



# IMPLEMENTATION OF NEW ALTERNATIVE IRONMAKING TECHNOLOGIES: EXPERIENCE AND RISK<sup>1</sup>

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## Abstract

The steel industry has struggled to implement alternative ironmaking technologies that can assure the future sustainability of the iron and steel industry. Understanding and managing the risks inherent to the introduction of new technology in a capital-intensive, high volume, low-margin industry is a key to implementing lasting change. New technology risk can be mitigated by recognizing the hierarchy of decisions that must be made, whether for a greenfield project or restructuring and modernizing existing facilities. This leads to a logical sequence of activities starting with an evaluation of technology maturity and scale-up factors, selection of appropriate technologies and plant concepts, development of capital and operating costs, risk management strategy, recruiting the best resources and management team, effective pilot and demonstration plant operations that leads to a successful commercial facility. Hatch's experience in assessing new technologies and identifying key success factors will be presented. The paper will focus on the technical aspects of alternative ironmaking technologies and will specifically address scale-up from pilot or demonstration plants to a commercial operation. The analysis/resolution of major problems and duration of ramp-up period to reach the design capacity will be reviewed for several well-known processes. Success in growing capacity after commissioning the first commercial unit will also be presented.

**Key words:** Alternative ironmaking; Ramp-up; Scale-up; Risk; Experience with implementation.

<sup>1</sup> *Technical contribution to the 6<sup>th</sup> International Congress on the Science and Technology of Ironmaking – ICSTI, 42<sup>nd</sup> International Meeting on Ironmaking and 13<sup>th</sup> International Symposium on Iron Ore, October 14<sup>th</sup> to 18<sup>th</sup>, 2012, Rio de Janeiro, RJ, Brazil.*

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## 1 INTRODUCTION

New technologies are vital to sustaining the future viability of the iron and steel industry. Restructuring of the entire iron and steel industry in North America in the 1970s and 1980s is a prime example of this. The wide implementation of the mini-mill concept dramatically improved the financial performance of the North American industry and enabled it to compete against the flood of steel import from around the world.

The prime incentive for introducing new technology into the iron and steel industry are as follows [1-2]:

- To produce a competitive product with increased profitability;
- to survive in the market place by producing a new product for future growth or revenues;
- environmental regulations or social issues, and
- to reduce dependence on expensive raw materials such as metallurgical coke.

Introduction of new technologies is a challenging task, fraught with risks. This is especially important for the steel industry, which is characterized by:

- Being capital intensive and extremely competitive,
- having long lead times for project implementation, and
- providing a low return on investment.

## 2 THE PROCESS OF IMPLEMENTING NEW TECHNOLOGIES

The process of new technology implementation must go through several distinct stages, the major of which are as follows:

- The idea phase. At this stage conceptual studies are carried out, including any required scientific development.
- the laboratory phase. Small scale test work to test key technical assumptions.
- the pilot phase stage. Integrated pilot scale testwork to check scale-up factors and the future performance of the production.
- demonstration scale trials. These are often critical in the metallurgical industry where a very large number of unknowns have to be managed. The future of the technology owner depends on the outcome of the demonstration plant results.
- implementation at the commercial scale. This covers the period from a board decision to proceed with a commercial plant, through design and construction, training and start-up until the plant meets its design capacity.
- achieving financial performance. First break even, followed by achieving the planned project ROI.

Statistics for the implementation of new technologies shows that:

- Typically only one in 3000 good ideas is successful.
- only one in 100 make it from the pilot or prototype scale to the commercial scale.
- only 1 in 4 makes it from the demonstration phase to commercial.



The successful management of risk entails the proper recognition of the project milestones and definition of the analysis, technical and financial, required to be carried out during each of these stages. The following questions should be asked to mitigate the risks as the projects evolve:

- Is there a need for this technology? (market information)
- Do we have a process? (scientific information)
- Can we scale up? (engineering information)
- Are adequate equipment, materials and controls available? (engineering information)
- Do we have a viable business? (business information)

The importance of defining key milestones involved with the implementation of new technology and rigorously carrying out the required analysis before advancing to the next phase cannot be overemphasized. Managing risk without this structure is impossible.

From a management point of view it is critical to recognize and minimize the risks related to each step of the implementation process. Throughout this process the implementation team should vary significantly at each step and the role and priorities of people on the teams are different at different stages.

