Batch Annealing Modernization at California Steel Industries

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California Steel Industries faced the choice of whether to repair, replace in-kind or upgrade the anneal shops to newer technology. Modernizing to a 100% hydrogen anneal shop was justified based on significantly reduced operating costs and the logistical advantages of consolidating two shops into one.

In the mid-1960s and early 1970s, as U.S. cold roll sheet producers were building 5-stand sheet cold reduction mills, many added batch annealing facilities in order to process the additional cold reduction throughput. Often these facilities consisted of a 4-stack-per-operating-base configuration, which led to handling and equipment efficiencies.

With these units being in service 30+ years, operators must now consider whether to continue to repair, replace in-kind or upgrade to newer technology. California Steel Industries (CSI) faced such choices in the late 1990s with its 1970s-vintage single-stack shop and an older 4-stack facility.

CSI considered the upcoming repair needs of the aging equipment and took the opportunity to gain operating, maintenance and spares efficiencies by consolidating to a modernized single shop. Through a careful evaluation of the advantages of 100% hydrogen atmosphere annealing, CSI decided to modernize all its annealing equipment in order to utilize this technology.

Working with several potential suppliers, CSI developed a compact design strategy to place the project in the available space ahead of the temper mill. A single turnkey supplier was chosen to finalize the design, direct the construction and commission the equipment. All this activity was to take place in close proximity to operating areas yet be transparent to the flow of cold rolled sheet product to CSI customers.

The project was successful in that it started early and was completed under budget. Numerous safety features for both hydrogen and natural gas were incorporated into the base, furnace and control systems. Stringent California NOx emission targets were met using the best available control technology. Savings of 50% or more in electricity and natural gas consumption were welcomed in a time of price and supply volatility in California utilities.

Background

Integrated mills began constructing the next generation of hot strip mills in the 1960s. These mills had more heating capacity, power and finishing capability than their predecessors. The resulting increased output made more bands available to cold rolled sheet products. Higher speed 5-stand cold mills and new annealing facilities, primarily 4-stack HN shops, followed.

Capital expenditures were directed back toward the primary end in the 1970s and early 1980s. BOF steelmaking was expanding, and continuous casting became a competitive necessity. Considerable sums were spent on related environmental issues and controls.

After the 1960s and until the late 1980s, only limited batch annealing capacity was added to steel plants. Annealing in a 100% hydrogen inert atmosphere made its first significant domestic debut at an integrated plant at U. S. Steel's Mon Valley Works at its Irvin Plant.

California Steel Industries

Kaiser Steel was built in 1942 to supply steel for West Coast shipbuilding and other markets. The plant was strategically positioned in southern California during the war years, thus making raw materials and the markets it served highly accessible. However, Kaiser Steel was shuttered in the early 1980s.

A 50/50 venture, under the name California Steel Industries, soon followed between Companhia Vale do Rio Doce of Brazil and Kawasaki Steel of Japan. CSI



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developed a business model to acquire slabs, averting environmental issues faced when attempting to make steel in the Los Angeles Basin. The CSI process began with hot rolling. The existing finishing facilities for galvanized and cold rolled sheet plus tubular products—what was once the Kaiser Steel plant—were restarted.

CSI serves four segments in the West Coast market. Roughly 40% of output is either shipped in the hot rolled or pickled and oiled state for products like spiral weld pipe, automotive wheels and rims, strapping, tubing, and construction. Another 35% leaves as galvanized sheet for drums, tanks, culvert, decking, fireplaces and HVAC. Cold rolled sheet comprises 16% for electronic cabinetry, lighting fixtures, metal office furniture, water heaters and tubing. The remainder is electrical resistance welded pipe for oil and gas transmission pipelines.

Capital Improvements — Since the formation of CSI in 1984, numerous capital projects have been undertaken by the company. Among these are a new continuous pickle line (1994) and a walking beam furnace (1997). The mill posts of the 5-stand cold reduction mill were widened out over 20 inches from their tin product's width, and the mill was fitted with new mechanical and electrical equipment (1997). A second hot dip galvanizing line was built, geared towards the expanding building products segment (1998). The hot coil handling and cooling system, constructed in 1999, conveys product from the hot mill downcoilers and immerses it in water. The cooling system lowers hot rolled coil temperatures down to pickling temperature in as quickly as two hours. Having made all these capital improvements, CSI then turned to evaluating its annealing facilities for cold rolled sheet.

