2

The Limits of Established PRM: The Circored Project[1]

2.1 Early Design of the Circored Technology

2.1.1 Cliffs' Strategic Business Idea

Cleveland Cliffs, based in Cleveland, Ohio, is one of the largest iron ore and iron ore pellet suppliers to blast furnace integrated steelmakers in the United States. In the late 1980s, Cliffs' management observed a demand shift from blast-furnace-based steelmaking to electric arc furnaces (the newly fashionable "mini-mills," such as Nucor). But they had no product for the mini-mills, which used mostly scrap as their iron source.

Scrap contains many contaminants, or other metals included in the products from which the scrap is made. Therefore, the mini-mills needed clean iron inputs, the so-called direct reduced iron (DRI). This would allow producers, such as Nucor, to go head-on profitably against the integrated mills, even for high-quality steel. Thus, the demand for DRI was expected to rise steeply, from 17.7 million tons in 1990 to double the volume by 1997. Almost half of the DRI came from Latin America, with its cheap natural gas and huge iron ore reserves; three million tons came from Venezuela alone.

At the end of 1992, Cliffs' management decided to develop their own DRI business. They approached several potential partners—three steel companies and one iron ore producer—and entered discussions with them about sharing the risks and the rewards of an attempt to move into the DRI business.

Cliffs set up a task force, led by Senior Vice Presidents Bill Calfee and Dick Shultz, to analyze the available options. The task force examined different kinds of process technologies for converting iron ore into DRI. The Midrex technology was the "classic" and dominant process of producing DRI, accounting for 61 percent of world production in 1990. As Cliffs felt they were a latecomer in DRI and needed to differentiate themselves, they decided to pursue a new technology.

Two new technologies looked interesting but could not be pursued further because the technology partner worked with someone else or because of licensing problems. Thus, by late 1994, the task force revived earlier discussions with the German company Lurgi Metallurgie GmbH. In April 1995, John Bonestell, head of Lurgi's U.S. ferrous metal unit, met Bill Calfee at an iron ore conference in Vienna and explained the new Circored process to him. Bonestell arranged for Calfee to meet Walter Schlebusch, then Managing Director of Lurgi Metallurgie. They met on May 2, when Schlebusch said, "We are interested. How would you foresee an agreement?" Calfee drafted three pages of what he thought could be a development agreement, prompting Schlebusch to react: "We could live with this!" The exchange led directly to a series of phased tests, cofinanced by the partners, and ultimately to the go-ahead.

2.1.2 The Circored Technology and Early Preparations

Lurgi Metallurgie GmbH, a subsidiary of the MG Technologies AG, was a metallurgical process engineering company with a long history and widely acknowledged expertise of working with circulating fluidized bed (CFB) processes. Since the 1950s, the company had fluidized solids by blowing high-pressure gas into them and circulating the fluidlike mass through a reactor and a cyclone. The circulation offered high mixing and, thus, a fast chemical reaction. The company successfully applied the principle in material processing, waste incineration, ore processing, and energy production.

In the late 1970s, Lurgi had developed the coal-based Elred process. The gas-based successor process to Elred was given the name “Circored.” In a climate of increasing interest in DRI, in 1994, Lurgi developed a process proposal and a lab pilot under the leadership of Dr. Martin Hirsch, the “brain father” of the CFB principle. The Circored process was simple and elegant, using only hydrogen to reduce the ore, and briquetting the DRI to produce hot briquetted iron (HBI). Lurgi argued that Circored was more efficient than Voest Alpine’s FINMET (the most-talked-about new technology), achieving, with two reactors, the same output as FINMET with four. Thus, physical plant size and capital requirements would be lower for the same capacity, maximum plant capacity would be higher, and, working at lower temperatures, the process would be more robust. In contrast to Midrex, Circored used fine ore instead of iron pellets, saving an expensive pelleting facility amounting to $15 per ton. A simplified Circored process diagram is shown in Figure 2.1.

When Bill Calfee talked to John Bonestell again in May 1995, Lurgi could show first test results that demonstrated excellent quality and efficiency performance in a test reactor that processed 20 kg/hour continuously. Cliffs financed two further rounds of tests in the summer of 1995 (in return for a share in the royalties of subsequent Circored plants), at a total cost of about $1 million. The tests produced excellent results.

That summer, a Lurgi engineering team prepared the preliminary design of a proposed Circored plant (process calculations including dynamic process modeling, flow sheet development, layout, and cost estimates). Based on this effort, Lurgi made Cliffs an offer that was more detailed than usual at this early stage. The team had even more detailed piping and instrumentation diagrams available internally.

