNulty's Series 3 line. While these poor results were due to technical challenges, Wasmund noted shortfalls in skilled labor pools, challenging locations, and over-reliance on technology and equipment suppliers. Wasmund found greater success for the second generation RK-ESF plants where more piloting was completed, and with ramp-up close to McNulty's Series 2 forecasts. The ramp-up of first- and second-generation ferro-nickel plants can be compared in Figure 6.

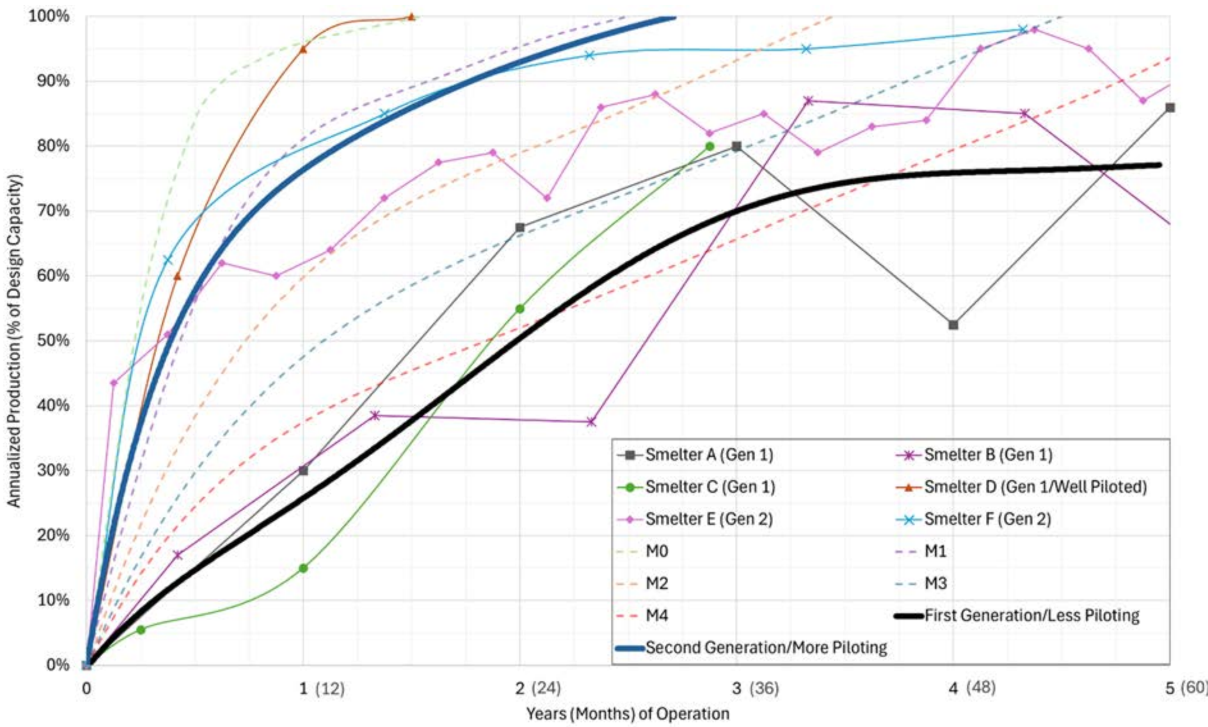


Figure 6. Ramp-up curves for first- and second-generation ferro-nickel smelters. The M0-M4 projection curves were developed by Wasmund to illustrate the ramp-up experience for ferro-nickel smelters. [1]

Wasmund identified seven key factors that contributed to most new process plant failures or exceedingly difficult start-ups:

1. Too many new elements, such as new process technology steps, unfamiliar plant locations, new markets for plant products, uncertain sources of raw materials, or a new business for the owners.
2. Inadequate pilot testing of new process steps or newly integrated process steps.
3. Over-reliance on process equipment vendors and suppliers for design of innovative technology equipment.
4. Insufficient financial and human resources for project development, implementation, and start-up.
5. Inadequate project team "champions", either too weak to provide leadership or too strong to accept objectivity.
6. Inadequate project stage-gating to ensure that defined targets and objectives have been met at each stage of the project, and insufficient attention to risk evaluation and mitigation.
7. Poor knowledge of the overall business case, particularly the marketing and pricing of products and sourcing of raw materials, and inadequate appreciation of the trade-off between rewards and risks.