Annealing Facilities — Prior to the recent modernization, CSI operated two anneal shops (Figure 1). The cold sheet mill (CSM) shop operated 15 single-stack Lee-Wilson HN bases; seven direct-fire, flat-flame furnaces; and eight air/water coolers. The 1969 vintage, 72-inch OD by 156-inch stack height shop produced 7000 tons per month. The HN bases used blended atmosphere gas of 6% hydrogen and 94% nitrogen.

The 4-stack anneal shop consisted of 12 4-stack HN bases, five direct-fire furnaces, and four air-only coolers installed in the 1960s. Various convection systems were used on the 63-inch OD by 156-inch stack height bases, generating about 5000 ft^3/min of convective flow. The shop produced 18,000 tons per month.

Figure 1

Aerial view of the CSI plant before the batch anneal modernization.

The two anneal shops were separated by roughly one mile. The 4-stack shop on the west end of the plant was located near the pickling line and 5-stand cold mill. The single-stack shop was in the CSM complex, along with the electrolytic cleaning line, the 2-stand temper mill, the slitting line and the shipping facilities, all at the east end of the plant.

Of the cold roll product coming off of the 5-stand, 20% was upended in the area and transported by crane for annealing as "mill clean" product (without precleaning) at the 4-stack shop. The remaining cold roll production was hauled with a large ram carrier, via the main plant highways, to the CSM complex, where it would be precleaned. After cleaning and upending, two-thirds returned to the western 4-stack shop on a truck, hauling two to three coils per trip, for annealing. The other third stayed in the CSM for annealing in the single-stack shop. After annealing in the 4-stack shop took place, both mill clean and precleaned soft coils rode the coil truck back to the CSM, joining the single-stack output in the queue ahead of the temper mill.

Project Justification

CSI's justification for the project was based on two factors: equipment consolidation and 100% hydrogen anneal capabilities.

Why Consolidate? — Equipment at CSI was 30 to 40 years old, and major repairs and investments were needed. Having one anneal shop instead of two would reduce the movement of coils between east and west facilities. This would be an even greater benefit for the soft coils after annealing, which are more susceptible to both mechanical and water moisture damage. Combining the pre-anneal coil inventory into one solitary anneal shop would result in a lower inventory and shortened leadtimes. The plant would also gain the efficiencies of having one operating crew, a single maintenance group and one type of spares.

The vision was to transport all full-hard coils from the western complex by rail to the CSM, where all remaining processing would occur. Also to be considered were ways to reduce costs by producing more coils that bypassed the cleaning line.

Why Hydrogen? — Research showed that low operating costs, superior quality and other commercial benefits have been realized by many greenfield and modernized facilities utilizing 100% hydrogen equipment. Optimal annealing performance comes not only from the use of hydrogen atmosphere, but also from highly engineered convection systems, variable frequency drives, sophisticated level 2 control systems (including thermodynamic modeling) and very efficient combustion systems with recuperation.

Lower Operating Cost — The hydrogen annealing OEMs and all of CSI's industry contacts estimated a 50% reduction in consumable costs (fuel gas, electricity, nitrogen and water) through modernization. Projections also showed lower maintenance costs because less equipment had to be maintained and fewer spares were required. Benefits also included a reduction in inventory-carrying cost due to shorter processing times, fewer stacks and the consolidation of preanneal inventories.

After looking at the reduced operating cost, CSI management was encouraged to increase the initial project request from a partial modernization of eight bases to a full modernization of its annealing capacity—a total of 20 bases.

Improved Quality — Another reported benefit of a 100% hydrogen anneal shop is a reduction in mechanical property variation. Such a reduction makes it possible to hit a tighter specification and therefore reduce rework to achieve mechanical properties. The use of Entec's level 2 control system would also assure consistent properties from charge to charge.

Historically, most of CSI's product was cleaned prior to annealing. After the tandem mill upgrade, efforts were taken to increase the amount of mill clean product. The justification for this was in the fact that most product (up to 80% from 20%) could be annealed mill clean with the same performance at the customers' facilities. Hydrogen atmosphere gas provides a more consistent surface cleanliness than HN due to various gas reactions that occur.