In the fall of 1995, Lurgi organized a conference with Dick Shultz and Bill Calfee from Cliffs and academics from several German engineering schools. The participants discussed the engineering challenges of the technology and concluded that there *were* risks, but that they were *known* and could be overcome. (The upper part of Figure 2.2 shows a simplified excerpt of the risk lists.) After this thorough risk assessment, they were convinced. While everyone was aware that the facility would be a first-of-its-kind, the technology looked straightforward, Cliffs had (in their mines) experience in the construction of large capital projects, and Lurgi had the process expertise. The project gained momentum.

Description of the Circored Process

The basic chemical reaction equation of the Circored process is $Fe_2O_3 + 3H_2$ _ $2Fe + 3H_2O$. A design capacity of 100 tons/hour of iron ore fines are dried and preheated in the preheater (Figure 2.1, left-hand side) to a temperature of approximately 850° to 900°C: High-pressure air is blown into the solid at the bottom, and the highly mixed air-ore fluid circulates through the recycling cyclone and is efficiently heated. High pressure is also needed in the first seal pot to ensure fluidization. Through the second seal pot and the bucket elevator, the hot material is introduced into the four-bar pressurized hydrogen atmosphere in the middle lock hopper (the hot material is introduced in batches, using valves above and below the middle hopper to prevent pressure being lost).

The ore has now entered the reduction part of the process, a pressurized hydrogen atmosphere of 650°C (Figure 2.1, center). This temperature is low enough for the iron not to stick together in clumps or to the chamber walls, but high enough to ensure an efficient reaction. In the first-stage CFB reactor, the material is again fluidized with high-pressure hot hydrogen blown into the reactor and the seal pot, and circulates through the reactor and the seal pot. In this perfectly mixed state, 70 percent reduction is achieved very quickly, with a retention time of about 15 minutes. After prereduction, the material is discharged into the secondary fluidized bed (FB) reactor. Here, the material is also fluidized by hot hydrogen blown in from the bottom, but it does not circulate. The fluid flows through four chambers, bubbling over the top of and through holes in the walls. The longer the retention time, the higher the extent of reduction. After 3 to 4 hours, a metallization of 93 to –96 percent is achieved, which is an excellent quality for steel production.

If the steel plant was next door, this would be the end of the process. After depressurizing, the high-quality DRI, exiting in the same form as the ore input (fine sand), could be inserted into a steel furnace.

However, DRI is unstable and unsafe for transportation—pure iron reoxidizes even at room temperature and may cause fires on a ship. Therefore, the DRI must be pressed into hot briquetted iron (HBI), high-density iron bars that have such a small surface to the air that they do not reoxidize. Briquetting requires a temperature of at least 680°C to obtain high-quality HBI (with a density of greater than 5.0 g/cm). Thus, the DRI is discharged from the FB reactor into a flash heater. Preheated hydrogen is blown from the bottom into this vertical shaft at high velocity and carries the DRI to the top, heating it to about 700° to 715°C.

Now, pressure and hydrogen are removed in a reversal of the initial lock hoppers: Through three sealed hoppers, the material is dumped, hydrogen is replaced by nitrogen, and then the pressure is released (Figure 2.1, right-hand side top). Hydrogen is extremely explosive, and great care must be taken to ensure that none of it leaks out of the closed circuit in order to guarantee safe operation of the plant. Each of three briquetting machines (Figure 2.1, right-hand side bottom) contains two wheels that turn against each other, each wheel having the negative of one half of a briquette on its face. The DRI is poured onto the wheels from the top and is pressed into briquettes, or iron bars.

Energy for the endothermic reduction reactions is supplied by heating both the ore and recycle gases. The off-gas from the recycle cyclone of the reactors passes through a process gas-heat exchanger and a multiclone for the recovery of ultra-fine dust particles, which are recycled into the last compartment of the FB reactor. The off-gas is then scrubbed and quenched simultaneously for the removal of dust and water produced during reduction (the chemical reaction produces 30 tons of water per hour). The cooled and cleaned process gas is then recompressed and subsequently preheated in gas-fired heaters to a temperature of approximately 750 °C before being reintroduced into the reactor system.