An integral part of risk management is the recognition that not all will go well and that alternate, fall-back positions must be established. This becomes critical as the stage of commercial operations is approached.

One of the most common causes of failure in technology development is skipping steps. Projects with external “entrepreneurial” capital are especially vulnerable. This may result from “overselling” at an early stage of development to raise the money to continue. It is unlikely this will ever change but the onus is now on the venture capitalist to get proper assessment of the project. Usually these assessments are sound on market analysis and business plan. They will often have a competent assessment of the technology itself. They almost never have any assessment of the proposed development process, the staging, identification of the weaknesses and of the “Go, No-Go” decision points. Without proper discipline imposed by the financier on how his money is spent, the development and his money are at risk.

### 3 PROJECTS RISKS AND TECHNOLOGY STATUS

For the success of a project it is important to establish a project structure that appropriately reflects the status of the technology development. Projects can be classified by the technology development status to be applied in the following five categories:

- Type 1: Well demonstrated technology, commercially operating in a similar plant setting, at similar scale and supplied as part of a defined vendor or equipment supply package.
- Type 2: Well demonstrated technology based on sound engineering principles developed or assembled on a case-by-case basis.
- Type 3: Existing technology specifically adapted to a new circumstance or scale for the proposed project.
- Type 4: New technology developed by others but to be implemented at commercial scale for the first time on the project.
- Type 5: New technology developed internally to be implemented on the project for the first time.



For each of the technology risk classifications above, significantly different approaches are required to successfully apply the chosen technology on a project opportunity. Types 1 and 2 represent low technical risk. Usually, process/equipment vendors can provide meaningful guarantees backed up by technical depth. These types of projects are common in mining, the steel industry or downstream industries. At the other end of the spectrum, project Types 4 and 5 are typical of those where testwork is a critical component of project/process development. Type 4, where the technology to be applied has been developed by others, can present the highest risk to the owner. Since the project owner may not have been intimately involved in the development of the technologies, the owner may rely too heavily on the claims of the developer.

In Type 5 projects, where the technology is developed in-house, usually to address a specific need the test work tends to be more specific and if managed properly, will increase the chance of success. For example, a mining company may have an ore body, which is not amenable to existing technologies, and develops a new or modified process to treat the ore.

#### **4 CATEGORIES OF RISKS AND TYPICAL FACTORS OF FAILURE OF NEW TECHNOLOGY IMPLEMENTATION**

The risks of development of new technologies fall into three broad categories:

- Process, will the technology work at industrial scale?
- Commercial, will the implementation of this technology make money?
- Human risk, how might people reduce or increase the technological and financial risk?

Typical examples of the various factors that can contribute to the partial or complete failure of new technology implementation are:

- Unknown or improper scale-up (science/engineering issue).
- Cost pressures on inputs (business issue).
- Deviation from design parameters, especially from designated raw materials.
- Poor engineering of pilot, demonstration or commercial plants (an engineering issue or, if due to cost pressures - a management issue).
- Improper operator background and training (a management issue).
- Unsuitable contractual arrangements (management issue).
- Poorly timed market opportunities (a marketing issue).

The improper management of technical hurdles and potential fatal flaws can lead to failures. The great SL/RN rotary kiln process, built in the early 1970s is a good example of this. During the process scale-up the efficiency of heat and mass transfer was overestimated. As a result, the kiln throughput was limited and the process became uneconomic. The plant was closed at substantial loss to the owner. Iron carbide is a second example of the fatal flaw when two processes (reduction and carburization) which require opposite heat demands were forced to take place in the in the same space within a single technological unit.

The focus of this presentation is on:

- Process, will the technology work at industrial scale?
- Unknown or improper scale-up.
- Poor engineering of pilot, demonstration or commercial plants.