Understanding Wasmund's observations, Hatch adapted our project management process for new technology projects to ensure success.

Adapting the Front-End Loading Process for New Technology Projects

The well-known front-end loading (FEL) project methodology is based on early engineering definition to reduce risk and minimize changes later in the project. This is a recognized methodology to manage complex projects and to avoid cost and budget overruns. It involves four developmental stages with rigorous gate reviews to advance through the project with increasing spending and business case development (Figure 7).

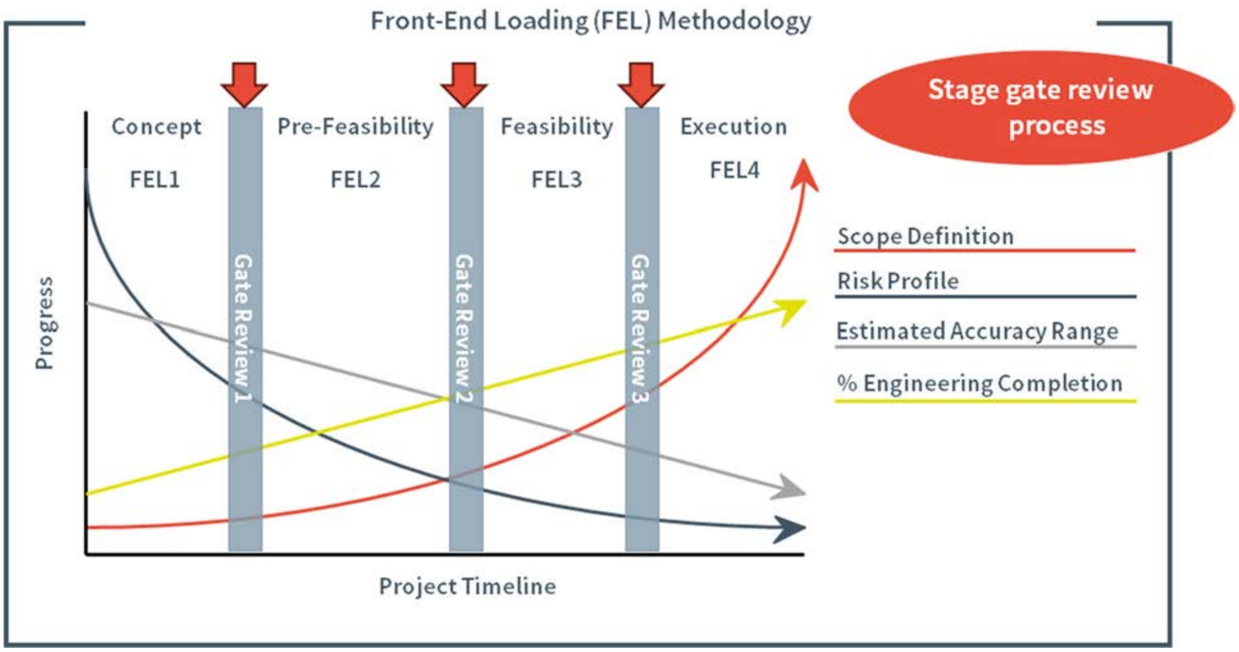


Figure 7. The FEL Process with increasing engineering definition and decreasing risk over the project timeline. [10]

A key step to managing uncertainty is the pre-feasibility stage or FEL2, where trade-off studies and pilot testing are completed to mitigate identified risk, establish process understanding, and mature the business case. Trade-off studies are focused on resolving known "unknowns" that are identified in a risk identification exercise completed as part of the FEL1 concept study. While this is also important with new technology projects, developers and stakeholders need to plan for both known "unknowns" and, importantly, for unknown "unknowns", an aspect that can be more pronounced in new technology projects and a challenge that requires more planning.