Project Requirements

In March 1999, a plan was developed to transform the consolidation vision into reality. Requirements, outlined in the request for quote (RFQ) to potential suppliers, originally specified modernization capacity equal to the combined total of the old shops (25,000 tons per month). The updated facility would be in the CSM, where the 15-foot basement could be used to achieve a stacking height in excess of 20 feet. At least half the project would then require no major excavation.

There was a need to maintain existing production volumes while keeping a safe operating and construction environment. The project would be built in two, perhaps three, phases. The planning, construction, equipment erection and start-up would be turnkey, most likely led by the equipment supplier.

Conditions from the South Coast Air Quality Management District (SCAQMD) had to be satisfied. "Best Available Control Technology" (BACT) was required to be utilized. Second, the combined MMBtu ratings of the modernized equipment could not exceed the total of the two old shops.

Vendor Selection

The RFQ and vendor evaluation were carefully controlled; CSI wanted its vendor selection to be based on a fair comparison. Three suppliers were deemed experienced and legitimate suppliers for a turnkey upgrade project of this scope. Each potential supplier was studied using the criteria detailed in Table 1.

By August 1999, funding for the project was approved and Rad-Con was chosen as equipment supplier the following month because of their high degree of redundancy in safety and control systems and their strong tie-in with the Entec predictive thermal stacking and heating optimization model. CSI had previous experience with Entec in its single-stack shop. Rad-Con also was selected as turnkey lead; The Industrial Company (TIC) was selected by CSI for construction and equipment setup.

Special Project Considerations

A few special considerations were necessary for this project. The annealing capacity could not be decreased during the modernization, so construction was integrated into the daily operation of the shop. Other special considerations included emissions control and earthquake sensitivity.

Construction Safety — Prior to the commencement of the construction phase, key safety issues for ongoing operations alongside the construction and erection were identified. The most critical concern was use of the overhead crane for moving equipment and material through the mill. To establish safe operating parameters, crane "fly zones" were established that disallowed plant equipment from flying over the construction zone during construction hours. In addition, crane lockout times where established in the production schedule to allow necessary construction and special equipment to operate within the plant.

To help ensure that all personnel were informed of the day-to-day construction status, a safety coordinator worked to synchronize plant and construction schedules, assuring effective and safe product workflow while maintaining the construction timeline. Weekly meetings were held with personnel from CSI, Rad-Con and TIC to discuss safety, upcoming issues and improvements to current project or organizational parameters. Also, daily toolbox safety meetings were held for construction workers.

Table 1

Vendor comparison table

Cost	• Equipment ($) • Installation ($) • Operating utilities ($/yr) • Operating spare parts ($/yr) • Operating service ($/yr)
Plant utilization	• Throughput (tons/yr based on specific grade mix and reference charge and anticipated oil shelf) • Maximum stacking height (inches) • Maximum weight on base (tons)
Safety features	• Hydrogen sensor? • Oxygen sensor? • Automatic leak test? • Timed nitrogen purge? • Flame safety system type (UV or flame rod) • Other safety sensors (list and specify redundant elements) • Power failure recovery (describe)
Performance	• Fuel gas (MMBtu/ton) • Electricity (kWh/ton) • Nitrogen (ft^3/ton) • Hydrogen (ft^3/ton)—omitted from guarantee because of relation to cleanliness • NOx (lbs/MMBtu, specify with or without recuperators) • Convection system (fan size, flow and horsepower) • Heating system (burner type and quantity) • Recuperation system (design, quantity and life)
Experience	• Experience with explosive atmospheres • Hydrogen installations • Technical support and service • Location and accessibility of experts
Control system features	• Level 1 redundancy—CPU, I/O bus, computer, RAID • Level 1 operation—ease of use, on-line documentation • Level 1 configuration (describe user adjustable parameters) • Level 1 to level 2 interface (describe interface to existing Entec)

Emissions — Typically, fuel efficiency gains from recuperation or regeneration processes are lost in the course of improving emissions. CSI was interested in ways to improve fuel efficiency without compromising emission requirements.

Without a specific rule to apply to bell annealing equipment, CSI decided that the furnaces should meet the SCAQMD Rule 1146 for Industrial Boilers. Using this existing rule, although more stringent than necessary, precluded the task of having SCAQMD write a rule specific for a high-turndown application like bell annealing. Exceeding the requirements simplified the approval process and improved the project timeline.