## 5 SCALE-UP PRINCIPLES FOR INDUSTRIAL PYROMETALLURGICAL FURNACES

The major principles for the proper scale-up of industrial pyrometallurgical processes are as follows:

- Pilot plant furnaces and kilns typically operate under the same temperature, chemical and physical conditions expected in the full-scale plant.
- The objective is to maintain similarity between pilot and full-scale processes, i.e., identical temperatures, raw materials and product composition, heat fluxes etc. at corresponding points and times.
- Even though kinetics (reaction time) will be of the same order, kinematic similarity may have to be sacrificed (attempts to scale velocities may yield unreasonably high, or low, velocities either in pilot or commercial).
- Heat and mass transfer are the most critical parameters to the successful scale-up of high temperature processes. Similarity in heat and mass transfer should be maintained or improved.
- For a cylindrical type furnace the increase in diameter is the critical scale-up factor.
- For a rectangular or rotary hearth furnace the critical scale-up factor is an increase in width. Similarity of distribution along the furnace periphery is provided by installation of additional burners, off-takes, ejectors etc.

Our analysis, coupled with experience with the scaling of other direct reduction processes and direct smelting processes, shows that the scale-up factor should not exceed 5-8 times.

- 5-8 times increase in the furnace diameter for Midrex and HYL direct reduction shaft furnaces with further diameter increase in the following stages.
- ~ 5 times increase in the hearth width for RHF processes.
- 2.2 times increase in SL/RN rotary kiln diameter and 5 times increase in a furnace cross-section.
- 2 times increase in Corex Smelter-Gasifier diameter.
- Scale-up factors of the HIs melt process is 2.4-fold in smelting reduction vessel diameter and 5-fold increase in furnace area (compared to pilot-scale).
- Romelt process was scaled-up by 2.5 times increase in the hearth area (width).
- 3.85 times increase in hearth diameter for Primus process.
- ITmk3 process effective width is increased by 3.85 times.

## 6 EXAMPLES OF NEW ALTERNATIVE IRONMAKING PROCESS DEVELOPMENT HISTORY

### 6.1 Midrex Gas Based Shaft Furnace Direct Reduction Process

Midrex process produces ~ 60% of total DRI production with 65 plants around the world. Largest operating plant – 1.8 Mt/y. A 2.5 Mt/y plant is in the design stage. The history of the process is as follows [3]:

- 1946 – Surface Combustion Company built electrically heated vertical furnace 4 ft. diameter, 6 ft tall (Midland-Ross bought Surface Combustion Company in 1959).
- 1963 - Midland-Ross develops Heat Fast rotary hearth process.



- 1967 - Toledo, Ohio pilot plant (basis for Portland), 1.5 ft. diameter shaft furnace, 2 - 8 inch diameter full sized reformer tubes, 0.223 tph. Operated one month using low Sulphur ore.
- 1969 Start up Oregon plant 2 modules 12 ft. diameter shaft furnace, each reformer was with 120 – 8 inch diameter reformer tubes, 26 tph, 220,000 tpa:
- Problems with high sulfur pellets - Desulfurization towers added to limit sulfur in off gas.
- Connected two reformers together to feed one shaft furnace - Demonstrated 27 to 28 long ton per hour (LTPH).
- Problems with overheating and clustering in the shaft furnace - Natural gas added to bustle gas.
- 1970 back to one reformer per shaft furnace, Tonnage 16 to 18 LTPH.
- 1971 replaced 8 inch I.D. reformer tubes with 10 inch I.D. reformer tube, Plant rerated to 20 LTPH.

Two years after startup plant stabilized at 75% of initial design capacity.

From 1971 - Success story: Numerous installations, in many cases with ramp-up of production shorter than 14 days.

## 6.2 HYL Gas Based Shaft Furnace Direct Reduction Process

HYL Natural Gas based direct reduction process is a well established process with more than 30 installations around the world. The HYL process has undergone change from a batch, to continuous process HYL III, and in 1998 the commercialization of a zero reforming (ZR) technology. Nucor is constructing world's largest single vessel HYL/Energiron ZR plant at 2.5 MM t DRI annual capacity.

The history of the process is as follows [3]:

- 1977– Started HYL III pilot plant, production rate 1 t/h.
- 1979– Started up HYL III 2M5 plant at 20 tph. Solids flow erratic, at times preferential center flow. Plant was shutdown; reactor modified and restarted 6 months later.
- 1980– Plant achieved rated capacity in 2 weeks, exceeded design capacity after 1 month.