Hatch uses a technological readiness assessment (TRA) methodology developed by NASA for new technology projects to manage the inherent risk. The TRA serves to accomplish the following:

- Complete a systematic assessment against a comprehensive equipment tree.
- Ensure alignment between stakeholders by providing clear definitions of technical readiness.
- Require proof to claim each level of maturity, thereby ensuring an honest assessment.
- Guide maturity development planning activities.
- Provide a heat map so focus can be placed in areas of lower technology maturity.
- Identify risks posed by lower technology maturity and related mitigation actions to address those risks. This provides traceability and support to design decisions being made at that point in time.
- Provide a baseline for periodic reassessments as maturation activities are progressed.
- Provide an opportunity to outline clear accountabilities around maturation activities and risk mitigation plans.
- Support the identification of the IP landscape and areas of lower maturity that are likely to generate new IP.

The project development team first identifies elements and processes needed to meet the project objectives. Maturation plans are then developed so that the new technology satisfies its intended purpose in a safe and cost-effective manner and that findings are defensible to expert reviews. Important aspects to consider in developing the TRA are summarized below:

- Aligning and agreeing on success criteria.
- Sorting out the "must-haves" from "nice to haves".
- Understanding the key risks and their fundamentals—driven by process requirements.
- Managing risks in the most effective way and at the right time.
- Using a transparent and holistic approach.

A common struggle for new technology projects is identifying the correct time to execute specific actions to derisk the project. There is no one-size-fits-all approach; the activities must consider the drivers for success that support the business case. The activities should answer the following questions in the order presented:

- Is there a potentially viable project?
- What is the optimum project?
- What project should be built?

Then, build the facility as defined and planned!

We embedded these principles into Hatch's new technology project FEL methodology to provide strong project governance while accommodating the unique aspects of new technology projects. These important activities are easily aligned with the FEL process and important gate reviews as illustrated in Figure 8.