The requirement called for carbon monoxide (CO) below 0.082 lb/MMBtu and oxides of nitrogen (NOx) below 0.05 lb/MMBtu. Also, as part of the SCAQMD source test written by CSI, the emission requirements had to be met at three distinct firing positions: high (4.64 MMBtu/hr), medium (2.32 MMBtu/hr) and low (1.16 MMBtu/hr) fire.

To meet the emission requirements, a combustion system design was needed that combined improved emissions with the fuel efficiency of recuperation. A wide range of burner designs was reviewed from various manufacturers. Ultimately, the design from Bloom Engineering was chosen as the only burner that would meet the requirements under all three firing ranges. Guaranteed values were then verified by laboratory test firing of the burner at the various levels of turndown.

With the burner chosen, the combustion chamber was altered to incorporate the ultralow NOx burner design while maintaining the necessary heating characteristics for the workload, burner requirements and recuperation technology. Furnace alterations were made using traditional engineering methods, finite element analysis and computational fluid dynamics.

Additional Earthquake Safety Features — The facility also needed to be designed for safe shutdown in the event of an earthquake. Some of the safety measures incorporated into the system were an auxiliary liquid nitrogen tank and "break glass" E-stop-activated safety shutoff valves for the hydrogen and natural gas lines.

To minimize piping lengths, a nitrogen purge tank was positioned next to the new anneal facility. To guarantee availability of a sufficient supply of purge gas, the tank was equipped with tank-level telemetry, switches and a regulation system. The regulation system would automatically make up flow from the purge tank in the event that a sufficient supply of purge gas was not available to the facility. Therefore, in the event of an earthquake or other catastrophe that may sever the existing landline, the purge tank would take over the supply of the hydrogen annealing facility safety purge gas.

The addition of emergency safety shutoff valves allowed isolation of the hydrogen and natural gas to occur automatically or manually through operator intervention. The system was equipped with redundant high/low pressure switches that would warn and then shut down the system automatically when irregular conditions occurred. Emergency "break glass" stops were incorporated into the facility at strategic locations, thereby giving plant personnel active control of the flammable gases in use throughout the annealing facility.

Figure 2

Cleared floor space for Phase 1.

Figure 3

Pit for Phase 1.

Project Overview

The RFQ specified that the project be proposed in three phases, with the option for CSI to combine phases if required. Once Rad-Con was chosen as the vendor, CSI, Rad-Con and TIC evaluated the two options based on final shop design, construction issues and operating impact. They determined that a two-phase installation was best. Other considerations were the number of bases per phase, size and location of the control room, and equipment features.

Project Schedule — The first installation phase (eight bases, four furnaces and four coolers) was originally scheduled to begin March 1, 2000, and be completed within seven months. The project was accelerated to start construction on Feb. 1, 2000, for completion by Aug. 31, 2000.

Phase 1 required excavation of a 15-foot pit adjacent to the existing cold sheet mill annealing equipment. Figures 2 and 3 show excavation of the pit used for Phase 1, with preanneal inventory located at the bottom and operating HN equipment at the top. Coils for production had to be carried through the construction zone.

The first production charge was completed on Aug. 11, 2000, with all eight bases from Phase 1 completed by Aug. 27, 2000. Production levels of Phase 1 needed to exceed the capacity of the CSM single-stack anneal shop prior to beginning Phase 2, which included decommissioning the CSM anneal shop.

By September, production hit a level that allowed Phase 2 to begin. Phase 2 included 12 bases, seven furnaces and five coolers, bringing the total to 20, 11 and nine, respectively. The project schedule called for completion by Aug. 31, 2001, but the schedule was expedited to avoid the high electrical costs of the California summer months. Commissioning of all bases was completed on June 29, 2001, two months ahead of schedule (Figure 4). The start-up of the equipment in Phase 2 also required simultaneous decommissioning of the 4-stack shop in order to remain below the total shop MMBtu limit.

Figure 4

View of the batch annealing facility upon completion of Phase 2.

Results

Justification for modernization was based on the projected benefits from a 100% hydrogen facility. Once the equipment was operational, it was important to prove that the shop performed as projected.