HYL III process achieved nominal capacity in one and a half years, however required redesign of the reactor profile. Experienced with HYL I and HYL II batch processes accelerated ramp-up:

- 1981– Pilot plant testing of CO<sub>2</sub> removal from the HYL III process off-gas.
- 1984 – Pilot Plant testing of HYL process without a natural gas reformer, Zero Reformer or ZR process. Again using the same 1.0 t per hour pilot plant reactor.
- 1998 – Started up 80 t per hour ZR process M4 plant. Plant reached nominal capacity in 2 weeks. Plant has achieved sustained production rates at 109 t per hour.

Two weeks to achieve design capacity for such a major change is surprisingly short. The extensive pilot plant testing (14 years from initial pilot plant to commercial plant), combined with 40 years of operational experience are important factors with this very short ramp up.



### 6.3 Corex Process

The Corex<sup>®</sup> process is a coal based two stage reduction smelting process. The first stage is direct reduction using a Midrex shaft furnace. The second stage is a melter-gasifier, where the DRI is completely metallized, melted, carburized and fresh reducing gas is produced. Six installations around the world are currently in operation with maximum capacity 1.5 Mt/y.

The history of the processes is as follows [3]:

- 1978 - Melter Gasifier (MG) pilot plant 0.76 m hearth to 1.0 m upper diameter.
- 1981 - Demonstration Plant 60,000 tpa, MG 3.5 to 5 m diameter, 12 tuyeres.
- 1981-1987 – plant ran 6,000 hrs, 10 campaigns, key developments are: dust recycling, burner system, screw discharge.
- 1987 - Iscor, SA. 1<sup>st</sup> Corex 1000 plant of 300,000 tpa, MG 5.5 to 10 m diameter, 20 tuyeres.
- 1987 - 1<sup>st</sup> Campaign 6 days, burned hole in shell, numerous mechanical stoppages etc.
- 1988 - 2<sup>nd</sup> Campaign 6 months, got to 2/3 of capacity, then lost to 1/3. Issues with ore type, cyclones and trough refractories. Tried numerous fixes, no success. Failure of DRI screw feeder stopped the campaign.
- 1989 - 3<sup>rd</sup> Campaign started after 8 months of repairs and re-design:
  - Cyclones redesigned – Chinese hats replaced & modified.
  - Modeled shaft at 1/5<sup>th</sup> scale for dust flow, develop operating techniques.
  - Added particle screen to control size on entry to the shaft.
  - Modified reduction gas lines, refractories and burners.
  - “It was obvious a total transformation had taken place”.
- Achieved 100% of design capacity in September 1990, 2.75 years after starting up.

### 6.4 Rotary Hearth Furnace

The Rotary Hearth Furnace (RHF) process goes back to mid 1960's with Midrex developing Fast Heat process. In 1990's the Fastmet<sup>®</sup> process was developed and brought into commercial operation in 2000. Other RHF's were developed by Inco, IDI, NSC and Paul Wurth [3].

#### 6.4.1 Heat fast<sup>®</sup> process

- 1963 – Bench scale test work.
- 1964 – Lab Simulation at 200 to 300 tph done as a batch process.
- 1965 – Cooley Pilot plant built 6 m diameter, 2.4 m hearth with 8 tph production rate.
- 1968 – National Fast Heat plant built, two modules, 36.6 m diameter, 12.2 m hearth width.
- Design 150 tph per unit. Shutdown after 2 years, numerous mechanical and process problems.
- Two years operation, massive 35 times scale-up in production, shutdown.



## 6.5 Fastmet

- 1981 – Two years of lab and pilot testing 2.7 m diameter rotary hearth. Stopped due to an economic recession.
- 1990 – research restarted to look at Fastmet process, computer modeling, bench scale.
- 1992 – Pilot Plant restarted, over 100 runs on 2.7 m diameter rotary hearth, 160 kg/hr.
- 1995 – Start running demonstration plant, 8.5 m diameter, 2.5 tph, 20,000 tpa Kobe Steel.
- 2000 – Start up of commercial plant, 21.5 m diameter, 190,000 tpa BOF Dust/sludge.
- Successful start-up, achieved design production in 5 months.

### 6.5.1 Inmetco rotary hearth

- 1978 – Startup 16.7 m diameter, 4.3 m hearth width, 60,000 tpa dust and sludge.
- 1979 – Process development and equipment shake down period, modifications made.
- 1980, 1981. Demonstrated capability to run at 100% of design mid-1981.
- Plant achieved stable operation 3 years after start-up.