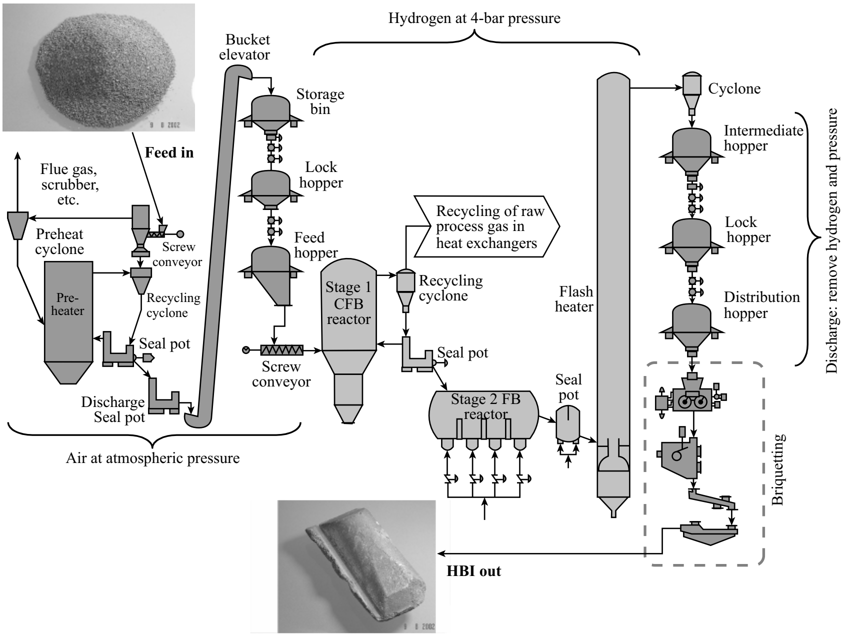
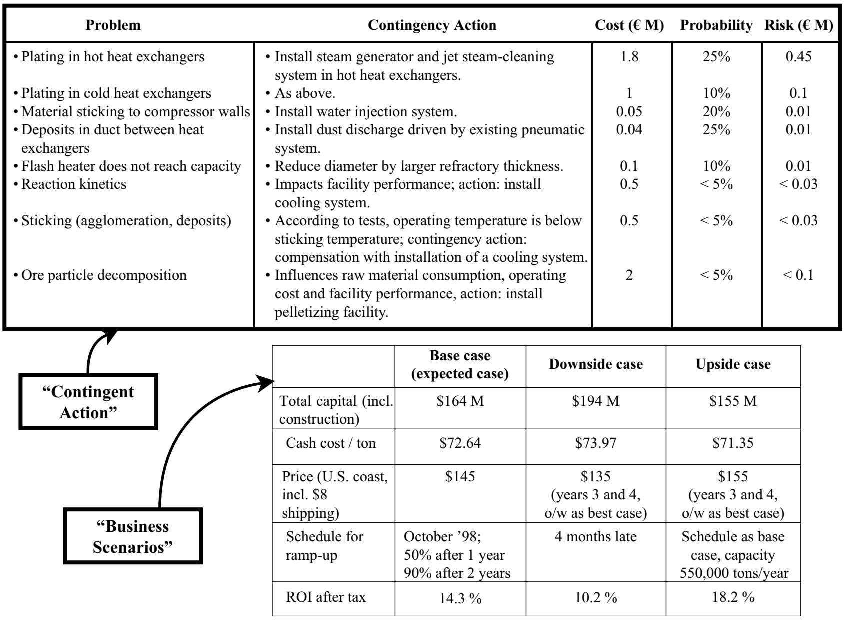


Figure 2.1 *Simplified Circored process diagram*

2.2 Joint Venture and Business Plan

As the project with Lurgi became more and more concrete, Cliffs pursued a joint venture structure for the facility. Of the originally identified partners, only LTV Steel, desirous of using DRI in a mini-mill they were building in Alabama, signed up. Shareholder negotiations for the Trinidad joint venture, called Cliffs and Associates Limited (CAL), went on through the second half of 1995. Cliffs wanted Lurgi to take an ownership position because Lurgi refused to give a performance guarantee for the plant—in general, process engineering companies are reluctant to give guarantees on first-of-its-kind technologies because the risks incurred would be too high for the usually small engineering suppliers who live on margins of about 3 to 5 percent. With part ownership, Cliffs hoped to give Lurgi an incentive to do their best to make the plant work. Lurgi reluctantly gave in. The shares in CAL were 46.5 percent each for CCI and LTV Steel, and 7 percent for Lurgi. Lurgi paid for its share with a cash injection of $6.8 million. A shareholder agreement was drafted in November 1995.

In parallel, Bill Calfee negotiated the ore supply from the Brazilian ore producer, CVRD, and finalized a preferred-price gas supply contract with the Trinidadian government. Also, an operating contract was drawn up that specified how CAL would be managed (Cliffs would get a management fee of 0.8 percent of revenues from CAL) and how the HBI would be sold (through another subsidiary of Cliffs).