General Project Results — Foremost, there were no recordable injuries during 58,000 manhours of construction. All delivery and performance guarantees were met or exceeded. The number of stool positions had been reduced by over two-thirds, from 63 to 20. Furthermore, the project was finished under budget and two months early.

The early finish allowed the less-energy-efficient 4-stack shop to be shut down prior to the summer of 2001 electrical rate shift, when higher rates were assured for this time period and supply was uncertain.

Not only was the project under budget, but the scope was increased within the original budget. Equipment was purchased and installed for 20% higher tonnage volumes. Both the east pit and the control room were enlarged. Additional spares were also purchased.

Emission Results — The data listed in Table 2 reflect those collected for the source test. The test was conducted following standard protocols.[1] The actual maximum measured value was less than 70% of the allowable value. Source test points were determined by analyzing a 17-hour annealing cycle model, and are at the predicted maximum, average and minimum firing rates.

The replaced HN furnaces were permitted to operate at 0.126 lb/MMBtu NOx emissions. Taking into account the reduced MMBtus per annealed ton and the lower NOx emissions per MMBtu, the potential to emit NOx was reduced 79.5%, from 51,800 to 10,600 lb/yr at the same production rate.

Delivery Improvements — With the transition to the hydrogen annealing process, the improved process routing, single inventory and quicker process shortened the standard cold rolled product lead-time from five weeks to four. The process also enhanced other ongoing plant activities to improve on-time promise performance for completed orders, ready for shipment. Cold rolled sheet product on-time performance rose from 50% levels to 70%, and eventually reached the 80% range.

Quality Improvements — Product uniformity improved by almost twice the original expectations. A 46% reduction in yield strength variation was appreciated on key high-strength, low-alloy orders. Surface cleanliness, as measured by the Ford procedure (0.20 mg/ft^2 C) and the Leco® method (1.0 mg/ft^2 C), was better than anticipated.

Operating Cost Reduction — Costs for precleaning full-hard coils prior to annealing were reduced by $500,000 annually. Realized utility savings are shown in Figure 5, and are compared to pre-existing and projected (justification) costs. All costs are based on consumption levels for each utility and actual 2002 utility rates. As can be seen in Figure 5, fuel gas costs were cut in half and electricity costs were reduced by 75%, thus enabling the goal of 50% overall utility cost savings to be met.

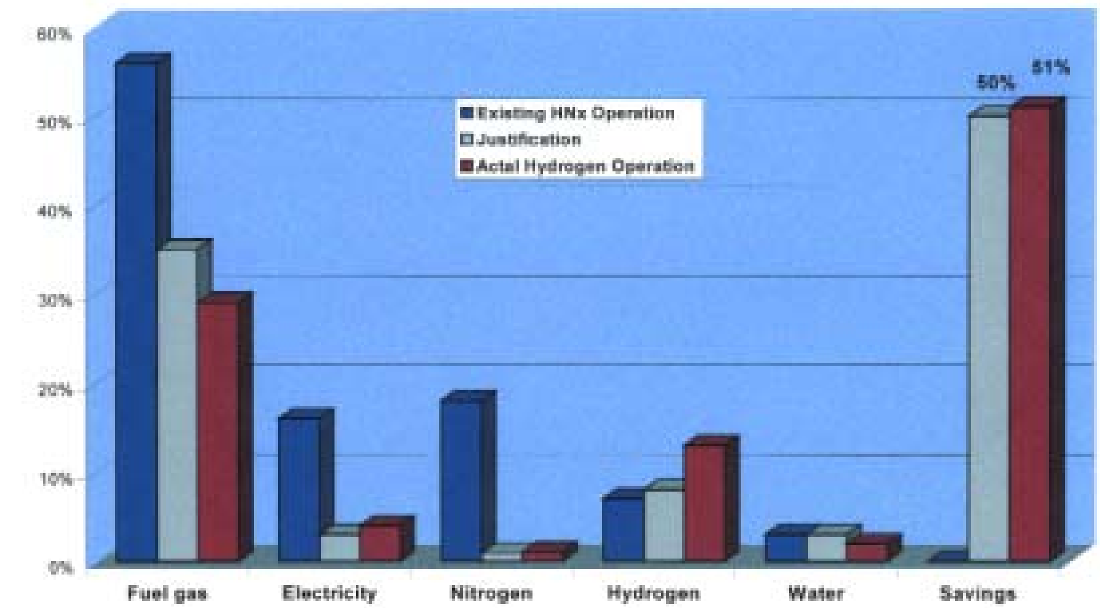
Payback Period — The capital expenditure request for this modernization claimed a 2.68-year payback. As seen in Figure 6, the actual period was determined to be 2.36 years. Although led primarily by utility savings, manpower and maintenance cost reductions also contributed. Reprocessing costs to salvage surface and mechanical