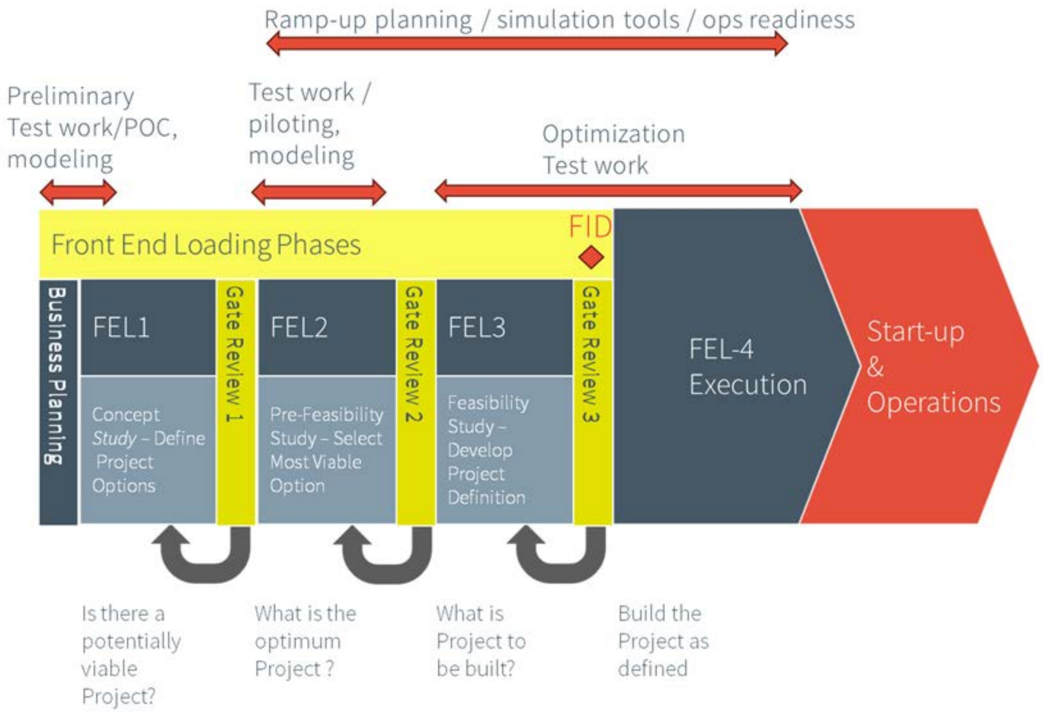


Figure 8. Integrating new technology activities and gate review criteria within the FEL project execution methodology. [11]

In Part 3, we present how Hatch incorporated the Wasmund approach as we advanced the CRISP+ direct reduced iron smelting process and prepare for the initial installations.

PART 3 – APPLYING THE WASMUND APPROACH TO CRISP+ IRONMAKING

To reduce the risk for new CRISP+ ironmaking facilities, Hatch used a holistic approach considering Wasmund's guidance to successfully build plants that work. Our focus is to provide hot metal and slag quality supporting the business case; achieve a predictable and rapid ramp-up to match the start-up of the upstream DRI Plant; and operate with predictable energy consumption and a high operating factor. Maturation activities focus on benchmarking from other pyrometallurgical applications, advanced modeling with supportive lab/pilot testing programs, and refinement of the CRISP+ design. Details of each focus area and how they consider Wasmund's observations for success are provided below.

Cross Industry Benchmarking

Wasmund identified that introducing too many new elements increases the likelihood of a slow ramp-up. To address this, Hatch reviewed other similar commercially proven smelting applications that we had direct involvement with and brought this experience to the CRISP+ furnace design. [4, 12] These include:

- Process understanding and key performance benchmarks from ferro-nickel, ilmenite and ironmaking electric smelting furnaces.
- Automated raw material handling systems that have delivered similar tonnages in ferro-nickel applications.
- Similarly sized furnaces by hearth area that are well established and have operated in the ferro-nickel industry for over a decade. These proven furnaces are configured as rectangular with six electrodes arranged in-line and maximize power input.
- Söderberg electrode sizes are well proven in 1.6–2.0 m diameter and can deliver the power needed for a large-scale ironmaking furnace (Figure 9).
- Fail-safe Söderberg electrode clamps that never release the electrode during the slipping cycle. Proprietary and commercially proven electrode seals that minimize unwanted air infiltration.