Problem	Contingency Action	Cost (€ M)	Probability	Risk (€ M)
• Plating in hot heat exchangers	• Install steam generator and jet steam-cleaning system in hot heat exchangers.	1.8	25%	0.45
• Plating in cold heat exchangers	• As above.	1	10%	0.1
• Material sticking to compressor walls	• Install water injection system.	0.05	20%	0.01
• Deposits in duct between heat exchangers	• Install dust discharge driven by existing pneumatic system.	0.04	25%	0.01
• Flash heater does not reach capacity	• Reduce diameter by larger refractory thickness.	0.1	10%	0.01
• Reaction kinetics	• Impacts facility performance; action: install cooling system.	0.5	< 5%	< 0.03
• Sticking (agglomeration, deposits)	• According to tests, operating temperature is below sticking temperature; contingency action: compensation with installation of a cooling system.	0.5	< 5%	< 0.03
• Ore particle decomposition	• Influences raw material consumption, operating cost and facility performance, action: install pelletizing facility.	2	< 5%	< 0.1

	Base case (expected case)	Downside case	Upside case
Total capital (incl. construction)	$164 M	$194 M	$155 M
Cash cost / ton	$72.64	$73.97	$71.35
Price (U.S. coast, incl. $8 shipping)	$145	$135 (years 3 and 4, o/w as best case)	$155 (years 3 and 4, o/w as best case)
Schedule for ramp-up	October '98; 50% after 1 year 90% after 2 years	4 months late	Schedule as base case, capacity 550,000 tons/year
ROI after tax	14.3 %	10.2 %	18.2 %

Figure 2.2 CAL risk lists and business scenarios

On March 12, 1996, Calfee and Shultz presented to Cliffs' board of directors a proposal to build a 500,000-tons/year plant in Point Lisas, Trinidad (Figure 2.3). This represented a scale-up of a factor of 5,000 compared to the tests, from a 20 kg/hour lab reactor to a 100 tons/hour plant. The maximum feasible capacity for the Circored process was 2 million tons/year. Thus, the proposed plant was sized in between a pilot facility (which might have had a 50,000-tons/year capacity) and a scale-efficient plant. This represented a compromise between a pure pilot that would be far from paying for itself (for which both Cliffs and Lurgi had decided they did not have the money) and the excessive risk of a huge first-of-its-kind facility.

The business case is shown in the lower part of Figure 2.2, with an upside and downside scenario, a further application of PRM. With prices at $155/ton over the previous two years, the consensus forecast by all external analysts was $145/ton delivered to the U.S. Gulf Coast with a range of plus-or-minus $10/ton. They felt that there was plenty of demand, as most of the growth in steel production was concentrated in mini-mills and scrap was scarce—Cliffs would sell all 500,000 tons; the only stumbling block was the price. The expected after-tax ROI of 14.3 percent was not sensational but was respectable for a small-scale plant, and the parties agreed that real money would be made when a follow-on facility of 2 million tons/year capacity was built next door, immediately after ramping up the first facility.

The boards of Cliffs, LTV Steel, and Lurgi approved the high-level technical plan, based on the thorough preliminary engineering, and a capital expenditure of $170 million.

Figure 2.3 The CAL Circored facility in Point Lisas, Trinidad

2.3 The Construction Phase, May 1996–April 1999

Cliffs put a wholly owned company in place to supervise the construction work. In parallel, Cliffs Associates Limited (CAL) was set up as the later operator of the facility, with General Manager Ray von Bitter. He was the general manager of Cliffs' big Minnesota ore mine, with sound experience in installing and managing capital-intensive equipment.

Cliffs selected Bechtel Canada as the EPCM (engineering, procurement, and construction management) contractor who would supervise the construction companies. They had a large presence in Trinidad, understood Trinidadian labor, and had experience working with Cliffs. Because of the newness of the technology, Bechtel insisted on a cost-plus-fee basis.

Lurgi was to supply the entire core of the plant as a subcontractor (all except loading and unloading, and heat and process gas supplies—this was their proprietary technology). Lurgi even asked for the contract for the whole plant, but while Cliffs trusted Lurgi's technology, they did not know how good Lurgi was as a construction manager. Lurgi was awarded a lump-sum contract of $56 million for the core equipment, with a contingency of $3.1 million (in addition, a separate contract worth over $12 million was awarded a year later to Lurgi Oel Gas Chemie GmbH, who was the lowest bidder for the hydrogen reformer plant). Both contracts being fixed price, Lurgi carried the risk of cost overruns up to 10 percent of the contract value. CAL would commission and start up the plant, with technical assistance from Lurgi.

The groundbreaking occurred in February 1997 in Point Lisas, in a festive ceremony. The project schedule was very tight for a first-of-its-kind plant: Mechanical completion (end of construction, erection, and cold/function testing) was planned for October 1998, 27 months after the start of process engineering, and operations (end of hot commissioning) were to begin in December 1998. After a one-month grace period, delay penalties would set in for Lurgi.