### 6.5.2 Iron dynamics (IDI) – Rotary Hearth Furnace + Smelter

- 1999 – Startup 51.7 m diameter, 7.0 m hearth width, plus submerged arc furnace, production 480,000 t DRI per annum. Significant problems with smelter, no production.
- 2000 – 33,000 t in 6 months, shut down for smelter repairs and modifications.
- 2001 – Restarted in March, shut down in July no production reported.
- 2003 – Restarted after additional modifications of smelter, 15,000 t in November-December.
- Production steadily climbs 2004 - 176,000, 2005 - 220,000 and has since averaged about 250,000 tpa of DRI, with about 200,000 tpa liquid iron production.

The IDI process took three starts and five years before the process becomes stable, a further two years required to reach 50% of initial design. Problems with the smelter operation and the off-gas system capacity were the major limitations to achieve 100 % capacity.

### 6.5.3 ITmk3<sup>®</sup> - Process

- 1995 - Kobe Steel while doing a RHF experiment at elevated above usual temperatures found that DRI could be melted and separated to pig iron droplets – nuggets and slag.
- 1998 – ITmk3 nuggets made on Midrex pilot RHF with 2.7 m diameter hearth.
- 1999 – Pilot Plant with a 3.0 m diameter hearth, 0.8 m effective width and productivity of 0.35 t/h started up in Kakogawa Steel Works.
- 2003 – Pilot Demonstration Plant (PDP) at Silver Bay, Minnesota, USA, operated from May 2003 to August 2004. The hearth diameter 11.28 m, effective width – 2 m, 3 t/h of nuggets per hour , 25,000 t/year capacity. The





longest of 4 campaigns was 81 days and plant availability of 93% was achieved.

- 2009, December, Mesabi Nugget - first large scale industrial plant with 60 m diameter RHF and 7.6 m effective width started operation. The designed production rate is 62.5 tph and designed capacity is 500,000 tpa.
- 2010 – Maximum production is achieved in third quarter - 24,600 t.
- 2011 – Maximum production achieved second quarter – 38,000 t
- Technology is at the middle of the third year of ramp-up

### 6.6 First Commercial Plant Scale-Up and Ramp-up Experience

Summary of the first commercial installation of alternative ironmaking technology scale-up and rump-up experience is presented in Table 1. The ramp-up for new commercial scale plants varies from 2 to 5 years, typically of about 3 years.

### 7 DISTRIBUTION OF COSTS AND BENEFITS IN A TYPICAL NEW TECHNOLOGY PROJECT

The main groups of stakeholders in the total process from idea to commercial success are:

- The owner/operator;
- The inventor/researcher;
- The engineer/constructor;
- Equipment suppliers;
- Financiers (internal or external).

It is important to examine these groups carefully as their aims and objectives as well as their rewards are different.

**Table 1.** Summary of first commercial alternative ironmaking plant scale-up and rump-up

Process	Scale-up 1 <sup>st</sup> Plant		Capacity 1 <sup>st</sup> Plant		Capacity Current Max MMtpa	Ramp-up, years	Number of operating units	Comments
	Critical parameter	Capacity	Designed MMtpa	Achieved MMtpa				
ITmk3	3.85	20	0.5	0.4	0.4	>2	1	By-weekly basis
Inmetco			0.06	0.06	0.06	3	1	Feed charge capacity
IDI			0.48	0.25	0.25	5	1	Off-gas system capacity
Fastmet		9.5	0.19	0.19	0.19	0.4	5	Feed charge capacity
SL/RN	2	6	0.2	0.2	0.20	3	multiple	Diameter <4.8 m
Corex	1.6-2	5	0.3	0.3	1.50	3	6	
Finmet			0.55	0.5	0.5	5	1	Campaign basis
Finex	1.6-2	11	0.6	0.6	1.50	0.4	2	
Midrex	8	120	0.22	0.17	1.76	2	65	
HYLI		9	0.075	0.075	1.1	2	14	3 operating now
HYLIII	4.5	22	0.2	0.25	1.60	1	22	Including 3 HYL ZR
Primus	3.85	4.7	0.06	0.06	0.125		2	Feed charge capacity
Hismelt	2.4	8	0.8	0.43	0.0	>6		Monthly basis. Shutdown



They all have different agendas and objectives as they bring their input to the project. It is critical to align these objectives. A good place to start is to understand the financial risk- reward profile for the main players. Table 2 explains the projects spending for new technologies.