Table 2

Emission results at furnace firing rates

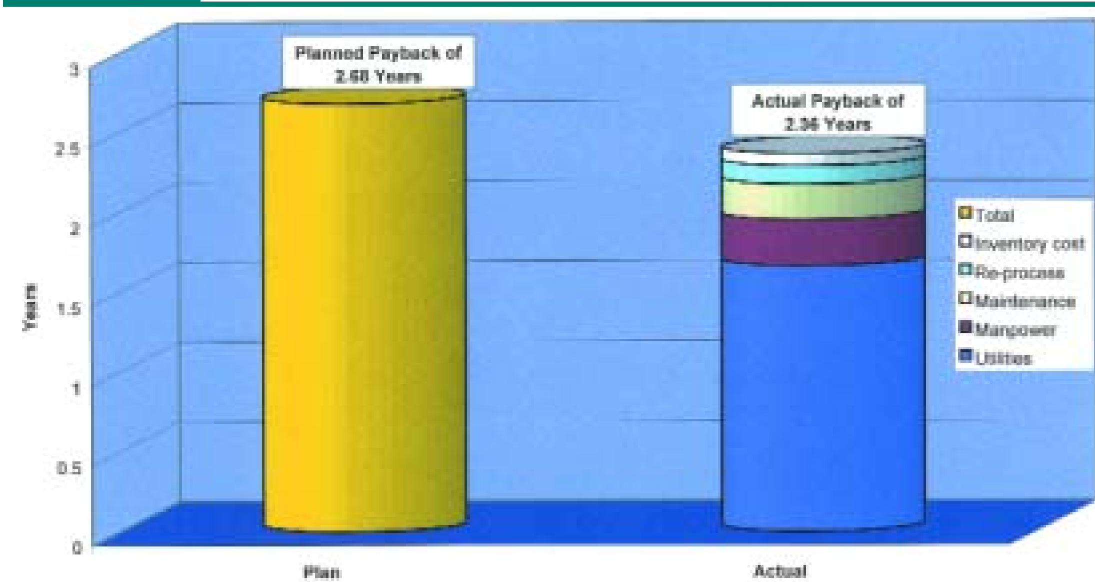
Firing rate (lb/MMBtu)	Average NOx (MMBtu/h)	Average CO (lb/MMBtu)
High fire (4.64)	0.025	0.001
Medium fire (2.32)	0.031	0.002
Low fire (1.16)	0.034	0.003

Figure 5



Pre-existing, projected and actual utility costs after the modernization project.

Figure 6



Actual versus planned payback, broken down by contribution.

property problems were also lowered. Reduced leadtimes supported lower inventories at various stages of production.

Summary

As more imported and domestic annealed steel is produced using 100% hydrogen, a successful annealing modernization project became essential for the long-term viability of CSI's cold rolled sheet products. With recent severe downward pressure on steel prices, CSI needed to focus on increased efficiency, improved customer service and reduced operating costs in order to solidify their position in the cold sheet market.

The upgrade originally consisted of an incremental installation of some hydrogen equipment, but grew into a comprehensive consolidation that streamlined material movement and in-process inventories. The end results for the customers are better delivery performance and shortened leadtimes. The bottom-line financial effect shows up as savings in utilities, reduced rejects, lower maintenance and reduced in-process transportation costs.

Most importantly, the turnkey project was delivered on time and under budget and met all the performance requirements. All the financial expectations for the project were also met and even exceeded. The partnership developed between CSI and Rad-Con has continued beyond the project scope, leading to additional process and product improvements at CSI.

Reference

1. South Coast Air Quality Management District Rule 100.1, "Continuous Emissions Monitoring for NOx, CO and O_2 from Stationary Sources," Diamond Bar, Calif.

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