CRIMCO would have preferred to deal with only one contractor, Bechtel, viewing Lurgi as an equipment supplier. But Lurgi did not accept that approach—they saw the core plant as *their* baby. Tensions between Lurgi and Bechtel started immediately and lasted throughout the project. Lurgi had reservations about cost-plus-fee contractors, and the two parties competed and wrangled over who was given the right to perform engineering on what project part (for example, the weight-bearing steel construction of the core plant). In addition, Bechtel, as the general contractor, exerted cost pressure on Lurgi.

A number of project management problems dogged the construction phase. Bechtel underestimated the total erection cost; all the bids came in twice as high as estimated. Bechtel, in its role as general contractor, was then allowed to award the lump-sum construction contract to themselves (a different office), in order to maintain the cost estimates. This contributed to a suspicion that Bechtel was protecting itself against overruns by aggressively logging small changes in the project to claim additional fees. Indeed, the year 1998 brought about a $20 million lawsuit in which Bechtel claimed additional fees.

Bechtel and Lurgi continued to criticize each other as errors occurred on both sides. For example, Bechtel underestimated the difficulty of transporting the huge 400-ton FB reactor to the site and had to build a sea landing specifically to unload it. Lurgi experienced its own problems with the core plant steel structure, which it had outsourced to German suppliers. Coordination failures among these subcontractors resulted in some steel structure components not fitting, and expensive and time-consuming rework having to be performed on the construction site.

The collaboration was not made easier by the fact that Bechtel and Lurgi had different problem-solving styles: Bechtel emphasized procedures and sign-offs, reflecting their tradition of large, cost-controlled projects, while Lurgi emphasized decentralization and local problem solving, reflecting their tradition of building facilities under unique and new circumstances. This inevitably caused daily clashes. Moreover, people from three nationalities had to work together on the site—Americans, Germans, and Trinidadians. Their different communication styles and work habits caused further tensions.

Cliffs also contributed its share of problems. Its overseeing procedure was too weak, as the responsible project manager remained in Cleveland, visiting the site only every few weeks. This had been enough in normal mining projects, but now it prevented the project manager from reacting fast enough, given the turmoil of the project. In the end, all these problems caused "mechanical completion" of construction to be delayed by six months, from October 1998 to April 1999 (see the project timeline in Figure 2.4).

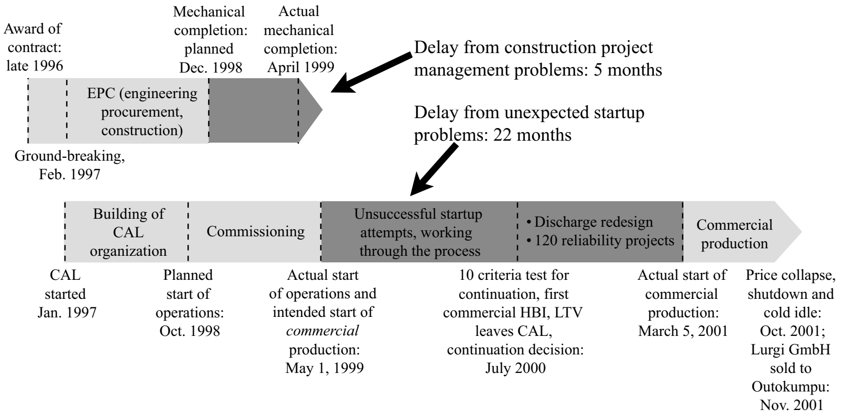


Figure 2.4 Project timeline and delays

2.4 The Startup Phase, May 1999–Summer 2000

Finally, mechanical completion was declared in April 1999, and Bechtel was released. On May 1, CAL took over responsibility from CRIMCO, and the startup team (run by Lurgi) heated up the facility with hydrogen. On May 9, they charged ore to test the whole facility, at a lower pressure of 2 bar and a lower temperature of 500°C. This produced great news and excitement. After only one day, they successfully produced DRI, which they dumped on a storage pile. On May 13, an operator erroneously poured DRI into the briquetting machine, and they even produced a small amount of HBI (although of low quality because of the insufficient temperature, and endangering the briquetter by putting the wheels under stress: DRI is less formable at the lower temperature). That night, champagne flowed to celebrate the success. The rest should follow quickly now.

The celebration was short-lived. From then on, bad news came in quick succession. Four days later, hot spots appeared on the reactor shell (because hot gas had migrated through the refractory), and the refractory in the FB reactor collapsed.[2] This shut the plant down for six weeks. Then, a shaft was bent in a fan for the preheater. The screw feeder going into the reactor leaked hydrogen through the seals causing a major fire, and the plant had to be shut down for three weeks to fix it. The main header of the gas heater, made of an exotic material, cracked and could not be welded—causing the plant to be shut down again. Then, the water depressurizer failed: 30 tons/hour of water were a by-product of the process and had to be relaxed to atmospheric pressure. Above 2 bar, hot hydrogen "shot through," and dust at the bottom seal pot regularly blocked the depressurizer.