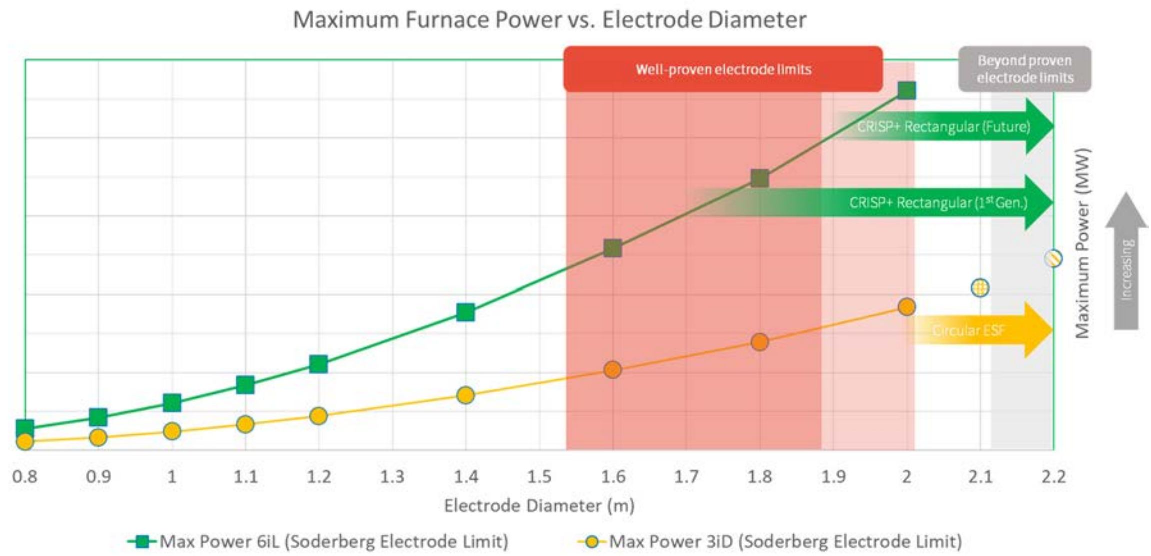


Figure 9. A six-in-line rectangular furnace delivers the needed power for ironmaking with Söderberg electrode diameters well-within proven capabilities. [4]

- Iron and slag tapping arrangements proven in ironmaking furnaces used for smelting ilmenite iron ores.
- Robust cooling technology includes advanced copper coolers and innovative air fin dry cooling that eliminated all shower cooling, and which has been implemented in high-powered ferro-nickel furnaces for decades.
- Supporting electrical power systems with strong grid protection features. Hatch builds on its long experience building high-powered electrical furnaces in locations with unique electrical grid conditions.
- Active binding systems to provide a long furnace life by holding the refractory system in compression throughout thermal cycles, minimizing metal and slag infiltration which compromises refractory service life. This is a key Hatch technology used in non-ferrous and ferrous facilities with campaign lives >20 years (Figure 10).

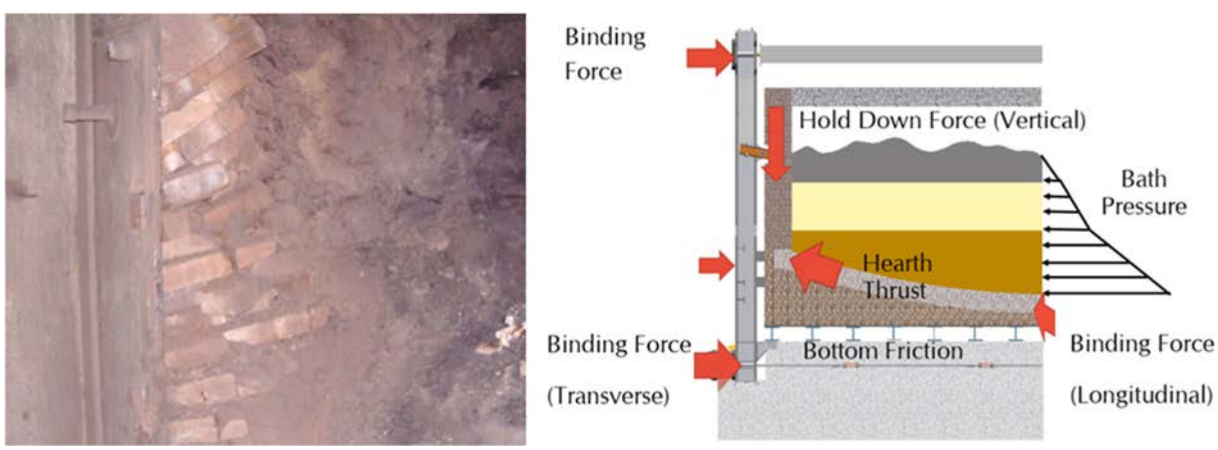


Figure 10. Wall infiltration without bindings (left) and load distribution from rectangular furnace bindings (right). [12]

Testing/Piloting/Modeling

Wasmund cited a lack of pilot-scale testing and other means to evaluate new process fundamentals as a factor for poor project outcomes. As electric ironmaking has been established for decades, including the production of high-carbon hot metal, Hatch focused its testing program on safety, product quality, and advanced control philosophies to ensure a rapid start-up of the new CRISP+ smelter.