Examination of this table reveals a few key facts that must guide a successful program:

- The owner reaps the bulk of the rewards.
- The contractors and suppliers as a group are generally not big beneficiaries in a project context.
- The cost of the design engineers and researchers are normally an insignificant part of the project life cycle cost but if underfunded, can put the project in jeopardy (as illustrated above). Doubling the input at this stage barely affects the lifecycle cost and can dramatically increase the lifecycle revenue or ROI.

**Table 2.** Distribution of costs and benefits in a typical new technology project

	Project cost, %	Operating cost benefits, %	Distribution of project benefits, %	Cost as % of life cycle cost
Research and Development	<b>0-10</b>	<b>0</b>	<b>0-5</b>	<b>&lt;1</b>
Engineering, Project and Construction Management	<b>5-15</b>	<b>0</b>	<b>0</b>	<b>&lt;2</b>
Equipment Suppliers	<b>30-40</b>	<b>0</b>	<b>0</b>	<b>&lt;3</b>
Construction Contractors	<b>30-40</b>	<b>0</b>	<b>0</b>	<b>&lt;3</b>
Owner/operator	<b>(100)</b>	<b>100</b>	<b>95-100</b>	<b>&gt;91</b>

Table 2 also illustrates a key issue for risk sharing. It is important that a project is structured so that the financial rewards match the risks. Otherwise real strains on a project will develop.

Secondly the risk must be placed in the hands of people competent to manage it. A typical practice is to demand a turnkey project from a contractor. If there is no new technology and other business risks are understood by all parties, then the practice may well make sense. In the context of application of new technology unless the contractor is the developer, it makes no sense. This cannot be over emphasized.

During the critical phases leading up to and during start-up the owner must have unimpeded direct access to the best people available from the technology developer, outside experts and/or his own staff. If the risk for technology performance is transferred to subcontractors or equipment sub-suppliers, the procedural issues can quickly get in the way of meeting the project objectives.

The contractual obligations must be matched and supported by the real expertise.

Ultimately it is always the Owner/Operator's responsibility to maintain sufficient depth of technical skills to manage the inputs. It is the owner-operator who loses money, market share or other key indicators if a project fails. He may be able to extract significant compensation under terms of guarantees – but after how many years in the courts? And can it come near to balancing the books on a project?

It is the owner's role to lead. Ultimately the risk is entirely on his shoulders and it his responsibility to be equipped properly to handle it.



## 8 CONCLUSIONS

In order to sustain and enhance its viability, the iron and steel industry must continuously modernize through the implementation of new technologies. This inherently involves risks. The risks of development of new technologies fall into three broad categories:

- Process, will the technology work?
- Commercial, will the implementation of this technology make money?
- Human risk, how might people reduce or increase the technological and financial risk?

Unknown or improper scale-up and poor engineering of pilot, demonstration or commercial plants are the major reasons for a long ramp-up period or complete failure of new technology. The other major problems during technology implementation are as follows:

- The cost of the design engineers and researchers is an insignificant part of the project life cycle cost but, if underfunded, can put the project in jeopardy.
- The owner must have unimpeded direct access to the best people available from the technology developer, outside experts and/or his own staff.
- The major risks of introducing new technologies are ultimately incurred by the owner/operator. The onus is thus on the owner /operator to develop the appropriate risk management program and to mobilize the required resources.
- An essential element of a successful risk management program is the understanding of the distinct phases involved in implementing new technologies and the rigorous evaluation of the development at each project milestone. Without this discipline the probability of failure is high.
- Attempts to skip project phases or to transfer responsibility for risks to other parties often due to perceived cost or schedule pressures frequently leads to project failure.
- On the other hand, there is ample evidence that enlightened management with a properly structured risk management program can successfully introduce new technologies and maintain a viable modern steel industry.

The ramp-up period for the first commercial scale of new ironmaking technologies varies from 2- 5 years, typically of about 3 years.

With proper project management and technology scale-up a “No-Go” decision regarding project continuation or technology failure could be premature and non-justified within the 5 year ramp-up period.

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