And so it went on. Ultimately, a major part of all equipment experienced problems and had to be repaired or replaced, in many cases not because of bad workmanship, but lack of knowledge about the design requirements placed on the equipment by the hot, aggressive, and abrasive material. As the team tried to bring the plant up to design temperature, they found that the texture of the material changed from that of sand to that of molasses, more and more viscous and sticky. The material would coat the internal surfaces of all the valves and "choke" them. Eventually, all the valves had to be redesigned, and in the intervening months, the existing valves had to be "pampered" and cleaned frequently.

Finally, once the team worked their way through the process to the end, the discharge system into the briquetting machine was quite simply found not to be working. The hot DRI at 700°C just did not flow; it got stuck in the discharge hoppers virtually every hour, and no continuous flow was possible. Moreover, the little HBI that *was* made was "fish-mouthed," meaning that parts of the briquettes stuck on the briquetting wheels, giving the briquettes a less-than-perfect look because of holes in their sides and endangering the machines.

The problems went on and on, surfacing one by one. As the plant contained hot hydrogen under pressure, it was, essentially, a bomb. Every problem forced the team to replace the hot hydrogen with inert nitrogen, cool the process down, do the repairs, and then heat it up again, only to run into the next problem. What exhausted everybody was constantly hearing, "We have solved this problem; now we are almost there, and we are going to make it," only to encounter another problem the next day. With the never-ending problems, the team felt that they had lost credibility, and dedication was burned out. Some felt that the pressure on individuals mounted too high, with personal costs on all sides.

2.5 A Management and Design Change

At the end of 1999, Ed Dowling, senior vice president of operations at Cliffs, was asked to go to Trinidad and fix the problems. He and Christof von Branconi, the successor of Schlebusch as managing director of Lurgi, put together a task force of experts from Lurgi, Cliffs, and external experts to investigate the last, and most intractable, problem of flow stoppages in the discharge system to briquetting.

In April 2000, Dowling appointed a new general manager for CAL, Steve Elmquist. Ray von Bitter became head of the discharge system task force, with the mission to come up with a design by the summer. Elmquist performed an audit on every piece of equipment, creating a punch list of the most important problems. This resulted in 120 reliability improvement projects, which essentially summarized the remaining problems after the efforts of the previous year.

In parallel, Lurgi produced a new design of the discharge system: a vertical pipe, with a seal pot at the bottom into which hydrogen was blown for fluidization and to drive out the hydrogen, and then a rising pipe within which the pressure was relaxed. This design was successfully piloted at the labs of two external engineering companies.

By June 2000, nerves were frayed within both Cliffs and Lurgi. They had still not produced sustained runs. Then another blow came: LTV decided that they had had enough and wanted to exit from CAL. LTV had suffered severe financial troubles since 1999 and were close to declaring bankruptcy. They proposed selling their 46.5 percent share to the remaining partners for $2 million (plus additional payments when DRI prices would recover).

In June 2000, CAL commissioned a report on the viability of the plant by a consulting company. The report argued that the market outlook was marginal, but more seriously, it saw some grave technical risks. In particular, residual hydrogen traces in the briquettes might make the product dangerous. The report concluded that the plant should be shut down. But Dowling and Branconi disagreed with the conclusions. They tested the briquettes and found no hydrogen traces. Still, there was little confidence left at Cliffs and Lurgi that the plant could ever run. So, Dowling commissioned a three-week test run in July (at a cost of $1 million), without the new discharge system in place. The run was to prove the fundamental viability of the process. Ten goals were formulated that had to be met in order for the plant to get a chance to continue. While the discharge hopper valves were still jammed up because of sticking DRI (implying that the new discharge system was badly needed), the test run did, indeed, meet all 10 criteria. Still, the facility was within a hair's breadth of being shut down.

Armed with the test results, Dowling and Branconi presented a new investment proposal to the combined boards of Cliffs and Lurgi in August: An additional investment of $45 million would allow the company to execute the new discharge system and to implement the 120 reliability improvement projects. The target startup date would be February 28, 2001. The data presented were convincing enough for the boards to accept the proposal. In addition, Cliffs and Lurgi were now the sole owners of CAL, with stakes of 82 percent and 18 percent, respectively.

By using stringent project management methods, the discharge system was completed on time. On March 8, 2001, at 4:38 P.M. local time, the first commercial HBI hit the ground under the briquetter. It was so exciting after such a long period of frustration that some employees just stood there and giggled uncontrollably. The following months saw a steady improvement of plant operations. During the three months of August through October, the plant managed several extended runs at the design availability of 85 percent for the whole system. This represented the system reliability that fulfilled Lurgi's obligations as a contractor. In the end, the facility had become a technical success.