CRISP+ process models leverage our experience for comparable smelter operations using modeling tools such as METSIM™ and FactSage™. Model development is complemented by appropriately-scale pilot tests focused on providing important data to confirm mechanisms and calculations. Hatch created a sophisticated slag modeling algorithm to rapidly assess fluxing strategies to improve the CRISP+ furnace efficiency and production rate. Slags that can be sold to cement producers have been designed, and test quantities can be produced for qualification testing per cement industry standards. Process control philosophies, focused on the unique aspect of each client's facility, will leverage these fundamental models of the CRISP+ ironmaking process. Hatch will continue to advance our models and related digital twins as these will accelerate the maturity of the CRISP+ process and optimize energy use and furnace productivity.

In parallel, Hatch is developing instrumentation for the CRISP+ furnace operations. PyroLIBS (Laser Induced Breakdown Spectroscopy) is a new technology that continuously measures the concentration of selected elements directly in hot metal and in real time as hot metal is tapped from the furnace. [13, 14] Knowledge of the degree of reduction will allow prompt adjustments to power and reductant rates that can optimize the CRISP+ operation and reduce energy use. PyroLIBS has completed advanced piloting at a blast furnace analyzing comparable hot metal with a focus on its continuously measuring silicon content (Figure 11).

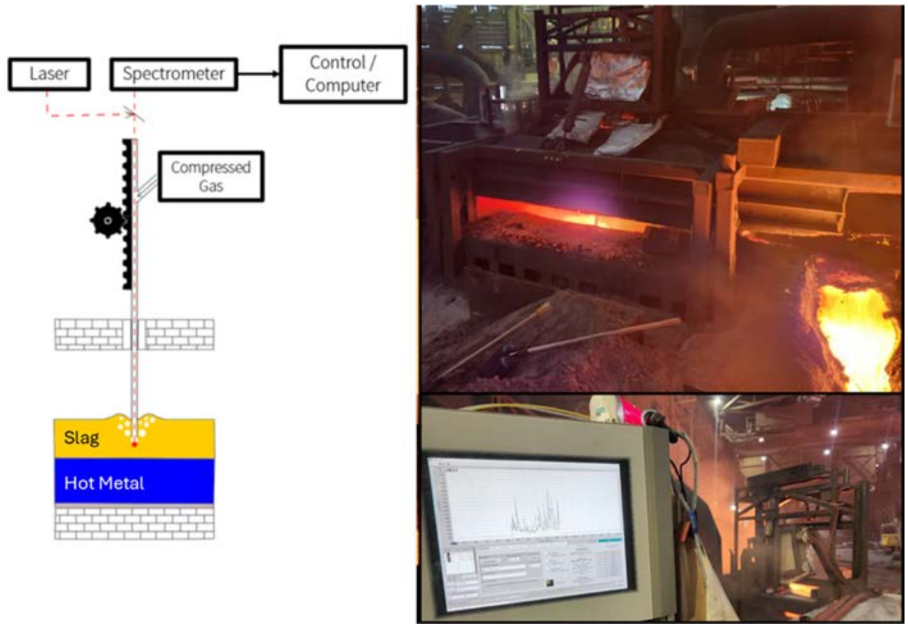


Figure 11. PyroLIBS technology to continuously measure blast furnace hot metal composition. [12, 13]

Flexible Design
Wasmund cited an over-reliance on equipment vendors for innovative equipment as a reason for poor start-ups. As an ESF technology supplier and experienced process integration company, Hatch partners closely with our clients to minimize this risk. In addition, Hatch adopted a flexible design approach to CRISP+ and, where possible, included features to consider variations in future operations. Examples of CRISP+ features that allow a range of operational modes include the following:

- Furnace transformers are designed to provide a wide operating envelope so operators can quickly adjust to varying conditions.
- A material handling system able to distribute feed mixes to multiple locations over the CRISP+ cross-section.
- Multiple iron tapholes to facilitate tapping and extend taphole campaign life, essential to reach target tonnages.
- A high-capacity, robust/low maintenance off-gas technology adapted to ironmaking service with high CO-content off-gas. This builds on designs used in newer high-capacity CaC_2 smelting furnaces Hatch implemented in 2010–2015.