2.6 Market Turmoil

In October 2001, DRI prices fell to their lowest point in recorded history, $75/ton, as the Manhattan World Trade Center attacks had pushed the world economy over the brink into a recession. At these prices, no one in the industry could make money. After a scheduled maintenance shutdown in October, Cliffs decided not to start the plant back up. Rather than permanently closing the plant, they "cold idled" it, implying a long-term shutdown while retaining the key personnel (about 90 people). The cost of the cold-idled plant amounted to $10 million per year.

In November 2001, MG Technologies sold Lurgi Metallurgie to the Finnish company Outokumpu. This led to von Branconi's departure. The negotiations between Cliffs and the new partner proved difficult, as Outokumpu was reluctant to share the cold-idling costs.

In the spring of 2002, DRI prices recovered somewhat, to $90/ton, thanks to changes in the world market supplies and to steel import tariffs imposed by the U.S. government. Still, in August 2002, the financial pain proved too great for Cleveland Cliffs to bear. The company decided to write off the Point Lisas facility, suffering a one-time restructuring charge of $108 million (a significant amount for a company with annual revenues of $450 million).

The end of the Circored facility seemed once again imminent, with the same fate looming that Nucor's competitive iron-carbide venture across the street in Point Lisas suffered—this facility had technically failed and was dismantled during 2002. Leo Kipfstuhl, CAL's CFO, attempted a management buyout during 2003, but without success.

In August 2004, the big break came. Cliffs reached an agreement with the International Steel Group (ISG) for $8 million plus assumption of liabilities and up to $10 million in future payments, contingent upon production and shipments. The license to the technology was transferred to ISG. ISG was a new steel company founded by private investors who had bought the defunct assets of LTV Steel and then bought bankrupt Bethlehem Steel at fire-sale prices. With assets bought at market prices and sweeping reforms in labor relations in force, ISG was able to operate profitably. Not only did they buy the Circored facility, but they also started planning for the expansion to the 2-million-tons-per-year target that had originally been foreseen as the fully efficient scale.[3]

Thus, the Circored plant seems, ultimately, to have achieved success and may yet have a significant influence on how the industry converts iron ore into pure iron, albeit five years later than originally planned, and under a different owner. As is often the case with breakthrough technologies, the original owner lost out financially, and got out. In addition, several competent people had their careers damaged by the events. The project manager and the board were surprised when the problem-solving activities turned out different from what had been predicted, and surprise turned into frustration and disappointment. The question is what was missing and what we can learn from this project that is applicable to PRM more generally.

2.7 The Limit of PRM: Unforeseeable Uncertainty

In diagnosing what had happened in the Circored project, we must start with two observations. First, the project management errors during the construction phase were avoidable, but they added, in the end, only four months to the schedule overrun. The majority of the delays, 22 months up to the successful ramp-up in March 2001 (see Figure 2.4), were attributable to the difficulty of getting the process to run.

Second, Cliffs and Lurgi had performed competent project risk management. The 1995 conference used combined experts to diagnose risks (Figure 2.2 summarizes some risk lists and business scenarios). The project plan included many contingencies, and even residual risks were tackled. Both Lurgi and CAL continued to refine their risk analyses all along, checking for new potential risk factors. Why was PRM not sufficient to handle the risks?

The short answer is that the plant represented a scale-up of a factor of 5,000 compared to the lab reactor that had been tested at Lurgi. In the words of Martin Hirsch, this meant that "the process kinetics were completely unknown. We simply did not know whether the circulating fluid would be stable. Nor did we know whether the stationary fluid bed would be sufficient for achieving 95 percent metallization. We were obsessed with retention time, which is why we made the walls in the stationary reactor too high. It turned out that we had plenty of retention time, but the high fluid level caused dust [that is, ore substance] to be sucked into the process gas circuit and cycling back to the CFB reactor. And so on. None of this could be calculated beforehand. I knew that because I had started up three novel process generations earlier in my career."

This implies that PRM simply was not able to predict the major potential problems. Problems had been identified, for sure, but most of these never materialized, while new ones appeared that were simply unforeseeable, and others, although foreseeable in principle, simply slipped through. As one Lurgi manager put it, "You face an entire forest, and each tree is a potential problem. In principle, you can focus on any one tree beforehand and study it, but you can't look at them all. You have to choose a few and focus on them, but then it may turn out that the relevant trees are totally different." In other words, it was not possible for PRM to proactively handle all uncertainty except for small residual risks, which could be handled with a risk management office commanding some extra resources. Rather, major problems were missed, not because of a lack of diligence but because of a fundamental lack of knowledge.