Partnering
To address Wasmund's concerns regarding sufficient financial and human resources, Hatch has been helping steel industry and raw material producers understand the application of electric smelting technology in their value chain. Site visits to operating electric smelting furnaces producing FeNi, hot metal and Ni-matte have been arranged to inform and share important industry knowledge with new steel industry entrants.

In 2023, BHP and Hatch developed the design of a large-scale pilot ESF to better understand how best to process Western Australia's Pilbara iron ore. [15] In 2024, BlueScope, Rio Tinto and BHP, all key Hatch clients, plus Woodside Energy launched the NeoSmelt project to implement a large-scale DRP-ESF demonstration plant to study the unique challenges encountered when processing Pilbara iron ores. [16] In the United States, and with Hatch's help in the initial planning, Cleveland Cliffs successfully secured a provisional award for USD 500 million in financial support from the U.S. Department of Energy to build two electric melting furnaces to replace the Middletown Blast Furnace No. 3. [17] Together, these important arrangements create the talent pool and supporting funding needed to advance electric ironmaking as a pathway to replace blast furnace operations.

Technical Readiness Assessment

To manage Wasmund's concerns about project sponsorship and project champions, the Hatch CRISP+ development team completed and continually updated a TRA matrix. Systems and sub-systems were defined and the technical maturity of each was identified. Identified risks consider classical scientific and engineering challenges as well as practical project and intellectual property management matters. Heat maps help the technology development teams understand and manage risk and prioritize maturity activities. This provides an objective perspective of risk and defines maturation activities in an impartial manner that can be reviewed and tested with internal and external subject matter experts at planned gate reviews.

Project Management

Wasmund called out inadequate stage gating as a contribution to poor project outcomes. To guard against this, the CRISP+ development project team follows the FEL process defined earlier with gate reviews with Hatch's investment committee. Technical readiness and maturation activities are reviewed, and plans/related funding are approved. An important aspect is to understand the needs of future clients and update the business case and any unique technical requirements that must be brought into the CRISP+ maturation activities.

Business Case Understanding

Wasmund cited a poor knowledge of the overall business case as a reason for poor outcomes with new technology plants. The Hatch multi-disciplinary Advisory, Climate Change and Pyrometallurgy teams continuously evaluate important economic drivers that support the transition to the DRP-ESF process route as a decarbonization pathway. Iron ore value chain studies and metallics value-in-use calculations confirm the merits of using commonly available blast-furnace-grade iron ore compared to low-gangue DR-grade iron ore pellets as a positive steel decarbonization strategy (Figure 12). [4, 18] Opportunities to leverage infrastructure, access government support, and understand changing environmental regulations and new electrical grid system requirements help project sponsors see the best opportunities to implement DRP-ESF technology.

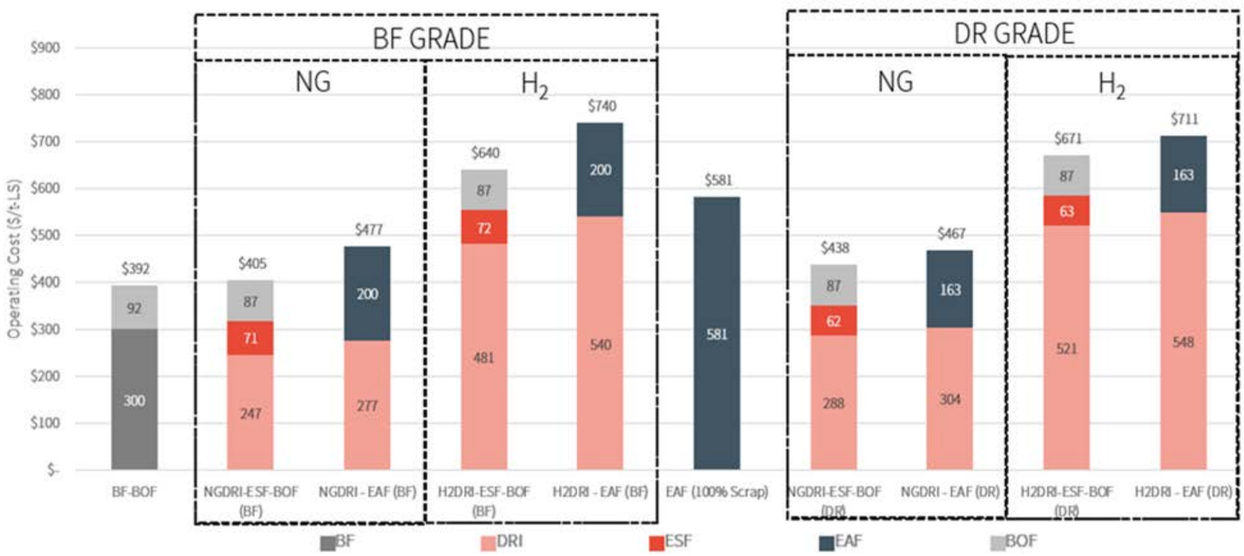


Figure 12. Operating cost comparisons of different process routes that reduce steel industry GHG emissions. [4]

Owner's Role

With the CRISP+ design established, the owner has an important role in bringing the new smelter to a commercial success. To efficiently and successfully implement the new CRISP+ plant, Wasmund emphasized that the owners and their project leaders must:

- Minimize new elements in the plant design and avoid unfamiliar plant locations.
- Together with the technology supplier (Hatch), characterize raw materials to avoid unexpected surprises.
- Integrate process equipment vendors and engineering specialists with a strong history, a collaborative delivery model, and strong leadership.
- Provide sufficient financial and human resources for project development, implementation, start-up, and for sustaining operations.

- Provide good governance to manage identified risk and position project "champions" to provide appropriate leadership and accountability.
- Define start-up conditions that provide the safest operating mode possible that will help operators learn routines and cope with the inevitable equipment issues any new plant faces. Decouple major unit operations to avoid domino effects where the performance of an up or downstream unit operation impacts the ESF ramp-up.
- Complete operational readiness planning early with a focus on operator/maintainer training.
- Understand and review the business case to make important trade-offs between rewards and risk during the smelter implementation. These include ramp-up costs, simplifying the start-up plan, and progressively ramping down the blast furnace while ramping up the new DRP-ESF facility.

With good governance and collaboration between the owner and the technology provider, the new CRISP+ smelter will safely ramp-up at a predictable rate, integrate with the upstream DRI plant, and meet the business plan objectives.

CONCLUSION

Dr. Bert Wasmund and colleagues clearly illustrated the unique challenges faced when implementing new metallurgical technology in their 2011 study. From this, Hatch developed a systematic way to better understand and manage new technology risk through thorough technology benchmarking, the application of a strong technology readiness assessment process and integration of technology gate reviews into the front-end loaded project (FEL) methodology. The adoption of these holistic methods is essential for transformational green steel projects to be successful, many of which have significant new technology features. Hatch's CRISP+ ironmaking development team has embraced Wasmund's keys for success with a focus on achieving a fast ramp-up. With a strong collaboration with future owners and following the principles that Wasmund outlined, the outlook is good for steel companies to reduce GHG emissions using the CRISP+ ironmaking process.

ACKOWLEDGEMENTS

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