Thus, the CAL people, supported by the Lurgi team, were forced into a trial-and-error mode. They resolved one problem after another, slowly "working their way through the process," each time hoping it would now run, only to be disappointed. The Cliffs people, led by Ray von Bitter, found this extremely stressful. Although they knew it was a first-of-its-kind facility, their project experience fundamentally consisted of new equipment installations in mines. They were emotionally unprepared for the iterations that were required. Ray von Bitter suffered intensely when he had to announce to the board that the successful startup, thought to be around the corner at the last presentation, had again to be pushed back. This was, of course, not helped by the fact that only two months had been foreseen for commissioning and startup in the original plan.

The Lurgi team, in contrast, was also stressed, but they knew that the ramp-up would not be linear. Although this was the first major assignment for Peter Weber, the project manager, during the ramp-up phase, he was extremely well trained and had listened many times to the war stories of Hirsch, who had ramped up three first-of-its-kind technology generations in his 30-year career. But this was implicit, uncodified, and tacit knowledge that Lurgi had not known to communicate effectively, and Cliffs had not known enough to understand, in the initial negotiations. In addition, Weber was not in control—according to the contract Lurgi had with Cliffs, he acted only as an advisor, amassing profitable engineering hours for Lurgi. Responsibility and risk had passed to CAL.

The intuitive knowledge of the fundamental novelty of the facility made Weber and his team approach the design parameters very slowly—they went to 1-bar process pressure (at 500°C), then to 2 bar, in order to ensure that all hydrogen leakages were found and a potential explosion risk was avoided. The ballpark of the right combination of the 300 process control parameters was not known, so the team had to feel its way toward controls that would at least work. This caused additional tensions with the Cliffs engineers, who thought this unnecessary fiddling; according to the Cliffs experience, testing of a facility was best done by going to the design load straight away. This is, of course, true for a known process, or even the second plant of a technology: The ballpark parameters exist, and approaching the design load becomes much simpler.

Based on the misunderstanding of the nature of the uncertainty, the methodologies used by von Bitter and CAL were insufficient. They did not develop extensive documentation of the known state of the process and of conjectured problems. They tested the process steps linearly (because they always thought they were close), rather than running multiple experiments in parallel wherever possible.

Inadequate documentation prompted Ed Dowling to diagnose incompetence when he intervened in January 2000. The success of his 120 reliability improvement projects and the discharge system redesign confirmed for him that a lack of rigorous methods had been the cause of the problems. But while, indeed, methods had not been sufficiently developed, this assessment underestimated the true nature of the challenge. When he took over and successfully applied control and quality methods, he built on the work of the previous year, which had removed the fundamental unforeseeable uncertainty and had reduced the problems to a manageable number that were all visible and, in principle, understood. In other words, when Dowling stepped in, the nature of the project's uncertainty had changed from unforeseeable to structured, so PRM methods now worked.

But it was too late for Ray von Bitter, who went into early retirement in the spring of 2001. He commented: "The difficulty of the project was not clear when I was asked to do it. But even though you can't do anything about it, you're still punished. I guess that's called life in the big city."

2.8 Summary and Conclusion

We demonstrated the power of the PRM mind-set, and the methods associated with it, in Chapter 1. This PRM approach rests on a fundamental assumption, namely that we are operating essentially on *known terrain*, where it is known, in principle, what events and outcomes of actions to expect, and with *moderate complexity*, where the nature of the "solution space" is roughly known, where an action does not cause entirely unexpected effects in different parts of the project, and where we can choose a best course of action. In other words, we know the *range* of things that can happen and their causes, even if we may not be able to predict with certainty which of the identified events will happen, or have good probability estimates.

Not all projects fulfill this assumption, however. On the contrary, projects that are novel in terms of the technology employed and/or the markets pursued, and projects of long duration, are commonly plagued by fundamentally unforeseeable events and/or unknown interactions among various actions and project parts.[4] A “straight” application of PRM, without recognizing the additional novelty challenge, is insufficient and may even have destructive effects. In this chapter, we have demonstrated this insufficiency on a quite typical example of a novel project.

Endnotes

1. This chapter is based on Loch and Terwiesch 2002. For further background, see also von Bitter et al. 1999; S. A. Elmquist, E. C. Dowling, and L. A. Kipfstuhl. 2001; S. A. Elmquist, P. Weber, and H. Eichberger 2001.
2. Refractories are special masonry walls inside the reactor that protect the metal walls from the heat of the chemical process.
3. Events continued to evolve at a fast pace. In October 2004, a merger between ISG Steel and the Indian company, Mittal Steel, was announced, creating the largest steelmaker in the world. In November, regulatory approval was still pending.
4. For examples, see Morris and Hugh 1987, Schrader et al. 1993, Hamel and Prahalad 1994, Miller and Lessard 2000, Pich et al. 2002.